UDC 621.3 **doi: 10.20998/2074-272X.2018.5.10**

M. Dehghani, Z. Montazeri, A. Ehsanifar, A.R. Seifi, M.J. Ebadi, O.M. Grechko

PLANNING OF ENERGY CARRIERS BASED ON FINAL ENERGY CONSUMPTION USING DYNAMIC PROGRAMMING AND PARTICLE SWARM OPTIMIZATION

Purpose. In the present article, a new approach of the energy grid studies is introduced to program energy carriers. In this view, a proper plan is designed on the use of energy carriers considering the energy optimum use. Indeed, the proper energy grid is designed by applying Iran energy balance sheet information. It is proper to mention that, the energy grid modelling is done in a matrix form. The electrical energy distribution among power stations is achieved by using the particle swarm optimization algorithm. In the present paper, concerning the dynamic programming method, it is tried to determine a suitable combination of energy carriers. References 16, tables 17, figures 1.
Key words: **particle swarm optimization, final energy consumption, energy planning, energy carriers, dynamic programing.**

Цель. В настоящей статье предлагается новый подход к исследованию энергетических сетей для планирования энергоносителей. С этой целью разработан корректный план использования энергоносителей с учетом оптимального потребления энергии. Разработана соответствующая энергосистема с использованием информации о энергетическом баланса Ирана. Необходимо отметить, что моделирование энергосистемы выполняется в матричной форме. Распределение электрической энергии между электростанциями достигается за счет использования алгоритма оптимизации методом роя частиц. В настоящей работе, посвященной методу динамического программирования, предпринята попытка определить подходящую комбинацию энергоносителей. Библ. 16, табл. 17, рис. 1.
Ключевые слова: **оптимизация методом роя частиц, конечное потребление энергии, планирование в энергетике, энергоносители, динамическое программирование.**

Introduction. One of the suitable criterions in determining the development level and the life quality of a typical country is the energy application. Both the durance of energy presentation and the long term access ability to sources require energy comprehensive planning. One of the key issues of energy planning is energy carriers.

Despite the present applied method, the energy planning program needs the initial comprehensive study of the energy system. It is possible to offer a general framework to model different systems holding different energy carriers like electrical, thermal, gas, etc. energies. The mentioned modelling framework is based on the energy-based approach. The energy-based main idea is defining a converter matrix having the ability of describing the generation, delivery and consumption within systems carrying some types of energies [1]. Based on the energy current optimization model, Cormio has proposed a linear-based planning optimization model in a region in south of Italy. This plan includes energy optimization details of the energy initial sources, thermal and electrical energies generation, transition and the consumption section. The energy system optimization model is introduced in [2] from the final energy consumption level to the initial energy carriers that is from down to up.

The global energy system is mainly based on applying fossil fuels like coal, oil and natural gas. Although renewable energy sources are under focused, their reliable ability is low. Considering the lack of fossil sources, transition to renewable energy sources by applying hydrogen as the energy carrier is introduced [3]. This economic transition includes uncertainty and it is simultaneously introduced by the greenhouse gases effects. By applying long-term planning, this energy substitution is investigated and it is highly tried to supply proper hydrogen or the energy carrier assessment in the future [4].

While renewable energies are introduced as the energy initial carriers, the transportation industry is highly dependent to oil energy carrier. Indeed, there is no simple renewable solution to answer the transition section demand. Today, biofuels along with electricity is introduced as a main planning choice in replacing the transportation fossil fuels [5].

Concerning the micro grid concept, the random energy planning is introduced by taking the renewable energy sources uncertainty and its oscillation entity. Renewable energy sources which are known as initial energy carriers are integral parts of a micro grid. The oscillatory entity of these sources makes a micro grid exploiting complex [6].

The common initial energy sources (the fossil fuels) are limited and they need to be programmed considering the renewable initial energy carriers. Considering the planning present limitations, four dimensions known as system, application, generation and technology terms can be discussed. Indeed, the generation and exploiting initial energy sources can be studied by considering the new energy industry properties [7]. Accordingly, different energy carriers are studied regarding their application efficiency and abilities. Thus, energy carriers exploiting is optimally done [8].

