International Journal of Engineering & Applied Sciences (IJEAS)
Vol.7, Issue 1(2015)59-67

COMPARISON OF LEVENBERG-MARQUARDT BASED LEAST SQUARES METHOD AND A HEURISTIC TECHNIQUE FOR ELECTRICITY DEMAND ESTIMATION

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Received date: October 2014
Accepted date: February 2015

Abstract

This paper focuses on demand estimation of electricity in Iran using artificial bee swarm optimization (ABSO) algorithm which is a recently invented metaheuristic technique. For this aim, two types of exponential and quadratic models are investigated to estimate the Iran's electricity demand. These models are defined based on socio-economic indicators of population, gross domestic product (GDP), import and export figures. Owing to the fluctuations of the economic indicators and nonlinearity of the electricity demand, an efficient technique must be employed to find optimal or near optimal values of the models' weighting factors. This paper proposes ABSO as an efficient approach for solving this problem. The available data of electricity demand in Iran from 1981 to 1999 is used for finding the optimal weighing factors and the data from 2000 to 2005 is used for testing the models. In order to evaluate the performance of the proposed methodology, the results are compared with the result obtained by the traditional nonlinear least-squares optimization method of and Levenberg–Marquardt (LM).

Keywords: Electricity demand estimation; Socio-economic indicators; Levenberg-Marquardt; Artificial bee swarm optimization

1. Introduction

Electricity demand of Iran has increased over the years and is expected to continue to increase in further years. According to the published statistics [1] electricity consumption in Iran has reached from 18.234 GWh in 1981 to 134.238 GWh in 2005. Increasing demand of electricity originates from the strong population and economic growth as well as rapid urbanization. Energy outlook of Iran manifests the importance of need for systematic management and optimization of energy. As a result, power utility has to know the accurate amount of electricity demand in the coming years to provide the required power. Study of literature shows that several methods have been used to estimate the energy demand such as mathematical models [2-7], artificial neural networks (ANNs) [8], fuzzy systems [9] and partial least square regression [10]. Most often, mathematical models which are defined based on socio-economic indicators are used to estimate the energy demand. These models may be linear, quadratic or exponential forms. With respect to the used model the number of the weighting factors varies. In order to estimate the energy demand, the optimal values of the weighting factors must be determined by the help of an optimization technique. Owing to the fluctuations of the economic indicators and nonlinearity of the electricity demand in Iran, an efficient technique must be employed to find optimal or near optimal values of the models' weighting factors. Because of their stochastic nature and global search ability, metaheuristic optimization algorithms could be suitable choices for accurate modeling of energy demand estimation. There are several studies in which metaheuristic algorithms have been proposed to model energy demand estimation problem. Genetic algorithm (GA) has been used to demand estimation of oil [4], fossil fuels [11] and electricity [2,5]. Ant colony optimization (ACO) has been suggested in [3] for energy estimation. Particle swarm optimization (PSO) has been proposed for demand estimation of oil [4] and electricity [2]. The main goal of this paper is to estimate the Iran's electricity demand based on socio-indicators of population, gross domestic product (GDP), import and export figures. For this aim, the exponential and quadratic models are used and artificial bee swarm optimization (ABSO) algorithm is proposed to find the optimal weighing factors. ABSO is a new version of bee swarm algorithms [12,13] trying to mimic the behaviours of bees for finding a food source with high quality. Though ABSO has simple concept and is easy to implement, the main advantage of this algorithm is high efficiency. High efficiency of ABSO originates from using different moving patterns to probe the search space. This feature makes the ability of establishing good balance between exploration and exploitation and increases the probability of finding the global solution. For estimating the Iran's electricity demand using population, GDP, import and export figures by exponential and quadratic models, 25 years observed data from 1981 to 2005 are used and ABSO algorithm is used to find the optimal weighting factors. Finally, the results are compared with the results obtained by least squares method.

