The Journal of Energy: Engineering & Management
Vol. 6, No. 4, Winter 1395, P. 2-13

Optimal Energy Management and Feasibility Study of a Hybrid Energy System for a Remote Area

M.H. Amirioun[1*], A. Kazemi[2]

[1]Faculty of Engineering, University of Shahreza, Shahreza, I.R.Iran
m.h.amirioun@gmail.com
[2]Center of Excellence for Power System Automation and Operation, Department of Electrical Engineering, I.R.Iran
University of Science and Technology, Tehran, I.R.Iran
kazemi@iust.ac.ir

Abstract: This paper investigates impacts of possible chances in energy policy and consumption behavior on optimal energy management and feasibility study of a hybrid energy system. The study was performed on a remote area near Esfarjan, a village located in Shahreza, Iran. In the main scenario, the current energy policy is applied while the consumption behavior of customers is studied by means of an incentive-based demand response algorithm. However, the sensitivity analysis scenario applies the near future condition that is gradually taking place by reducing the energy subsidies while customers are assumed to be inflexible. Impacts of uncertainties related to gas and electricity prices, environmental issues and the inflation rate were evaluated in the latter scenario. Simulations were done on six different system configurations for both scenarios. Results highlight the significant role of long-term energy policies in comparison with short-term consumption behavior of customers. It is also indicated that configurations involving renewable resources will become stronger rivals for configurations involving the external grid in the near future, which in turn results in more economical investments on renewable resources.

Keywords: Hybrid Energy System (HES), Energy policy, Distributed Energy Resources (DERs), Demand Response (DR), Linear Programming (LP).

* Corresponding Author

1. Introduction

Distributed Energy Resources (DERs) are often operated integrally due to special features of these resources. These features include: weather-dependency, small-scale generation, and power market challenges. [1-5].

A hybrid energy system (HES) is a platform where two or more different sources of electricity are connected to a common grid and operate hand in hand to supply the desired load [6].

Due to numerous benefits of hybrid energy systems, optimal design of these systems has been widely addressed by researchers and governments through academic studies and pilot projects. The major task in these researches mostly deals with selecting the optimal configuration to supply the desired load in terms of economic and environmental issues [5, 6].

A number of optimization techniques for hybrid system design have been presented. Among them, genetic algorithm (GA), particle swarm optimization (PSO) and simulated annealing (SA) have attracted much attention and been used vastly by researchers in the literature.

Various methods in addition to the mentioned approaches have been used by researchers to design optimal hybrid systems in terms of economic and environmental issues. These methods include: linear programming, evolutionary algorithms, neural networks, simplex algorithm, dynamic programming, stochastic approach, iterative and probabilistic approaches, etc. [6]. Hybrid Optimization Model for Electric Renewables briefly known as "HOMER" developed by National Renewable Energy Laboratory (NREL), United States [7], [8] is a computer model that is utilized by designers to simulate and optimize stand-alone and grid-connected electric power system operation. HOMER can model any combination of wind turbines, solar PV panels, hydro, small modular biomass, conventional generators, and battery storages [8]. Output figures include different details of the solution that makes it easy to perceive the main concepts of a sizing procedure. It provided the researchers with a black box code framework and first-degree linear models for hybrid system components, resulting in an approximation of the source characteristics instead of considering the exact features of components. Simulation, optimization, and sensitivity analysis are the three principal tasks performed in HOMER. This tool uses an enumerative method to obtain the optimal design by evaluating all the possible solutions [6].

Several researchers have investigated the use of HOMER for optimal sizing of both standalone and grid-connected power systems. A feasibility study has been performed in [9] for a rural off-grid hybrid system in Ethiopia with a high emphasis on hydro power. Considering environmental impacts, an economic analysis has been done for a hybrid PV, wind, split diesel and battery system in [10]. An optimization model is introduced in [11] for hybrid photovoltaic/wind turbine/fuel cell power generation systems. A sensitivity analysis is also done for considering the uncertainties due to parameter variations. Reference [12] has performed a comparative study to evaluate economic analysis and environmental impacts of a PV with diesel-battery system for remote villages using both HOMER and MATLAB Simulink. The solution of the design problem for remote areas has been addressed in some other papers like [13-17], etc.

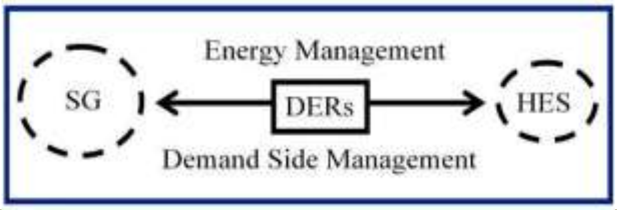

Fig. 1. Role of DERs in distribution networks

In the present work, impacts of changes in energy policy (driven by the government) and consumption behavior of customers on economic feasibility of hybrid energy systems (HESs) for remote areas are studied through a real case study. The main task of the study points out the future condition when the use of external grid to meet the demand may not be economical anymore. Impacts of uncertainties related to gas and electricity prices, environmental issues and the inflation rate are evaluated in this work.

The rest of the paper is as follows; section 2, mainly focuses on description of model concepts. In sections 3 and 4, the model is defined and formulated, respectively. A case study with two scenarios is defined in section 5. In section 6, the simulation results are discussed. Finally, in section 7, a conclusion has been presented and the future work outlines are drawn.

2. Conceptual Framework

Today, smart grid's (SG) concepts and frameworks are widely discussed and different aspects of the future smart grid are studied. From the point of view of energy and demand-side management, DERs play an important role to make it easier to achieve valuable goals of smart grid implementation. An HES is the best platform where DERs can be effectively installed and utilized (Fig. 1). In fact, in terms of the energy management, the smart grid key concept lies in the perception of design fundaments related to such systems.

Fig. 2 shows how HESs play their important role and help develop smart grid energy goals from the viewpoint of both customers and distribution networks. As shown, the main benefit for the society is the social welfare improvement as it is one of the most important goals of SGs.

In Fig. 3, DERs, AC and DC loads, AC/DC converter and the point of common coupling (PCC), where an HES can connect to SG, are illustrated.

In terms of operation and market management, the relationship between HESs and the SG is depicted in Figs. 4 and 5. The smart distribution grid's operator (SDGO) is able to exchange information with the HES's central operator (HESCO). SDGO manages the distribution network so that it can be operated optimally and safely. HESCOs try to make decisions in a cost effective way considering the security and operation constraints. Any decision to connect to or disconnect from the SG should be made by HESCOs. With the development of advanced metering infrastructures (AMI), SDGO will be able to control and monitor the whole network to make sure that the grid is operated optimally in each time slot. The aggregator unit (AU) of each HES checks the state of the system and is the responsible of bids and offers for the generation and demand, respectively.

All bid and offer proposals are received and then aggregated by the central aggregator unit (CAU) of the smart distribution grid to compete in the day-ahead market of SG. In fact, HESs can't participate in power markets due to their small scale power provision or demand request, but they can be aggregated and then introduced as a whole load or generator to the market. In this paper, such mechanism has been assumed for the participation of HESs in the day-ahead power market.