Different studies have been proposed by researchers within the field of energy planning and management. Therefore, in none of these studies, an hourly exploiting of these energy carriers to supply the final energy consumption is not investigated. In the present article, the ultimate effort is done to exploit energy carriers by neglecting energy carriers' independency. To implement this planning, the proper energy grid is designed.

In the following, in section two, the present problem is introduced. Then, in section three, the energy grid modelling is analyzed. The particle swarm algorithm is introduced in section four. Designing the proper energy grid to be used in energy studies is done in section five. Section six simulates planning. Finally, discussion and conclusion are studied in section seven.

Problem presentation. In planning energy initial carriers, the lowest energy level that is the final energy application is considered as the first level; then, different energy losses and their converting are analyzed step by step to determine the quantity of initial energy carriers in order to supply the final energy consumption.

An important portion of the final energy use is related to the electrical energy. In each hour of planning, different modes of power stations can supply the consumption of electrical energy. For each mode, the best economic distribution among power stations must be determined. Therefore, in each hour considering different modes of power stations' combination, there are different modes of energy carriers. Indeed, we are facing the power station commitment problem. The only difference is that instead of having different combinations of power stations, we face with energy carriers different combinations. Considering the study period and the grid information, the proper combination is chosen by taking the study period length into account.

The energy grid modelling. After compiling and expanding the notion of the referent energy system in the Brochain national laboratory, the energy system simulator is developed. The matrix formulation main concept is to cut the energy system vertically [9].

The energy grid matrix model starts from the lowest energy level or the final energy consumption. Then, it reaches the highest energy level or the initial energy carriers.

At first, the final energy consumption matrix is defined as V_1 matrix based on different sections. In this case, there is

$$V_2 = T_{1,2} \times V_1, \tag{1}$$

where V_2 is the final energy consumption based on different carriers and $T_{1,2}$ is the consumption part to carriers converter part.

Considering the energy consumption, distribution and transition losses, the final energy consumption is defined as

$$V_3 = T_{2,3} \times V_2, \tag{2}$$

where V_3 is the final energy consumption based on different carriers considering losses, $T_{2,3}$, is the transition, distribution and consumption efficiency matrix.

To model the final electrical energy consumption, the electrical supply shares of different power stations are calculated by applying (3); then, the power stations input fuels are measured by (4)

$$V_{e2} = T_{e_{1,2}} \times V_{e1}, \tag{3}$$

$$V_{e3} = T_{e_{2,3}} \times V_{e2}, \tag{4}$$

where V_{e1} is the total generated electrical energy, $T_{e_{1,2}}$ stands for the separation matrix of the electrical energy generation at different power stations, V_{e2} is the electrical energy generation of different power stations, V_{e3} is different power stations input fuel and $T_{e_{2,3}}$ is the power stations efficiency matrix.

Besides, to compute the electrical energy generator carriers (5) is used

$$V_{e4} = T_{e_{3,4}} \times V_{e3}, \tag{5}$$

where V_{e4} is the electrical energy generator vectors and $T_{e_{3,4}}$ is the power stations' input fuel separated from different vectors input fuel matrix.

After simulating the electrical energy generation process, the need for different vectors is computed by considering the electrical energy generation

$$V_4 = V_3 + V_{e4} - V_e, \tag{6}$$

where V_4 stands for the need for different vectors considering the consumption, distribution and transition losses of electrical energy generation, and V_e is the generated electrical energy.

Some of these carriers are derived from refining process. Therefore, it is necessary to simulate the petroleum refinery; thus, (7) is used

$$V_{p_2} = T_p \times V_{p_1}, \tag{7}$$

where V_{p_1} is the refineries maximum capacity, T_p is the share of each generated products of the petroleum refinement, and V_{p_2} shows the carriers generated by refinement.

By using (8), the need for carriers can be computed considering refinement

$$V_5 = V_4 - V_{p_2} + V_p, \tag{8}$$

where V_p is the refined petroleum and V_5 shows the need for carriers after considering the electrical energy generation losses and refinement.

Finally, the quantities of carriers' import and export are determined by applying

$$V_6 = V_5 - P, \tag{9}$$

where P is the national generation quantity of the initial energy carriers; V_6 is the initial energy carriers' import and export. Noticeably, the positive sign represents import and the negative sign shows the export.