2. Problem formulation

2.1. Electricity demand estimation

Energy demand estimation based on socio-economic indicators may be expressed using various forms of equations. Most often, linear, quadratic and exponential forms of mathematical models are used to forecast the energy demands. Thanks to the fluctuations of Iran's socio-economic indicators, nonlinear forms of equations can better estimate the energy demand. As a result, "two nonlinear forms of equations including exponential and quadratic functions defined by Eq. (1) and Eq. (2) are used".

Exponential model:

$$ED_{\exp} = w_1 y_1^{w_2} + w_3 y_2^{w_4} + w_5 y_3^{w_6} + w_7 y_4^{w_8} + w_9 \quad (1)$$

Quadratic model:

$$\begin{aligned} ED_{quad} = {} & w_1 y_1^2 + w_2 y_2^2 + w_3 y_3^2 + w_4 y_4^2 \\ & + w_5 y_1 y_2 + w_6 y_1 y_3 + w_7 y_1 y_4 + w_8 y_2 y_3 + w_9 y_2 y_4 + w_{10} y_3 y_4 \\ & + w_{11} y_1 + w_{12} y_2 + w_{13} y_3 + w_{14} y_4 \\ & + w_{15} \end{aligned} \quad (2)$$

where ED denotes the electricity demand, y_1, y_2, y_3 and y_4 are population, GDP, import and export figures, respectively, and w_i ($i = 1,2,...,15$) indicates the weighting factor. The main problem is to determine the optimal values of the weighting factors by which the used model can estimate the electricity demand as well as possible. Electricity demand estimation can be considered as an optimization problem in which the ultimate aim is to determine the optimal values of the weighting factors by an efficient optimization technique. Number of the unknown weighting factors is 9 and 15 for the exponential and quadratic models, respectively. For this aim, "the objective function is defined by Eq. (3) for minimizing the difference between the actual and estimated electricity demands".

$$F(x) = \sum_{q=1}^{Q} \left(ED^{q}_{\exp(or\ quad)} - ED^{q}_{actual} \right)^2 \tag{3}$$

where F is the objective function value, x is a vector (with the length of 9 or 15 based on the used model) which contains the weighting factors and Q in the number of observations. The nonlinearity of the economic indicators and energy demand make electricity demand estimation as a complex optimization problem which needs an efficient technique to find optimal or near optimal values of the weighting factors. In the following subsection, ABSO is introduced as an approach to conquer the complexity of this problem.

2.2. ABSO algorithm

A bee swarm makes use of intelligent behaviors for collection and processing of nectar. Inspired from these intelligent behaviors, bee swarm algorithms are optimization techniques trying to find the optimal solution of complex optimization problems. In comparison with the other optimization techniques, bee swarm-based algorithms have a prominent feature. They employ different kinds of bees with distinct searching patterns. This ability provides a flexible algorithm to avoid premature convergence and discover the optimal solution. Recently, a new version of bee algorithm known as ABSO has been proposed by the authors [12,13] in which two types of bees are employed: onlooker and scout bees. In ABSO, each bee shown by a d-dimensional vector is a feasible solution of the problem on hand and its type is specified according to the quality (objective function value) of the food source discovered. The bees have memory and memorize their experiences. At each iteration, the bees are classified into onlookers and scouts, based on the quality of the best food source that they have found so far. Consequently, the bees are ranked in light of their objective functions. Then, a predefined number of the bees which have the worst quality are chosen as scouts and the others make onlookers. The percentage of each group is selected manually. It is better to select a small number of the bees as scouts. Scout bees are those bees that use random strategies to fly over the food source area (search space). ABSO algorithm makes use of scout bees to provide exploration. Each scout bee searches the food source region randomly with a walk function, wf, for finding new food sources. "The updating pattern used by this type of bee is shown by Eq. (4)".

$$x^{j}_{new} = x^{j} + r_s \times wf^{\,j} \tag{4}$$

where x_{new} is the new position, x denotes the current position, $j = 1,2,\ldots,d$ denotes the variable index, r_s is a random number between -1 and 1, and "wf, defined by Eq. (5), is a vector depending on the lower bound, l, and upper bound, u". "The radius of walk function, τ, decreases with a linear function from a large value, τ_{max}, to a small one, τ_{min}, during the iterations as Eq. (6)".