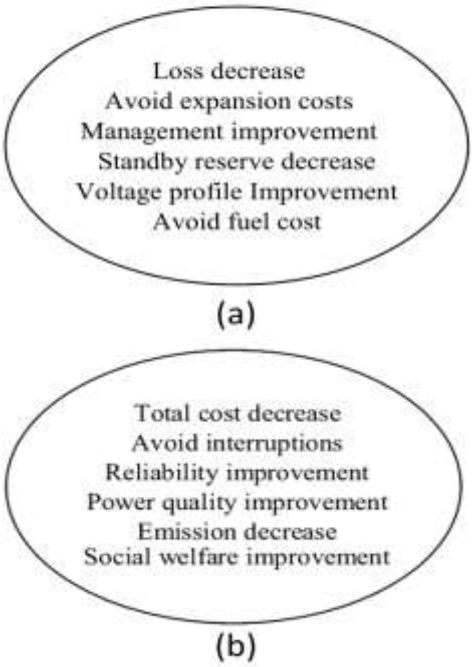

Fig. 2. Benefits of HESs: (a). From distribution network's point of view, (b). From customer's point of view

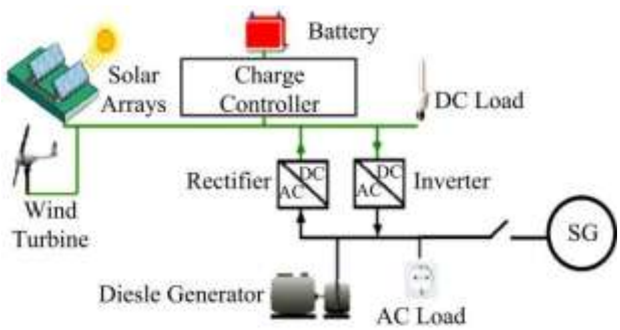

Fig. 3. A schematic diagram of a sample HES, [3]

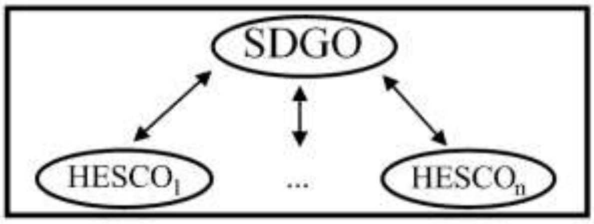

Fig. 4. Operation management scheme of HESCOs in a SGDS

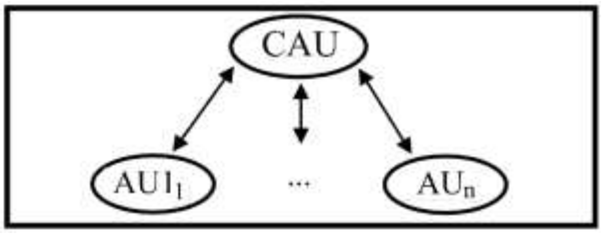

Fig. 5. Market scheme of HESCOs in the power market

3. Problem Definition

3.1. Evaluation Indexes

The strategic purpose of this work is clearly finding the most economical configuration that is technically acceptable. The proposed economic indexes t are defined as the net present cost (NPC) and the normalized cost of energy (COE) which both depend on the total annualized cost of the system [8].

To bring the total annualized cost of the n^{th} year to the net present cost, (1) can be used [8]:

$$C_{NPC}^{n} = \frac{C_{TANN}^{n}}{(1+i^{'})^{n}} \tag{1}$$

Then total NPC can be aggregated in (2) [8]:

$$C_{TNPC} = \sum_{n=1}^{N} C_{NPC}^{n} \tag{2}$$

Where N denotes for the project lifetime. The uniformed annualized cost (C_{UANN}) of the system is calculated using (3). In fact, the net present value of the overall cost of the system is distributed evenly in the entire years of the project lifetime. The relationship between C_{TNPC} and C_{UANN} is shown in (3) [8]:

$$C_{UANN} = C_{TNPC} CRF_{(i^{'},N)} \tag{3}$$

Where $i^{'}$ is the annual real interest rate and is given in (4) [8]:

$$i^{'} = 100 * \ (i-f)/(1+f) \tag{4}$$

Where i is the nominal interest rate and f is the annual average inflation rate. $CRF_{(i^{'},N)}$ denotes for the related capital recovery factor and is calculated by equation (5) [8]:

$$CRF_{(i^{'},N)} = \frac{i^{'}(1+i^{'})^{N}}{(1+i^{'})^{N}-1} \tag{5}$$

By defining the interest rate as given in (4), the proposed economic analysis puts aside the inflation rate and all costs will become real; that is they are defined in terms of constant dollars. It is assumed that the rate of inflation is the same for all costs. The relation between COE and C_{UANN} can be written as [8]:

$$COE = \frac{C_{UANN} - C_{boiler}}{E_{electricload} + E_{grid\,sale}} \tag{6}$$

Where C_{boiler} is the uniformed annual cost of boiler while $E_{electricload}$ and $E_{gridsale}$ are average annual electric energy consumed and sold to external grid, respectively. In fact, COE is the pure electrical cost per *kWh* of the electrical energy served by the system.

HOMER calculates C_{TNPC} using the total annualized cost of each year in equation (2). Then COE is achieved by calculating (3) and (6). The decision making variable to select the best configuration when no sensitivity study is desired, will be the NPC cost. It ranks the options from the least total NPC cost to the highest one. However, to compare static scenarios with those including sensitivity variables, COE gives a better analytical view.

3.2. Cost Types

Different cost types were used to formulate the problem which are described as follows.

3.2.1. Capital Cost (C_{cap})

The cost incurred by the launch of the project is called the capital cost. It mainly includes the fund needed to buy and install the components and provide essential infrastructures.

3.2.2. Operation and Maintenance Cost ($C_{O\&M}$)

It includes the cost of running and keeping the system ready to use at each hour. The overall system's operation and maintenance cost is the sum of all components' $C_{O\&M}$ whereas that of grid is the cost of buying power from the grid minus any revenue earned by selling power to the grid.

3.2.3. Replacement Cost (Crep)

The system's replacement cost is the overall cost of replacing system components at the end of their lifetime.

3.2.4. Salvage Cost (Csal)

The value remaining in a component of the power system at the end of the project lifetime is called the salvage cost. In other words, it must take a negative value to show its concept.

3.2.5. Fuel Cost (Cf)

It is the overall cost of fuel for the components needing fuel to work.

3.2.6. Grid Sale Cost (Csale)

This type of cost includes the revenue earned by selling energy to the grid. Clearly it takes negative values to signify its concept as an income.

3.2.7. Emission Penalty Cost (Cpen)

It is the overall penalty cost incurred by the production of pollutants.