In (3), in order to determine different power stations shares of the electrical energy generation, it is necessary to establish the economic distribution. To fulfill this aim, the particle swarm optimization is used.

The particle swarm optimization. The particle swarm optimization (PSO) was first introduced by Candy and Aberheart [10]. After then, it was used in different scientific and applied fields. PSO is a population based optimization algorithm in which each person is considered as a particle. These particles positions within the search space determine the problem solution. Particles can search the best position in cooperation with each other. Particles' movements can be determined by applying (10) and (11)

$$x_i(t+1) = x_i(t) + v_i(t), \tag{10}$$

$$v_i(t+1) = wv_i + c_1 r_1 (pbest_i(t) - x_i(t)) + c_2 r_2 (gbest(t) - x_i(t)), \tag{11}$$

where $x_i(t)$ is the position, $v_i(t)$ is the i-th particle velocity at t moment, $pbest_i(t)$ is the best position found by the i-th particle, and $gbest(t)$ is the best found position by the whole population till t moment, w is the inertial coefficient, c_1 and c_2 are the controlling parameters of each particle and the whole population best effect on the particles velocity and r_1 and r_2 are random numbers within (1-0).

Designing the energy grid suitable for studies. Since the present study is novel, information related to the proper energy grid is not accessible. Indeed, in this study, the energy grid comprising the 24-hour final energy consumption information is needed. Both Iran energy balance sheet information [11] and the standard electrical grid used in the power station commitment problem studies are used.

The idea of designing the proper energy grid is proposed based on the concept of the electrical energy vital role. Indeed, some part of the final energy consumption is related to the final electrical energy consumption. In the energy balance sheet, there is no information of the final energy use. However, it is clear that the final energy consumption of different energies is not independent of one another and the final energy consumption of different energies is symmetric.

Considering the energy balance sheet, the final energy consumption for a year is in Table 1.

Table 1

Different sections of the final energy consumption [11]

Row		Sectors of energy	
1	E1	Residential, commercial, general	399.9 mboe
2	E2	Industrial	188.2 mboe
3	E3	Transportation	254.3 mboe
4	E4	Agriculture	33.4 mboe
5	E5	Other	2.5 mboe
6	E6	Non-energy	85.3 mboe
7	E_{tf}	Total of final energy consumption	9636.6 mboe
8	E_{ef}	Final electrical energy consumption	79.7 mboe

The final electrical energy consumption in the above table is shown by E_{ef}. It is known that considering the electrical energy losses from generation till consumption (consumption, distribution and transition losses) of power stations must generate more electrical energies in order to supply this quantity.

Concerning the final energy consumption, the electrical final energy consumption in different power stations is calculated as below

$$E_{ef} = \sum_{i=1}^{n} a_i E_i , \qquad (12)$$

$$E_{ef} = a_1 E_1 + a_2 E_2 + a_3 E_3 + a_4 E_4 + a_5 E_5 + a_6 E_6 , \qquad (13)$$

where E_{ef} is the final electrical energy consumption, n is the number of different energy consumption power stations, a_i is the electrical final energy consumption coefficient in the relation which is related to i-th final energy consumption, and E_i is the i-th section final energy consumption.

Considering losses of consumption, distribution and transition of electrical energy, its consumption is calculated by applying

$$E_e = \frac{1}{\eta_e} E_{ef} , \qquad (14)$$

where E_e is the electrical energy consumption; η_e is the energy grid efficiency concerning losses of consumption, distribution and transition of electrical energy.

In the next phase of designing, it is possible to approximately compute the final energy per hour by applying information related to the power station commitment problem

$$V_1^h = \frac{load^n}{E_e} V , \qquad (15)$$

where V_1^h is the designed final energy consumption, $load^n$ is the grid electrical energy quantity in h hour and V is the balance sheet based final energy consumption for the E_e electrical consumption quantity or E_{ef} electrical final energy consumption quantity.

Therefore, the 24-hour information of the final energy consumption is computed. Although, this final characteristic is approximately calculated and it might differ from the real value, this information answers our energy study.

The energy grid information and designing by applying ten power stations. In order to plan energies of initial energy carriers, a ten power station system is proposed. The electrical grid is derived from [12] reference. Information related to the mentioned system is designed based on the afore-said process. These data are attached to the same paper. The maximum power station capacities equals to 3721.1 boe. It is necessary to mention that quantities related to the power station capacity are chosen approximately and in accordance with the energy balance sheet.