$$wf = \tau \times \left(\left|u^1 - l^1\right|, \left|u^2 - l^2\right|, \ldots, \left|u^d - l^d\right| \right) \tag{5}$$

$$\tau = \tau_{\max} - (\tau_{\max} - \tau_{\min}) \, {iter}/{iter_{\max}} \tag{6}$$

where *iter* is the iteration index and $iter_{max}$ is the maximum number of iterations. The large value of τ in the first iterations makes the possibility of global search and a small value in the last iterations allows a local search.

Among the onlooker bees, ne bees with the best quality are chosen as elites. Each elite bee dances in the hive and attempts to encourage the other onlookers to search the vicinity of the best food source that it has discovered so far. The way by which each onlooker bee makes a decision to follow a specific dancer is not obvious, but is likely in relation with the best quality of that dancer. Hence, as the quality of a dancer increases, the probability of its selection increases, too. The value of ne has a significant role on the ABSO performance. If it is selected too small, the algorithm may be influenced by premature convergence, while the large values of ne have bad effect on the search ability of the ABSO algorithm.

Each onlooker bee selects one of the dancers by a probabilistic approach as its elite bee. Here, the used approach is tournament selection. In this approach, weak dancers have a smaller chance of being chosen when the tournament size is large. This approach permits the selection pressure to be adjusted easily by the tournament size set at 2. “The onlooker bee then adjusts its position using its own knowledge and that of its interesting elite using the following pattern as Eq. (7)”.

$$x_{new}^{j} = x^{j} + w_b \times r_b (x_b^{j} - x^{j}) + w_e \times r_e (x_e^{j} - x^{j}) \quad (7)$$

where x_e is the interesting elite bee, x_b is the best achievement found by the onlooker bee, and r_b and r_e are random numbers from the interval [0, 1]. To make a trade-off between global and local search, w_b and w_e are defined as decreasing linear functions. For enhancing the global search in the beginning of the algorithm the maximum values (w_{bmax} and w_{emax}) and converging toward an optimal solution at the end of the algorithm minimum values (w_{bmin} and w_{emin}) are used. “The parameters of w_b and w_e are defined as Eq. (8) and Eq. (9)”.

$$w_b = w_{b\max} - (w_{b\max} - w_{b\min}) \, {iter}/{iter_{\max}} \quad (8)$$

$$w_e = w_{e\max} - (w_{e\max} - w_{e\min}) \, {iter}/{iter_{\max}} \quad (9)$$

The steps of the proposed algorithm used in this study to find the optimal weighting factors for the electricity demand models are as follows:

Step 1: ABSO starts with a swarm of N candidate solutions, called bees. It is usual to specify each bee by a d-dimensional vector, where x = [*w1 w2* ... *w9*] for the exponential model and x = [*w1 w2* ... *w15*] for the quadratic model. The bees are randomly initialized in the search space. The initial swarm should cover the entire search space as much as possible. “This is achieved by uniformly randomizing the bees using Eq. (10)”.

$$x_i^{j} = l^{j} + \alpha \times (u^{j} - l^{j}) \quad (10)$$

where α is a random number between 0 and 1.

Step 2: the value of the objective function for each bee is computed based on Eq. (3).

Step 3: the bees are ranked based on their objective functions.

Step 4: onlooker and scout bees are specified.

Step 5: the position of the onlooker and scout bees is updated according to their patterns.

Step 6: if a bee exceeds the search space, it is replaced with the previous position.

Step 7: steps 2 to 6 are repeated until itermax is met.

Step 8: the best achievement of the swarm is selected as the optimal solution.