4. Problem Formulation

Equations (7) to (13) formulate the costs described in previous section. Equation (7) models the overall capital cost of system based on capital cost function of each component:

$$C_{cap} = \sum_{DG=1}^{N_{DG}} C_{DG}^{cap} + \sum_{WT=1}^{N_{WT}} C_{WT}^{cap} + \sum_{PV=1}^{N_{PV}} C_{PV}^{cap} + \sum_{BAT=1}^{N_{BAT}} C_{BAT}^{cap} + \sum_{CONV=1}^{N_{CONV}} C_{CONV}^{cap} + C_{GE} \tag{7}$$

Where *DG*, N_{DG}, *WT*, N_{WT}, *PV*, *NPV*, *BAT*, *NBAT*, *CONV* and N_{CONV} denote for diesel generator and its considered number, wind turbine and its considered number, photovoltaic array and its considered number, battery bank and its considered number, converter and its considered number respectively. C_{GE} is the cost of grid extension if needed. Set D_{GE} as the grid extension distance and π_{GE} the cost of extension per unit of distance, then the grid extension cost can be declared as in (8):

$$C_{GE} = D_{GE}\pi_{GE} \tag{8}$$

Equation (9) depicts the operation and maintenance cost of system related to n^{th} year of the project lifetime using operating cost function of each component:

$$C_{O\&M}^{n} = \sum_{t=1}^{8760} \Big\{ \sum_{DG=1}^{N_{DG}} C_{DG}^{O\&M}(t) + \sum_{WT=1}^{N_{WT}} C_{WT}^{O\&M}(t) + \sum_{PV=1}^{N_{PV}} C_{PV}^{O\&M}(t) + \sum_{BAT=1}^{N_{BAT}} C_{BAT}^{O\&M}(t) + \sum_{CONV=1}^{N_{CONV}} C_{CONV}^{O\&M}(t) \Big\}, \forall \text{ year} \tag{9}$$

Putting π_{fg} as the price of fuel type g and $F_{j,g}$ the consumption curve of fuel type g for component j, then the yearly fuel cost of system is written as:

$$C_{f}^{n} = \sum_{t=1}^{8760} \sum_{g,j} F_{j,g}(t)\pi_{fg}, \forall \text{year} \tag{10}$$

If there is any replacement case during year n for component j then the annual replacement cost of system is:

$$C_{rep}^{n} = \sum_{j} C_{rep}^{j,n}, \forall \text{year} \tag{11}$$

Set R_{rem} and R_{com} to be the remained and nominal age of component j, then its salvage cost in n^{th} year is written as:

$$C_{sal}^{n} = -\sum_{j} C_{rep}^{j,n} \frac{R_{rem}}{R_{comp}}, \forall \text{year} \tag{12}$$

To minimize the use of air-polluting resources, we consider a penalty cost as declared in (13):

$$C_{pen}^{n} = \sum_{g} em_{g}\pi_{pen,g}, \forall \text{ year} \tag{13}$$

Where em_g and $\pi_{pen,g}$ are amounts of emission type g sent to the air and the punishment cost per unit of emission, respectively.

As explained in section II, the desired HES can exchange electric power with the external grid through SG infrastructures. If the total energy sold at hour t is shown by $E_{sale}(t)$ and $\pi_{sale}(t)$ is the price per unit of sold energy at that hour, then the annual revenue earned by HESCO can be written as in (14):

$$C_{sale}^{n} = \sum_{t=1}^{8760} E_{sale}(t)\pi_{sale}(t)\text{, }\forall\text{ yea} \qquad (14)$$

Finally, the objective function of the problem can be modeled as the total system NPC cost using (1), (2) and (7)-(14):

Minimization of:

$$C_{TNPC} = C_{cap} + \sum_{n=1}^{N}\{(C_{O\&M}^{n} + C_{f}^{n} + C_{rep}^{n} + C_{sal}^{n} + C_{pen}^{n} + C_{sale}^{n})(1+i^{'})^{-n}\} \qquad (15)$$

Equality and inequality constraints of the problem include equations (16) to (19) as below.

The generation and consumption balance and limitation of unit's production must be satisfied:

$$\sum_{i} P_{gen,i}(t) = Load_{elec}(t) + Load_{thermal}(t) + P_{BAT}(t) + P_{sale}(t) + P_{loss}(t) \qquad (16)$$

$$p_{gen,i}^{\min} \le p_{gen,i}(t) \le p_{gen,i}^{\max} \qquad (17)$$

Where $P_{gen,j}(t)$, $Load_{elec}(t)$, $Load_{thermal}(t)$, $P_{BAT}(t)$, $P_{sale}(t)$ and $P_{loss}(t)$ denote for the generated power of generating component i, total electric load, total power transferred to battery banks, total power sold to external grid and power loss in system (due to batteries and converters) at hour t, respectively.

Next constraint sets the operating reserve (OR) of system as a function of PV and wind generation and total electric load:

$$OR(t) = a * Load_{elec}(t) + b * (P_{WT}(t) + P_{PV}(t)) \qquad (18)$$

Where a and b are two constant coefficients set by the modeler.

The next constraint signifies the maximum allowed capacity shortage of the system (ACS), that is the capacity needed to meet both the load and the reserve (s is a constant around 0 set by the modeler):

$$ACS \le s \qquad (19)$$

5. System under Consideration

The area under study is located between 31°42′N and 51°42′E near a small village, Esfarjan, in shahreza's countryside, Isfahan, Iran, having a high potential for both PV and wind resources. The available options to supply the load are solar PV arrays, wind turbines, battery banks, diesel generator, dump load, boiler, AC/DC converter, micro-turbine and external grid.

In the following sections, the main features of system components are discussed.

5.1. Load

Both electric and thermal demand have been modeled. The detailed description of each type is presented as follows.

5.1.1. Electrical Load

The considered area is quite residential, therefore no difference was considered between weekends and weekdays. However, two demand patterns were created, one for the cool and cold months, i.e. October to March (first segment) with a 400 *kW* peak demand and the other for the warm and hot months, i.e. April to September (second segment) with a 500 *kW* peak demand. Fig. 6 illustrates the daily profile of electric demand in both segments. As clearly seen, there are two peak periods in the second segment, one during 13 to 16 due to cooling systems and the other between 20 and 22 due to the lighting load added while there is only one peak period in the first segment between hours 20 and 22.