Simulation. Regarding the energy grid modelling, the simulation trend can be represented as the followings:

1) defining parameters and converting matrices;
2) applying 3 to 10 steps for each hour of under studied 24 hour span;
3) determining the final energy consumption;
4) determining the final energy consumption based on different carriers;
5) determining the final energy consumption considering the energy, distribution, transition and consumption of energies;
6) determining possible combinations of power station generators in order to supply the electrical energy;
7) the economic distribution of the electrical energy among power station generators by means of the optimization algorithm for all possible combinations;
8) the contribution of each carrier from the refining of crude oil;
9) determine the need to provide energy to the final energy consumption for each of the possible combinations;
10) determining the import and export of energy carriers regarding the national energy carriers presentation for each possible combination;
11) determining the total request, import and export values of the energy carriers in the whole under studied span (24 hours) by means of the dynamic planning method.

The objective function. One important stage in planning energy carriers is to distribute electrical energy economically. The objective function of the electrical energy economical distribution is introduced in (16). This objective function can be solved using optimization algorithms [13]

$$F_{obj} = \sum_{i=1}^{N_{FIU}} E_{FIU}^{i} C_{FIU}^{i} + \sum_{i=1}^{N_{DU}} S_{U_i} C_C^{i} , \qquad (16)$$

$$E_{FIU}^{i} = \sum_{j=1}^{N_{DU}} \sum_{k=1}^{N_U^j} e_{i,j} E_{IU}^{k} \quad \& \quad i = 1 : N_{FIU} , \qquad (17)$$

$$e_{i,j} \in [ETF]_{N_{FIU} \times N_{DU}}, \quad (18)$$

$$E_{IU} = \frac{1}{\eta_U} E_{OU}, \quad (19)$$

where F_{obj} is the objective function, N_{FIU} is the number of different input fuels of power station generators, E^i_{FIU} is the sum of input energy to power stations of the *i*-th fuel type, C^i_{FIU} is the *i*-th type input fuel type cost of power stations, N_{DU} is the number of different fuel generators, S_{U_i} stands for the *i*-th power station on or off position, C^i_C is the *i*-th power station constant costs, N^j_U shows the number of *j*-th power station generators within the under studied energy grid, $e_{i,j}$ represents the *i*-th fuel share coefficient from the *j*-th power station energy input, *ETF* is the power station input energy matrix converting to fuels appropriate with different power stations, E_{IU} is the power station input energy matrix, η_U shows power stations efficiency vector and E_{OU} stands for power stations output electrical energy.

In the optimization algorithm, E_{OU} is the power stations generated electrical energy which is chosen as the problem variables. Optimization limitations are defined as below:

1) the load balance

$$\sum_{i=1}^{N} P_i(t) = D(t); \quad (20)$$

2) the upper and lower unit generations

$$P^i_{\min} \le P^i \le P^i_{\max} \quad (21)$$

where *N* represents the number of units, $P_i(t)$ shows the *i*-th unit generated power at the *t* time, $D(t)$ is the value of electrical power request at *t* time, $P^i_{\min}$ is the lower limit, P^i manifests generation, and $P^i_{\max}$ shows the *i*-th unit upper limit.

The dynamic planning application. After distributing the electrical energy in each hour of planning that is done in appropriation with each possible energy division among power stations, the planning trend continues'; thus, energy carriers combinations parallel with power stations combinations are concluded. By applying the dynamic planning method, the proper strategy of energy carriers planning is determined along with the study.

At *K* hour with *I* combination, the retrospective algorithm of computing the minimum cost is defined as

$$F_{cost}(K,I) = \min_{\{L\}} \begin{bmatrix} P_{cost}(K,I) + S_{cost}(K-1,L:K,I) + \\ + F_{cost}(K-1,L) \end{bmatrix}, \quad (22)$$

where $F_{cost}(K,I)$ is the minimum total cost to arrive at the (K,I) mode, $P_{cost}(K,I)$ is the (K,I) mode cost and $S_{cost}(K–1, L: K, I)$ shows the transition cost from $(K–1, L)$ to (K,I) mode. The (K,I) mode is the *I* combination at *K* hour [14].