3. Simulation results

For finding the optimal weighting factors, ABSO algorithm is coded in MATLAB environment. The adjustable parameters of the algorithm are set by trial. For the exponential model the swarm size is set to 50 with 40 onlooker and 10 scout bees. In this case, the number of elite bees is set to 5. For the quadratic model, the swarm size is set to 200 with 180 onlooker and 20 scout bees. For this function, n_e is set to 20. Since the problem dimension is higher when using the quadratic model, for effectively searching the population size is selected bigger. Other parameters are set as follows: $w_{bmax} = w_{emax} = 2.5$, $w_{bmin} = w_{emin} = 0.25$, $iter_{max} = 5000$, $\tau_{max} = 0.2$, $\tau_{min} = 0.02$, $l = -3$ and $u = 3$. In order to estimate the electricity demand of Iran in terms of population, GDP, import and export figures by the exponential and quadratic models, 25 years observed data from 1981 to 2005 are used in this study. "Table 1" represents the electricity demand, population, GDP, import and export figures of Iran between 1981 and 2005. This data stems from the reported statistics [1,14]. For each model, first 19 years observed data from 1981 to 1999 is used to find the weighting factors (Q = 19) and the 6 years data from 2000 to 2005 is used to test the estimated model.

Table 1. Electricity demand, population, GDP, import and export figures of Iran between 1981 and 2005.

Year	Electricity demand (GWh)	Population (Thousand Persons)	GDP (10^9 Rial[a])	Import (Mboe)[b]	Export (Mboe)
1981	18.234	40825.6	170281.2	21.4	339.8
1982	21.753	42420	191666.8	31.2	787.7
1983	25.153	44076.6	212876.5	61.7	764.3
1984	28.177	45720.7	208515.9	39.6	610.6
1985	30.812	47541.4	212686.3	65.3	652.3
1986	32.619	49445	193235.4	62	566.5
1987	34.74	50650	191312.4	72.9	635
1988	36.147	51890	180822.5	69.6	682.5
1989	39.956	53167	191502.6	50	765.5
1990	45.107	54483	218538.7	46.8	919.5
1991	49.175	55837	245036.4	48.4	964.8
1992	52.306	56963	254822.5	64.6	1023.3
1993	58.114	58114	258601.4	57.9	1058.6
1994	63.625	59290	259876.3	42.6	991
1995	65.854	59151	267534.2	28.5	1002.8
1996	69.671	60055.5	283806.6	29.1	880.4
1997	73.358	60936.5	291768.7	28.7	855.1
1998	77.646	61830	300139.6	24.6	854.6
1999	84.656	62736	304941.2	26.9	810.6
2000	90.366	63663.9	320068.9	39.6	955.9
2001	97.171	64528.2	330565	51.3	901.1
2002	105.525	65540.2	355554	67.3	928.4
2003	114.624	66991.6	379838	99.6	1109.6
2004	125.528	67477.5	398234.6	121.6	1184.9
2005	134.238	68467.4	419705	116.7	1182.3

[a] Rial: Currency unit of Iran.

[b] Mboe: Million barrel of oil equivalents.

To speed up the convergence rate of the ABSO algorithm, the data used for finding the weighting factors is normalized. “Data normalization is made by using the following expression as Eq. (11)”.

$$\bar{y} = \frac{y - Max(y^i)}{Max(y^i) - Min(y^i)} \qquad i = 1,2,\ldots,19 \tag{11}$$

where $\bar{y}$ is the normalized value and y denotes the real value. Normalization is made for each indicator using the minimum and maximum values of that indicator shown in “Table 2”.

Table 2. Minimum and maximum of each indicator for doing normalization

	Minimum value	Maximum value
Population (Thousand Persons)	40825.6	62736
GDP (10^9 Iranian Rial)	170281.2	304941.2
Import (Mboe)	21.4	72.9
Export (Mboe)	339.8	1058.6
Electricity demand (GWh)	18.234	84.656

ABSO algorithm is run 20 times the best performance of the algorithm during these runs is considered. The optimal weighting factors of the models are determined by ABSO algorithm using the data from 1981 to 1999. “Table 3” and “Table 4” summarize the optimal weighting factors found for the exponential and quadratic models. To validate the estimated models, the testing procedure is performed to obtain the relative error between the observed and estimated electricity demand in the period of 2000 to 2005. “Table 5” shows the relative error between the observed demand and estimated values by the exponential and quadratic models.