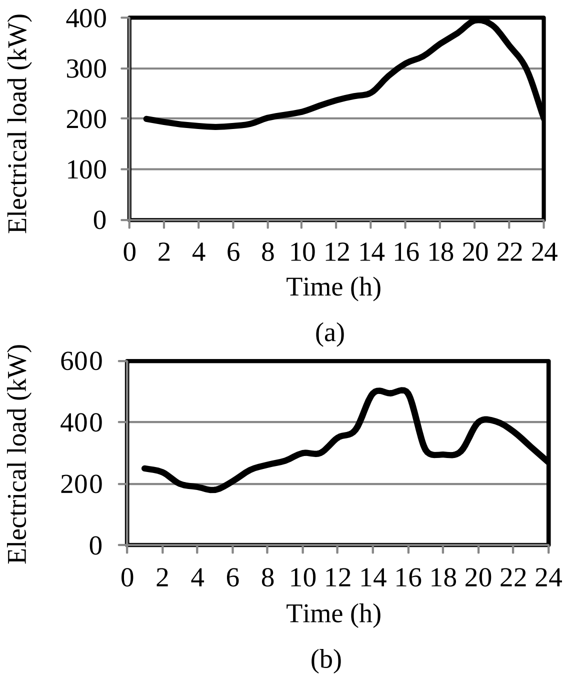

Fig. 6. Daily profile of electric demand:(a). first segment (October to March), (b). second segment (April to September)

5.1.2. Thermal Load

Fig. 7.a and Fig. 7.b illustrate the daily thermal load for the two mentioned segments. The peak load is 20 kW for the first segment and 12 kW for the second one. The idea of adding thermal load in this paper is to evaluate the effect of excess energy feeding the thermal load. The peak periods seen in Fig. 7 mainly relate to heating energy needed for cooking and/or heating buildings in peak hours. As for simplicity, the load growth (both electric and thermal) has been neglected.

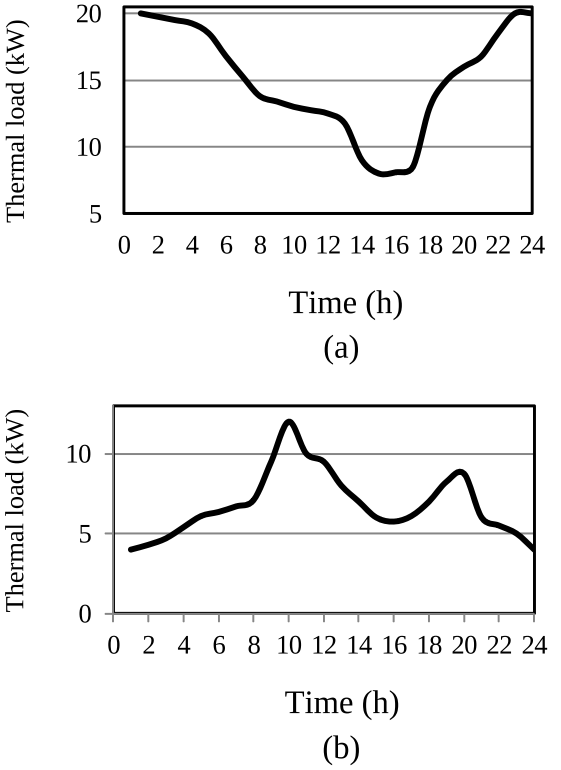

Fig. 7. Daily profile of thermal load: (a). first segment (October to March), (b). Second segment (April to September

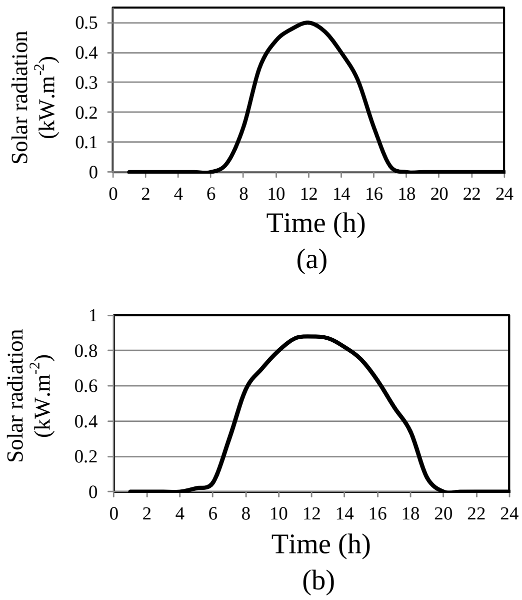

Fig. 8. Daily solar radiation profile, (a): first segment (October to March), (b): second segment (April to September)

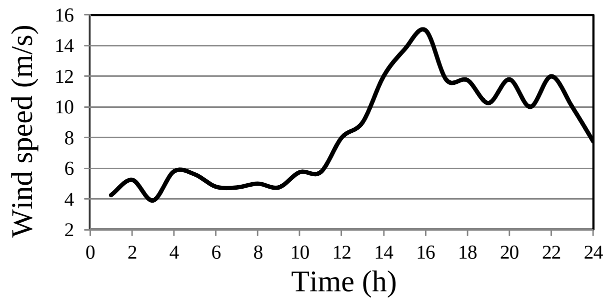

Fig. 9. Daily wind speed profile

5.2. Resources

5.2.1. Solar Resource

The solar radiation profile of the considered region is expected to be like Fig. 8 for a one-year period according to NASA Surface Meteorology and Solar Energy [18]. The annual average solar radiation is 5.32 $kWh/m^2/day$, indicating a good potential of solar energy in this area. A derating factor of 90% reduces the PV production by 10% to take into account the varying effects of temperature and dust on the panels.

5.2.2. Wind Resource

Fig. 9 shows the profile of wind speed of the region over a one-year period [18]. The annual average of wind speed is 7*m/s*, providing a rather good potential for wind energy.

6. Simulations

Six case studies are assumed and depicted in Table 1. Without loss of generality, all cost functions used in the problem formulation (see section IV), are considered linear in a way that all include the origin of coordinates and points shown in Table 2. Input data on option sizing and other parameters are also presented in this table. Fuel consumption function of diesel, CHP and boiler are assumed to be linear with slopes of 0.30, 0.30 and 0.12 (*L/h/Kw Output*), respectively [8].

Table 1. Description of the six case studies

Case study	Case description
1	Diesel-dependent System
2	Renewable-based System
3	Diesel-Renewable
4	Renewables-External grid
5	External grid
6	External grid-Diesel generator

This introduces a linear programming (LP) problem solvable by HOMER. To make it easy to solve, HOMER was used in the main scenario and a combinational application of HOMER and MATLAB was tested in sensitivity scenario to improve the accuracy of solutions.

6.1. Main Scenario

As mentioned before, in this scenario the project design is examined considering values near the real condition of parameters. According to [19], a ten-year average for inflation '*f*' is approximately 0.147 (14.7%), while based on the announcement of power ministry, an interest rate of 0.140 (14%) for the supplied finance of DERs is considered [20], resulting in a negative annual real interest rate equal to -0.61%. The project lifetime is set to be 15 years. The constant coefficients *a*, *b* and *s* are set to be 0.1, 0.25 and 0.02, respectively [8]. It is assumed that the diesel needed for the operation of diesel generator is supplied without any discount by the government, hence, the price of diesel in this scenario is set to be 0.170 *$/L* [20].

A time of use (TOU) price pattern for the external grid power exchange was applied (see Fig. 10), making an approximation of what in reality exists in electricity market of Iran [20]. No penalty cost is considered for the emission released for polluter components.

It should be noted that the reference value for the price of 1 U.S $ is assumed to be 35000 *Rials* [19].