The energy grid simulation with ten power stations. The final energy consumption based planning of energy carriers designed with ten power stations is implemented. The dynamic planning is done by saving paths equal with the number of each study hour maximum modes and its results are shown in Table 2.

Table 3 holds the need for energy carriers in order to provide final energy consumption. The need for energy carriers of the total study period is determined in Table 4. The economical distribution of electrical energy among units is represented in Table 5. The optimization algorithms access trend to the economical distribution of the electrical energy is depicted in Fig .1. Besides, considering the quantity of energy carriers national representation, the value of carriers import and export quantities are listed in Table 6.

Table 2

The output of dynamic planning in ten unit energy grids by means of PSO

Strategy						Hour
S6	S5	S 4	S3	S2	S1	
2	2	2	2	2	2	The initial state
3	3	3	3	3	3	1
3	3	3	3	3	3	2
3	3	3	3	3	3	3
3	3	3	3	3	3	4
3	3	3	3	3	3	5
4	4	4	4	4	4	6
4	4	4	4	4	4	7
9	9	9	9	9	9	8
9	9	9	9	9	9	9
9	9	9	9	9	9	10
10	10	10	10	10	10	11
10	10	10	10	10	10	12
10	10	10	10	10	10	13
9	9	9	9	9	9	14
9	9	9	9	9	9	15
9	9	9	9	9	9	16
9	9	9	9	9	9	17
9	9	9	9	9	9	18
9	9	9	9	9	9	19
9	9	9	9	9	9	20
9	9	4	4	4	4	21
9	6	4	4	3	3	22
7	6	4	4	3	3	23
7	6	5	4	3	2	24
8557932	8557192	8557153	8554502	8554182	8555398	Cost (dollar)

Table 3

The need for energy carriers in ten unit energy grids by means of PSO

8	7	6	5	4	3	2	1	Hour
3721.1	3721.1	3721.1	3721.1	3721.1	3721.1	3721.1	3721.1	Petroleum
51.78965	44.67028	37.55091	23.31218	16.19281	1.95407	–12.2847	–19.404	Liquid gas
–350.552	–365.265	–354.657	–429.906	–466.355	–539.254	–612.154	–647.68	Fuel oil
–11.7441	–61.1345	–123.351	–210.1	–253.46	–340.182	–426.903	–470.252	Gas oil
17.72885	1.640607	–14.4476	–46.6241	–62.7124	–94.8888	–127.065	–143.154	Kerosene
405.1893	363.9642	322.7392	240.289	199.0639	116.6137	34.16357	–7.06152	Gasoline
53.06305	50.85209	48.64113	44.2192	42.00824	37.58632	33.1644	30.95344	Plane fuel
4380.603	4190.728	3988.239	3615.204	3432.123	3065.959	2699.796	2519.415	Natural gas
26.60254	25.4941	24.38566	22.16878	21.06034	18.84346	16.62658	15.51815	Coke gas
58.79772	56.34781	53.89791	48.9981	46.54819	41.64838	36.74857	34.29867	Coal
16	15	14	13	12	11	10	9	Hour
3721.1	3721.1	3721.1	3721.1	3721.1	3721.1	3721.1	3721.1	Petroleum
30.43155	51.78965	66.02839	80.26713	94.50586	87.3865	80.26713	66.02839	Liquid gas
–459.901	–350.552	–275.868	–198.861	–135.511	–158.969	–198.861	–275.591	Fuel oil
–141.826	–11.7441	74.99814	161.7678	260.843	205.169	161.7678	75.0014	Gas oil
–30.5359	17.72885	49.90533	82.0818	114.2583	98.17004	82.0818	49.90533	Kerosene
281.5141	405.1893	487.6395	570.0897	652.5398	611.3148	570.0897	487.6395	Gasoline
46.43017	53.06305	57.48497	61.90689	66.32881	64.11785	61.90689	57.48497	Plane fuel
3831.358	4380.603	4751.988	5130.168	5531.033	5323.32	5130.168	4752.798	Natural gas
23.27722	26.60254	28.81941	31.03629	33.25317	32.14473	31.03629	28.81941	Coke gas
51.448	58.79772	63.69753	68.59734	73.49714	71.04724	68.59734	63.69753	Coal
24	23	22	21	20	19	18	17	Hour
3721.1	3721.1	3721.1	3721.1	3721.1	3721.1	3721.1	3721.1	Petroleum
–5.1653	9.073439	37.55091	66.02839	80.26713	51.78965	37.55091	23.31218	Liquid gas
–595.486	–548.095	–423.452	–275.868	–198.861	–350.552	–423.452	–496.351	Fuel oil
–370.456	–277.548	–98.4652	74.99813	161.7678	–11.7441	–98.4652	–185.186	Gas oil
–110.977	–78.8006	–14.4476	49.90533	82.0818	17.72885	–14.4476	–46.6241	Kerosene
75.38865	157.8388	322.7392	487.6395	570.0897	405.1893	322.7392	240.289	Gasoline
35.37536	39.79728	48.64113	57.48497	61.90689	53.06305	48.64113	44.2192	Plane fuel
2913.867	3278.051	4014.44	4751.988	5130.168	4380.603	4014.44	3648.277	Natural gas
17.73502	19.9519	24.38566	28.81941	31.03629	26.60254	24.38566	22.16878	Coke gas
39.19848	44.09829	53.89791	63.69753	68.59734	58.79772	53.89791	48.9981	Coal