Table 3. Optimal weighting factors of exponential ED model found by ABSO

Weighting factor	w_1	w_2	w_3	w_4	w_5
Value	0.82938	2.13822	0.06891	2.52589	0.00020

Weighting factor	w_6	w_7	w_8	w_9
Value	2.99060	0.08851	0.000001	0.00099

Table 4. Optimal weighting factors of quadratic ED model found by ABSO

Weighting factor	w_1	w_2	w_3	w_4	w_5
Value	0.07088	1.15188	−0.02041	0.48477	−1.37333

Weighting factor	w_6	w_7	w_8	w_9	w_{10}
Value	0.27286	−0.33429	−0.35993	0.24524	−0.08558

Weighting factor	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
Value	0.88779	0.35206	−0.04168	−0.43929	0.01147

Table 5. Comparison of exponential and quadratic models for demand estimation of Iran.

Year	Actual electricity demand (GWh)	ED_{exp} (GWh)	Relative error (%)	ED_{quad} (GWh)	Relative error (%)
2000	90.366	90.368	0.002	89.238	−1.248
2001	97.171	96.464	−0.728	90.525	−6.840
2002	105.525	105.706	0.171	103.692	−1.737
2003	114.624	118.732	3.584	112.515	−1.840
2004	125.528	125.327	−0.160	120.192	−4.251
2005	134.238	136.522	1.702	144.372	7.549
Average	−	−	1.06	−	3.91

As “Table 5” indicates, the average relative errors are 1.06% and 3.91% for the exponential and quadratic models, respectively. It seems that these models can estimate the electricity demand of Iran with acceptable relative errors. Comparison of the exponential and quadratic models reveals that the exponential model can estimate the demand more accurate than the quadratic one because it has found a smaller relative error. “Fig. 1” and “Fig. 2” illustrate the comparison between the actual electricity demand and the estimated one using the exponential and quadratic models, respectively. The agreement between the values shows the validity of the estimation approach.