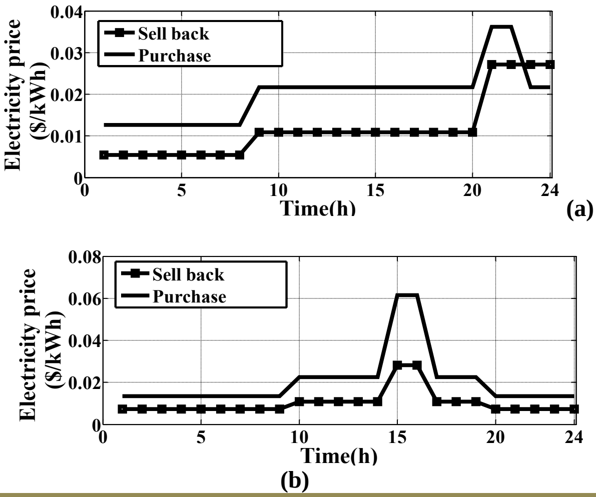

Fig. 10. Hourly Electricity price; (a): first segment (October to March), (b): second segment (April to September

A summary of cost types and comparison of electrical energy production for each case is presented in Tables 3 and 4. Comparing NPC as a criterion for all considered cases in Table 4, it is clearly seen that when the whole demand is supplied depending only on the external grid, the most economical case takes place. However, when the external grid is not available, using a renewable–based system increases the NPC significantly. However, a mix of diesel generator or external grid and renewables (Cases 3 and 4) can decrease the NPC in some degrees. It should be noted that the normalized Cost of Energy (COE) can also be used to analyze the results which gives a better view of the money expended for 1 kWh of electricity produced.

Comparison of electrical energy production for each case is also presented in Table 3. As shown in this table, in the renewable-based system (case 2), the total energy produced is much higher than other cases, whereas the system has to dump a substantial portion of the energy generated.

This is mainly due to the intermittent behavior of renewable resources. Therefore, systems with fully reliance on these sources are more exposed to such mismatches in between generation and load.

With the contribution of diesel generator (cases 1, 3), the excess energy is enormously reduced compared to Case 2, whereas due to the contribution of the external grid, i.e. cases 4, 5 and 6, the excess energy is zero in these cases.

As shown, just in case 4, the system sells energy to the external grid, which results in reduced costs related to external grid. The considered cost of loss is related completely to power exchange with the DC link and energy storage in batteries and converters. In cases 2 and 3, where there is a contribution of renewables, power loss is high. It is mainly due to batteries, which causes some losses. The contribution of electricity power to supply thermal load and also the unmet electric energy for each case are also presented in Table 3.

Table 2. Input data on option costs, sizing and other information [8]

Options	Options on size and unit numbers	Life	Other information	C_{cap}	C_{rep}	$C_{O\&M}$
Wind	25 kW- 0,1,2,5,8,10 (turbines)	15yrs	Hub height :15m	50000 $/turbine	40000 $/turbine	300$/yr.
Solar	0,20,40,60,80,100 kW	20yrs	De-rating factor:92%	7000 $/kW	7000 $/kW	0
Diesel	0 to 1200 kW	15000hrs	Minimum load: 30%	450 $/kW	400 kW	0.6 $/hr.
CHP	0 to 1200 kW	45000hrs	Minimum load: 60%	750 $/kW	600 $/kW	0.5$/hr.
Battery	1,5,10,50,100,500,1000, 2500,4000 (batteries)	1900 kWh	Nominal capacity :1900 Ah	700 $/battery	700 $/battery	14$/yr.
Converter	1,10,50,100,150,200, 250,500 kW	15yrs	Converter Efficiency: 90% Rectifier Efficiency: 85%	700 $/kW	600 $/kW	50$/yr.
Grid extension	——	—	——	100000 $/km	60000 $/km	100 $/km/yr.
Boiler	Unlimited	Unlimited	——			

6.1.2. Environmental Impacts

Numerous disadvantages of air pollution to the health of society and its long-term indirect costs imposed to governments have brought about the selection of green sources in the majority of countries [21].

Table 3. Comparison of electrical production for the six cases

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
			Production (Mwh/yr.)			
Diesel generator	2336.50	0	350.9	0	0	0
Solar PV	0	0.61	0.61	0.61	0	0
Wind	0	3886.49	3026.25	1392.40	0	0
External grid	0	0	0	1792.70	2268.40	2268.40
Total Production	2336.50	3887.10	3397.57	3185.71	2268.40	2268.40
Renewable contribution (%)	0	100	89.09	43.73	0	0
			Consumption (Mwh/yr.)			
Electrical load energy supplied	2258.80	2268.47	2257.71	2268.47	2268.40	2268.40
Excess electricity energy	77.70	612.56	342.6	0	0	0
Energy sold to grid	0	0	0	916.17	0	0
Loss	0	1006.07	797.26	1.07	0	0
Total Consumption	2336.50	3887.10	3397.57	3185.71	2268.40	2268.40
Thermal energy load	91.25	91.25	91.25	91.25	91.25	91.25
Electricity energy contribution to thermal load	76.70	15. 50	20.60	5	0	0
Unmet electric energy	9.67	0	10.76	0	0.07	0.07

Table 4. Summary of costs for the main scenario

Cost type	Case study					
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
NPC,M$	10.14	10.97	8.89	1.91	0.77	0.77
COE,$/kWh	0.30	0.32	0.26	0.05	0.007	0.007
$C_{O\&M}$,M$/yr.	5.21	2.79	3.2	0.57	0.73	0.73
C_{cap}, M$	0.22	7.9	5.1	1.9	0	0
C_{rep}, M$	1.5	1	0.64	0	0	0
C_{sal}, M$	-0.04	-0.75	-0.48	0	0	0
C_f, M$	3.25	0.03	0.43	0.04	0.04	0.04
C_{sale}, M$	0	0	0	-0.6	0	0
C_{pen}, M$	0	0	0	0	0	0

The results given in Table 5 show that the renewable-based system significantly reduces the total system emissions. In contrast, diesel-dependent system produces the most emission rate. However, in Cases 3 and 4, where renewables help diesel generator or the external grid to produce power, the amount of emission is reduced. In cases 5 and 6, with the complete dependence on the external grid, the rate of emissions is quite high. It can be concluded that the renewable-based system is the most environmentally friendly case and the diesel-based system is the most unfriendly one.

Table 5. Comparison of emissions for the main scenario

Case study	Pollutant emissions, (ton/yr.)			
	CO_2	CO	SO_2	NO_3
Case 1	2488	6	4	55
Case 2	26	0	0.05	0
Case 3	369	0.975	0.35	2.5
Case 4	530.6	0	2	0.95
Case 5	1462	0	6	3
Case 6	1462	0	6	3

6.1.3. Effect of Grid Extension Distance

To compare the two important cases, i.e. renewable-based system (Case 2) and completely grid-dependent system (case 5), the external grid connectivity should be analyzed. Fig. 11 shows the NPC variation with the grid extension distance needed. Due to the geographic feature of the area which is mostly mountainous and difficult to extend the grid, the external grid extension price per *km* is set to be 100000$, as was shown in Table 2. Having in mind that the grid extension distance of the project is about 10 *km*, the NPC for cases 4, 5 and 6 (which include the external grid) will increase. For case 5, it reaches up to about 2 *M$*, but it is still the most economical case. The breakeven extension grid is about 100 *km*; where the connection to external grid is no longer economical.