Table 4

The need for different energy carriers within the total study period of the energy grid

Energy	Carrier	Row
89306.4	Petroleum	1
1000.893	Liquid gas	2
–9132.05	Fuel oil	3
–1916.25	Gas oil	4
–121.508	Kerosene	5
8322.891	Gasoline	6
1198.34	Plane fuel	7
98855.34	Natural gas	8
600.7739	Coke gas	9
1327.848	Coal	10

Table 5

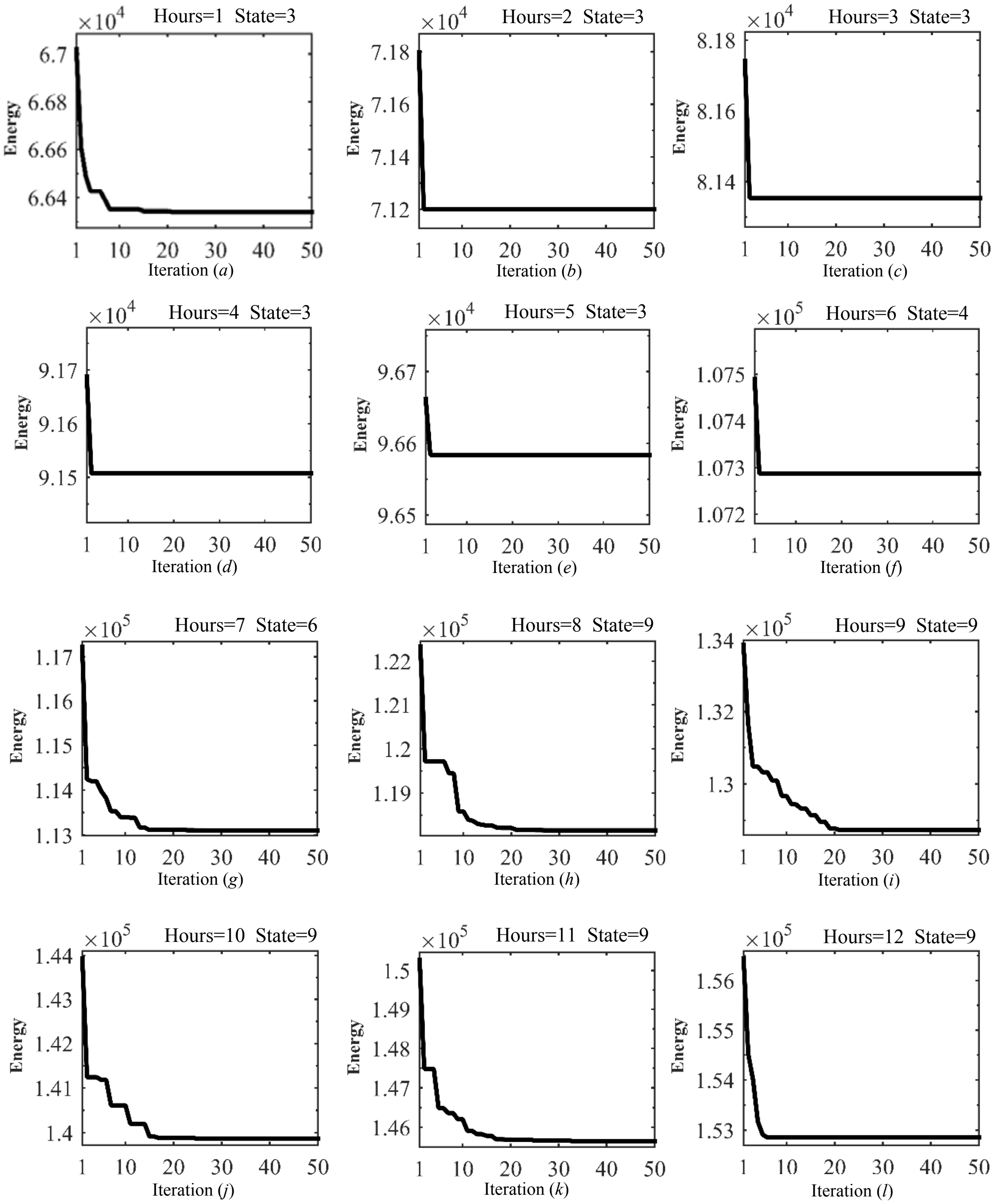
The electrical energy economical distribution within the energy grid by utilizing PSO