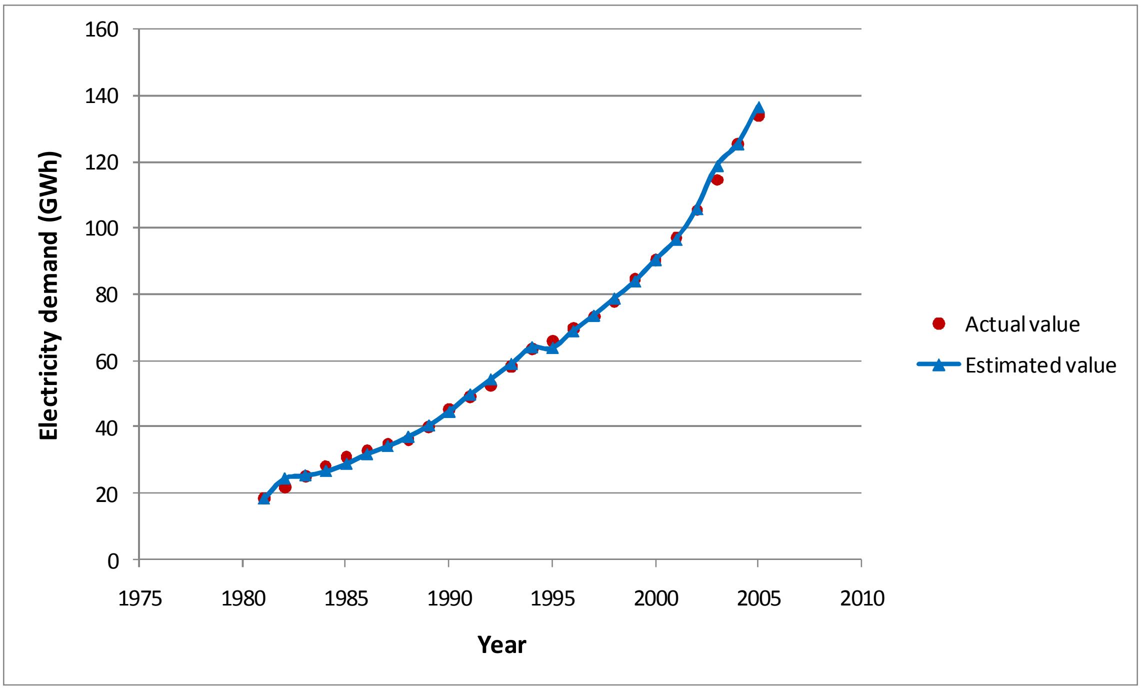

Figure 1: Comparison of electricity demand estimated by the exponential model and the actual value

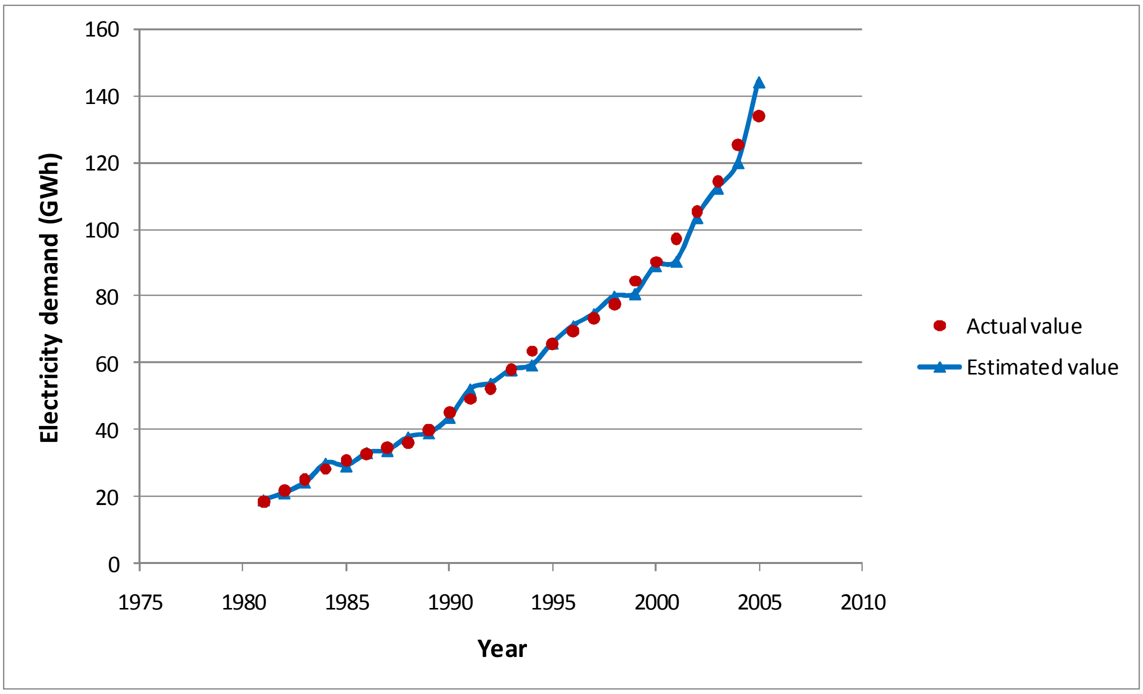

Figure 2: Comparison of Electricity demand estimated by the quadratic model and the actual value.

In order to assess the performance of the proposed ABSO algorithm, a popular least squares method, namely, Levenberg-Marquardt (LM) is used to find the weighting factors. Table 6 lists the weighting factors. As can be seen, the average relative errors are 1.28% and 4.03% for the exponential and quadratic models, respectively. Comparison of "Table 5" and "Table 6" shows that the results obtained by ABSO algorithm are more accurate than the results obtained by LM method.