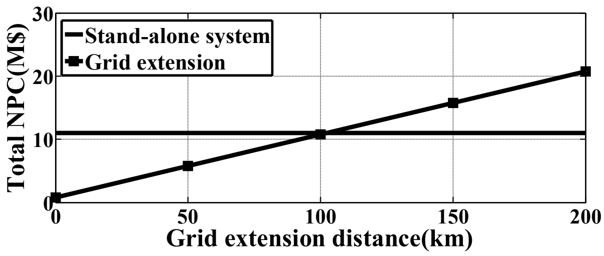

Fig. 11. Variation of NPC with the grid extension distance

6.1.4. Effect of Demand Response

Demand response (DR) is a new concept in demand-side management (DSM) framework. Recently, a growing attention has been paid on applications of DSM in power systems (especially distribution networks). Based on the definition of the U.S Department of Energy (DOE), DR is the change of electricity energy consumption pattern by the consumers in response to a change in the electricity price or incentive payments applied to lower the electricity consumption in peak hours [22]. DR programs have been addressed comprehensively in [23-24].

To investigate impacts of consumption behavior on the overall cost of supplied energy, a DR algorithm has been introduced and implemented on the renewable-grid case. The purpose of this selection is to study COE and the sensitivity of renewable contribution to demand response. In fact, we tend to investigate impacts of a short-term scheduling program on a long-term planning factor.

The proposed algorithm in [25] takes customer's preferences, load priorities and privacy into consideration. The most important factor for household customers to attend DR programs is their satisfaction provision. Having this in the mind, the mentioned incentive-based DR algorithm in [25] has been selected to be investigated in this paper. A 20% increase in the selling back price has been chosen as the incentive payment for the considered DR program. Suppose that such an algorithm has been implemented and a new system load curve has been extracted for the second segment. Fig. 12 shows the load curves before and after the DR implementation.

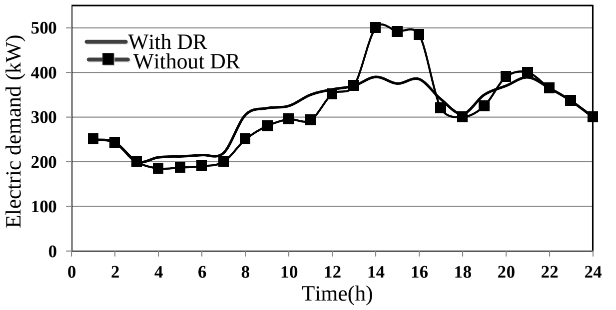

Fig. 12. Load curves before and after DR implementation for the second segment

Table 6 makes a comparison on the results with and without DR programs for case study 4. Shifting energy consumption period from peak periods to off-peak hours decreases COE and as a matter of fact more energy can be sold at peak hours. Renewable fraction has slightly increased due to the less dependence on external grid at peak hours and consequently Co_2 emission has decreased.

Table 6. Case study 4 with and without DR

Component	Without DR	With DR	Variation (%)
COE, ($/kWh)	0.05	0.04	-20
Renewable Fraction, (%)	43.73	48.50	10.90
Energy sold,(kwh/yr)	916.17	1125	22.79
Co_2 emission, (ton/yr)	530.6	488	-8.02

6.2. Sensitivity Analysis Scenario

From 2007, a robust act was passed by the parliament and then performed by the government to gradually reduce and finally eliminate the energy subsidies [19].

The sensitivity scenario is a bi-level procedure, consisting of two sensitivity analysis (see Fig. 13). The main purpose of this scenario is to find out how sensitive the overall cost of system is to each of parameters.

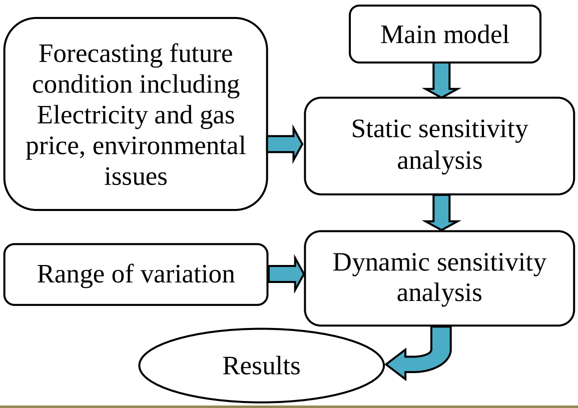

Fig. 13. Flowchart of the sensitivity analysis scenario

6.2.1. Static sensitivity analysis

An increased price pattern for the electricity energy purchase/selling back was applied as shown in Fig. 14. The price of diesel was set to be 0.29*$/L* with an average increase of 166% in comparison with the main scenario.

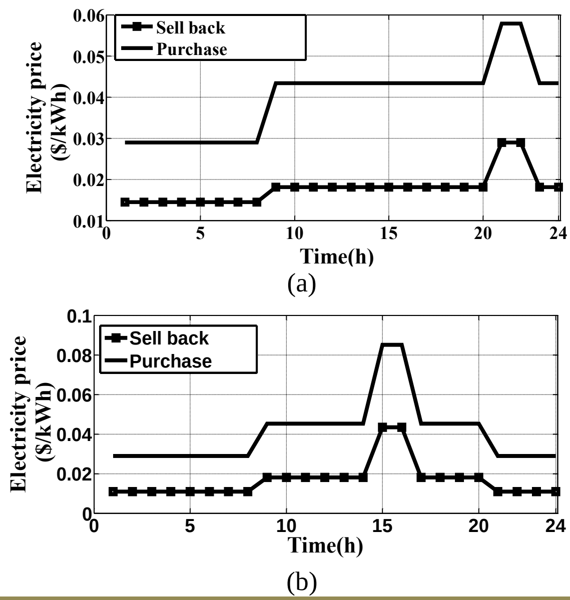

Fig. 14. Hourly Electricity price for the sensitivity scenario: (a). first segment (October to March), (b). second segment (April to September)

In contrast with the electricity and diesel price augment, it is not easy to forecast the environmental policy changes. It is a problematic issue around the world to set emission penalties due to difficulties of precise measurement of emissions and the lack of enough green resources. However, under the latest update to the Canada Federal Climate Change plan, the price in all cases would start at 15*$* per ton of carbon and rises in steps to 65*$* by 2018 [26]. We set the emission penalties to be 50*$/ton* for all the pollutants

Comparing results in Table 7 with those of Table 4, it is seen that grid-dependent system is still the most economical case. However, case 4 (a mixture of grid and renewables) is in the second stage with a close distance to cases 5 and 6. It is mainly due to the high penalty cost and the fuel cost. The grid extension distance cost for both the cases was assumed to be the same and was ignored. Diesel-based system is the most expensive case incurring both a high penalty cost and the fuel cost. Table 8 summarizes the emission rate for the different pollutants. Compared with the results of the main scenario in Table 5, the rate of emission is reduced about 60% in diesel-renewable system due to the contribution of renewables. In other cases no change is seen due to economic preference or lack of a substitution option to use instead of environmentally unfriendly resources.

Table 7. Summary of costs for the sensitivity scenario

Case study	Pollutant emissions, (ton/yr)			
	CO_2	CO	SO_2	NO_3
Case 1	2488	6	4	55
Case 2	26	0	0.05	0
Case 3	147	0.95	0.35	2.5
Case 4	530.6	0	2.5	0.85
Case 5	1462	0	6.5	3
Case 6	1462	0	6.5	3

Table 8. Comparison of emissions for the sensitivity scenarion

Cost type	Case study					
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
NPC,(M$)	16.43	11.31	10.05	2.44	2	2
COE,($/kWh)	0.45	0.32	0.29	0.08	0.5	0.05
$C_{O\&M}$,(M$/yr.)	8.55	2.95	2.22	1.5	1.1	1.1
C_{cap}, (M$)	0.16	7.95	6.95	1.03	0	0
C_{rep}, (M$)	0.9	1.09	1.09	0	0	0
C_{sal}, (M$)	-0.03	-0.82	-0.91	0	0	0
C_f, (M$)	5.85	0.12	0.6	0.12	0.4	0.4
C_{sale}, (M$)	0	0	0	-0.42	0	0
C_{pen}, (M$)	1	0.02	0.1	0.21	0.5	0.5

6.2.2. Dynamic Sensitivity Analysis

For the renewable-grid configuration (which is technically the bets configuration), a dynamic sensitivity analysis has been done to investigate impacts of continuous variation of inflation uncertainties and emission penalties on system's economic and technical parameters.

6.2.2.1. Effect of Inflation Variation

A range of inflation rates from 0 to 25% has been applied instead of setting a fixed value for that. As shown in Fig. 15, COE decreases with the inflation increase. This conclusion is justifiable based on Equations (1) to (6). It means that the cost of energy supply for the desired area is reduced when the inflation rate increases. In other words, it will become more economical to operate the system with higher values of the inflation rate. As seen in Fig. 16, due to the fact that capital cost includes a large portion of renewables resources' cost, they are preferred to those having large operation cost in high inflation rates (see equations (1) to (6)).

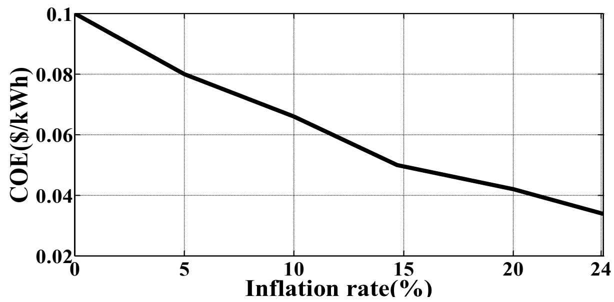

Fig. 15. COE variations with the inflation increase

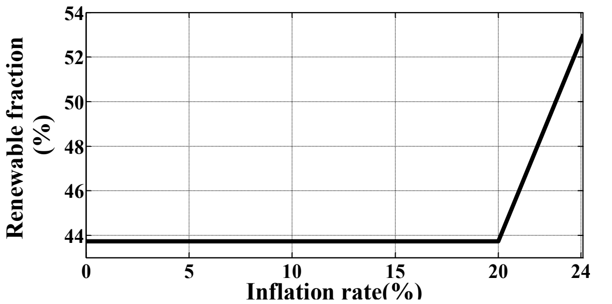

Fig. 16. Renewable contribution variation with the inflation increase

6.2.2.2. Effect of Emission Penalty Variation

A range of penalty cost from 0 to 100$ per ton of CO_2 emissions has been taken into consideration. To show the role of emission penalties, we define and evaluate a novel index that links COE with the amount of emission produced. It is called extra cost of pollution (ECP) and is written as below:

$$ECP = \frac{COE - COE_{ref}}{em - em_{ref}} \tag{18}$$

Where COE_{ref} and em_{ref} are reference values for normalized cost of energy and emission rate, respectively. We set the condition with no penalty cost as the reference case. A negative value for ECP shows that the cost of energy supply increases in exchange for less emission production while a positive value signifies more expensive energy in exchange for more emission production (that rarely occurs).

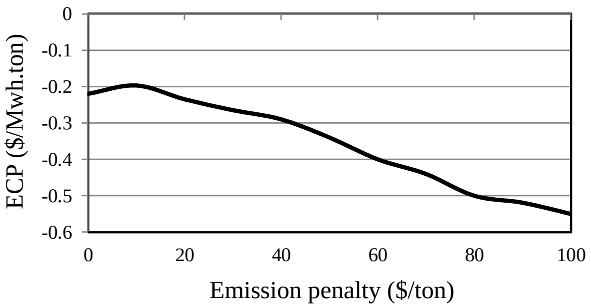

Fig. 17. ECP variation with emission penalty increase

Fig. 17 shows how ECP varies with the variation of emission penalties. A small variable extra cost is paid for a *kWh* of energy supplied per ton of CO_2 emissions. As shown, from the penalty rate of 10*$/ton*, the slope of ECP decrease has been accelerated.

As environmental concerns are becoming more critical, ECP may decrease due to higher penalty costs. Thus, an acceptable limit should be set as a criterion to highlight the beneficiary margin of external grid's utilization.

7. Conclusion

A comparative study has been reported in this paper to investigate the role of long-term energy policies and short-term consumption behavior of customers in optimal design of hybrid energy systems. The study was done for a quite residential remote area located near a small village, Esfarjan, Shahreza, Iran considering two scenarios and six case studies.

In the main scenario, the system design was evaluated regarding the real economic parameters like annual interest and inflation rate and current energy policies of the government i.e. time of use (TOU) pattern of electricity energy price, diesel price and environmental issues. No emission penalty was considered in this scenario. The results showed that using the external grid was significantly cheaper than other cases.. Environmental impacts of different cases and the effect of grid extension distance for the grid connectivity option were also investigated. Impact of demand response (consumption behavior) as a tool to decrease energy cost, was studied.

Sensitivity scenario is a bi-level procedure, consisting of two sensitivity analyses. The main objective of this scenario is to find out how sensitive the overall cost of system is to each of variable parameters. In the static analysis, augmented price patterns for the electricity purchase/selling back and diesel has been considered. In addition, an emission penalty has been applied for polluter resources. Results show that although the grid dependent system is still the most economical selection, it is not the superior one since a contribution of grid and renewable sources is in the following with a close distance.