Table 6. Comparison of exponential and quadratic models optimized by LM method.

Year	Actual electricity demand (GWh)	ED_{exp} (GWh)	Relative error (%)	ED_{quad} (GWh)	Relative error (%)
2000	90.3660	89.5325	−0.9223	82.3856	−8.8312
2001	97.1710	95.8870	−1.3214	93.1585	−4.1293
2002	105.5250	105.7772	0.2390	107.0122	1.4093
2003	114.6240	116.9207	2.0037	115.6703	0.9128
2004	125.528	121.7356	−3.0212	130.6427	4.0746
2005	134.2380	134.0454	−0.1434	140.7238	4.8315
Average	–	–	1.28	–	4.03

4. Conclusion

This paper proposes ABSO algorithm to determine the weighting factors of the exponential and quadratic models for Iran's electricity demand estimation. Using two updating patterns in ABSO helps to provide a balance between exploration and exploitation. This feature increases the opportunity of finding the optimal or near optimal solution. Simulation results accentuate that ABSO can be a helpful tool for electricity demand estimation based on socio-economic indicators. Furthermore, the exponential model reaches to less relative error than the quadratic model for estimating the Iran's electricity demand. Moreover, ABSO outperforms LM method in terms of accuracy.

References

[1] Central bank of islamic republic of Iran, Report and statistics; 2007.
[2] M.H. Amjadi, H. Nezamabadi-pour, M.M. Farsangi, Estimation of electricity demand of Iran using two heuristic algorithms, Energy Conver Manage 51 (2010), 493-497.
[3] M.D. Toksari, Ant colony optimization approach to estimate energy demand in Turkey. Energy Policy 35 (2007) 3984-3990.
[4] E. Assareh, M.A. Behrang, M.R. Assari, A. Ghanbarzadeh, Application of PSO (particle swarm optimization) and GA (genetic algorithm) techniques on demand estimation of oil in Iran. Energy 35 (2010) 5223-5229.
[5] H.K. Ozturk, H. Ceylan, O.E. Canyurt, A. Hepbasli, Electricity estimation using genetic algorithm approach: a case study of Turkey. Energy 30 (2005) 1003-1012.
[6] H. Ceylan, H.K. Ozturk, Estimating energy demand of Turkey based on economic indicators using genetic algorithm approach. Energy Conver Manage 45 (2004) 2525-2537.
[7] O.E. Canyurt, H.K. Ozturk, Application of genetic algorithm (GA) technique on demand estimation of fossil fuels in Turkey. Energy Policy 36 (2008) 2562-2569.
[8] A. Azadeh, S.F. Ghaderi, S. Sohrabkhani, A simulated-based neural network algorithm for forecasting electrical energy consumption in Iran. Energy Policy 36 (2008) 2637-2644.
[9] A. Azadeh, M. Saberi, O. Seraj. An integrated fuzzy regression algorithm for energy consumption estimation with non-stationary data: a case study of Iran. Energy 35 (2010) 2351-2366.
[10] M. Zhang, H. Mu, G. Li, Y. Ning, Forecasting the transport energy demand based on PLSR method in China. Energy 34 (2009) 1396-1400.
[11] M. Nava, J. Gasca, U. Gonzalez, The energy demand and the impact by fossil fuels use in the Mexico City Metropolitan Area, from 1988 to 2000. Energy 31 (2006) 3381-3390.
[12] A. Askarzadeh, A. Rezazadeh, A new artificial bee swarm algorithm for optimization of proton exchange membrane fuel cell model parameters, Journal of Zhejiang University Science C 12 (2011) 638-646.
[13] A. Askarzadeh, A. Rezazadeh, Artificial bee swarm optimization algorithm for parameters identification of solar cell models, Applied Energy 102 (2013) 943-949.
[14] Energy Balance Annual Report. Tehran: Ministry of Energy; 2005.