For the renewable-grid configuration (which is technically the best configuration), a dynamic sensitivity analysis has been done to investigate impacts of continuous variation of inflation uncertainties and emission penalties on system's economic and technical parameters. Impact of continuous inflation variation on normalized cost of energy and renewable contribution of the system has been studied. A novel index has been defined and evaluated to investigate impact of continuous variation of emission penalty on overall performance of the system.

It can be concluded that long-term economic, energy and environmental policies have a more significant role in optimal design of hybrid energy systems in comparison with short-term consumption behavior of customers. Results also highlight the prosperity of renewables' contribution in the design of hybrid energy systems with the upcoming policies of the government.

References

[1] Amirioun, M.H., Kazemi, A., *"A new model based on optimal scheduling of combined energy exchange modes for aggregation of electric vehicles in a residential complex"*, Energy, Vol. 69, pp. 186–198, 2014.

[2] Eid, C., Codani, P., Perez, Y., Reneses, J., Hakvoort, J., "*Managing Electricity Flexibility from Distributed Energy Resources: A Review of Incentives for market Design*", Renewable and Sustainable Energy Reviews, Vol. 64, pp. 237-247, 2016.

[3] Adefarati, T., Bansal, R.C., "*Integration of Renewable Distributed Generators into the Distribution System: A Review*", IET Renewable Power, Vol. 10, pp. 873-884, 2016.

[4] Siano, P., "*Assessing the Impact of Incentive Regulation for Innovation on RES Integration*", IEEE Trans. Power Syst., Vol. 29, pp. 2499-2508, 2014.

[5] Ball, M., Wietschel, M., Rentz, O., "*Integration of a Hydrogen Economy into The German Energy System: An Optimizing Modeling Approach*", Int. Journal of Hydrogen Energy, Vol. 32, pp.1355-68, 2007.

[6] Al Busaidi, A.S., Kazem, H.A., Al-Badi, A.H., Khan, M.F., "*A Review of Optimum Sizing of Hybrid PV–Wind Renewable Energy Systems in Oman*", Renewable and Sustainable Energy Reviews, Vol. 53, pp. 185-193, 2016.

[7] Razali, N.M.M., Hashim, A.H., "*Backward Reduction Application for Minimizing Wind Power Scenarios in Stochastic Programming*", In: proc. 4th International Power Engineering and Optimization Conf. (PEOCO), pp.430–4, 2010.

[8] Kassam, A., "*HOMER Software: Training Guide for Renewable Energy Base Station Design*", 2010, Available: http://www.gsma.com. [accessed Feb. , 2016].

[9] Getachew, B., Tadesse, G., "*Feasibility Study of Small Hydro/ PV/Wind Hybrid System for Off–grid Rural Electrification in Ethiopia*" In: Proc. 3th International Conf on Applied Energy. Perugia. Italy, 2011.

[10] Ogunjuyigbe, A., Ayodele, T., Akinola, O., *"Optimal Allocation and Sizing of PV/Wind/Split-diesel/Battery Hybrid Energy System for Minimizing Life Cycle Cost, Carbon Emission and Dump Energy of Remote Residential Building*", Applied Energy, Vol. 171, pp. 153-171, 2016.

[11] Maleki, A., Pourfayaz, F., Rosen, M.A., "*A Novel Framework for Optimal Design of Hybrid Renewable Energy-based Autonomous Energy Systems: A Case Study for Namin, Iran*", Energy, Vol. 98, pp. 168-180, 2016.

[12] Wies, W., Johnson, R.A., Ashish, N., Agrawal, A.N., Chub, J.T., "*Simulink Model for Economic Analysis and Environmental Impacts of a PV With diesel-Battery System for Remote Villages*", IEEE Trans. Power Syst., Vol. 20, 2005.

[13] Kamali, S., "*Feasibility Analysis of Standalone Photovoltaic Electrification System in a Residential Building in Cyprus*", Renewable and Sustainable Energy Reviews, Vol. 65, pp. 1279-1284, 2016.

[14] Siddaiah, R., Saini, R.P., "*A Review on Planning, Configurations, Modeling and Optimization Techniques of Hybrid Renewable Energy Systems for Off-grid Applications*", Renewable and Sustainable Energy Reviews, Vol. 58, pp. 376-396, 2016.

[15] Mostafaeipour, A., Qolipour, M., Mohammadi, K.,

"*Evaluation of Installing Photovoltaic Plants Using a Hybrid Approach for Khuzestan Province, Iran*", Renewable and Sustainable Energy Reviews, Vol. 60, pp. 60-74, 2016.

[16] Salehin, S., Ferdaous, M.T., Chowdhury, R.M., Shithi, S.S., Rofi, M.B., Mohammed, M.A., "*Assessment of Renewable Energy Systems Combining Techno-Economic Optimization with Energy Scenario Analysis*", Energy, Vol. 112, pp. 729-741, 2016.

[17] Corona, B., Cerrajero, E., López, D., San Miguel, G., "*Full Environmental Life Cycle Cost Analysis of Concentrating Solar Power Technology: Contribution of Externalities to Overall Energy Costs*", Solar Energy, Vol. 135, pp. 758-768, 2016.

[18] Geographic Information (Weather conditions, Natural topology,etc). Available from: http://eosweb.larc.nasa.gov/sse/. [accessed Feb. , 2016].

[19] Iran's economy: A View of the Future. Available from: http://www.cbi.ir/. [accessed Feb. ,2016].

[20] Electricity Energy Tariffs in Iran. Available from: www.tavanir.org.ir. [accessed Feb. ,2016].

[21] Qu, B., Liang, J., Zhu, Y., Wang, Z., Suganthan, Z., "*Economic Emission Dispatch Problems with Stochastic Wind Power Using Summation Based Multi-objective Evolutionary Algorithm*", Information Sciences, Vol. 351, pp. 48-66, 2016.

[22] U.S Department of Energy, "*Benefits of Demand Response in Electricity Markets and Recommendations for Achieving them*", Technical report to the United States Congress. Feb. 2006. Available from: http://eetd.lbl.gov. [accessed Jan. 2016].

[23] Aalami H.A., Parsa Moghaddam, M., Yousefi, G.R., "*Demand Response Modeling Considering Interruptible/Curtailable Loads and Capacity Market Programs*", Applied Energy, Vol. 87, pp.1243-50, 2010.

[24] Aalami, H.A., Parsa Moghaddam, M., Yousefi, G.R., "*Modeling and Prioritizing Demand Response Programs in Power Markets*", Electric Power Systems Research, Vol. 80, pp. 426-435, 2010.

[25] Shengnan, Shao, Pipattanasomporn, M., Saifur, R., "*Grid Integration of Electric Vehicles and Demand Response with Customer Choice*", IEEE Trans. Smart Grid, Vol. 3, pp. 543-550, 2012.

[26] Gorrie, P., "*Ontario Catches Break on Coal Plants. The Star 2008*": Available from: http: //www.thestar.com/sciencetech/article/33.9591