OF	unit 10	unit 9	unit 8	unit 7	unit 6	unit 5	unit 4	unit 3	unit 2	unit 1	Hour
66339.36	0	0	0	0	0	0	0	129.9054	150	420.9897	1
71199.98	0	0	0	0	0	0	0	130	165.9591	455	2
81353.53	0	0	0	0	0	0	0	130	266.087	455	3
91507.08	0	0	0	0	0	0	0	130	366.2149	455	4
96583.85	0	0	0	0	0	0	0	130	416.2788	455	5
107287.4	0	0	0	0	0	0	61.40668	130	455	455	6
113108.7	0	0	0	0	0	0	111.4706	130	455	455	7
118165.9	0	54.94904	10	25	78.91501	25	20	129.9395	403.1555	454.5755	8
128802.2	0	54.92522	38.19602	25	79.91727	25	40.51524	129.8847	454.393	453.831	9
139852.8	0	54.99011	46.54565	75.69185	79.97855	25	129.9675	129.966	454.8779	454.8368	10
145735.7	55	55	55	85	80	51.98213	130	130	455	455	11
152855.1	55	55	55	85	80	157.1164	130	130	455	455	12
139852.8	31.11385	55	55	85	80	25.80435	130	130	455	455	13
128737.4	0	55	46.5999	25.09276	80	25.18803	130	130	455	454.9096	14
118165.9	0	50.46745	10	25	42.35772	25	20	129.0834	452.7482	446.8778	15
102935.5	0	54.57776	10	25	75.61226	25	20	129.572	260.4829	451.0978	16
97858.76	0	54.58248	10	25	75.74856	25	20	129.4813	209.902	451.5645	17
108012.3	0	55	10.06585	25.04071	80	25.08315	20.12963	130	401.2152	455	18
118165.9	0	55	46.61355	25.03679	80	25.13997	130	130	455	455	19
139852.8	0	53.36535	10	25	79.89353	25	70.70835	129.7906	454.3342	453.5704	20
128737.4	0	0	0	0	0	0	61.40668	130	455	455	21
108012.3	0	0	0	0	0	0	0	130	316.1509	455	22
87907.97	0	0	0	0	0	0	0	130	216.023	455	23
78494.37	0	0	0	0	0	0	0	130	216.023	455	24

Table 6

Import and export of carriers

Import	Export	Carrier	Row
0	163006	Petroleum	1
1000.893	0	Liquid gas	2
0	9132.05	Fuel oil	3
0	1916.25	Gas oil	4
0	121.508	Kerosene	5
8322.891	0	Gasoline	6
1198.34	0	Plane fuel	7
2221.738	0	Natural gas	8
0	37.6261	Coke gas	9
367.8484	0	Coal	10



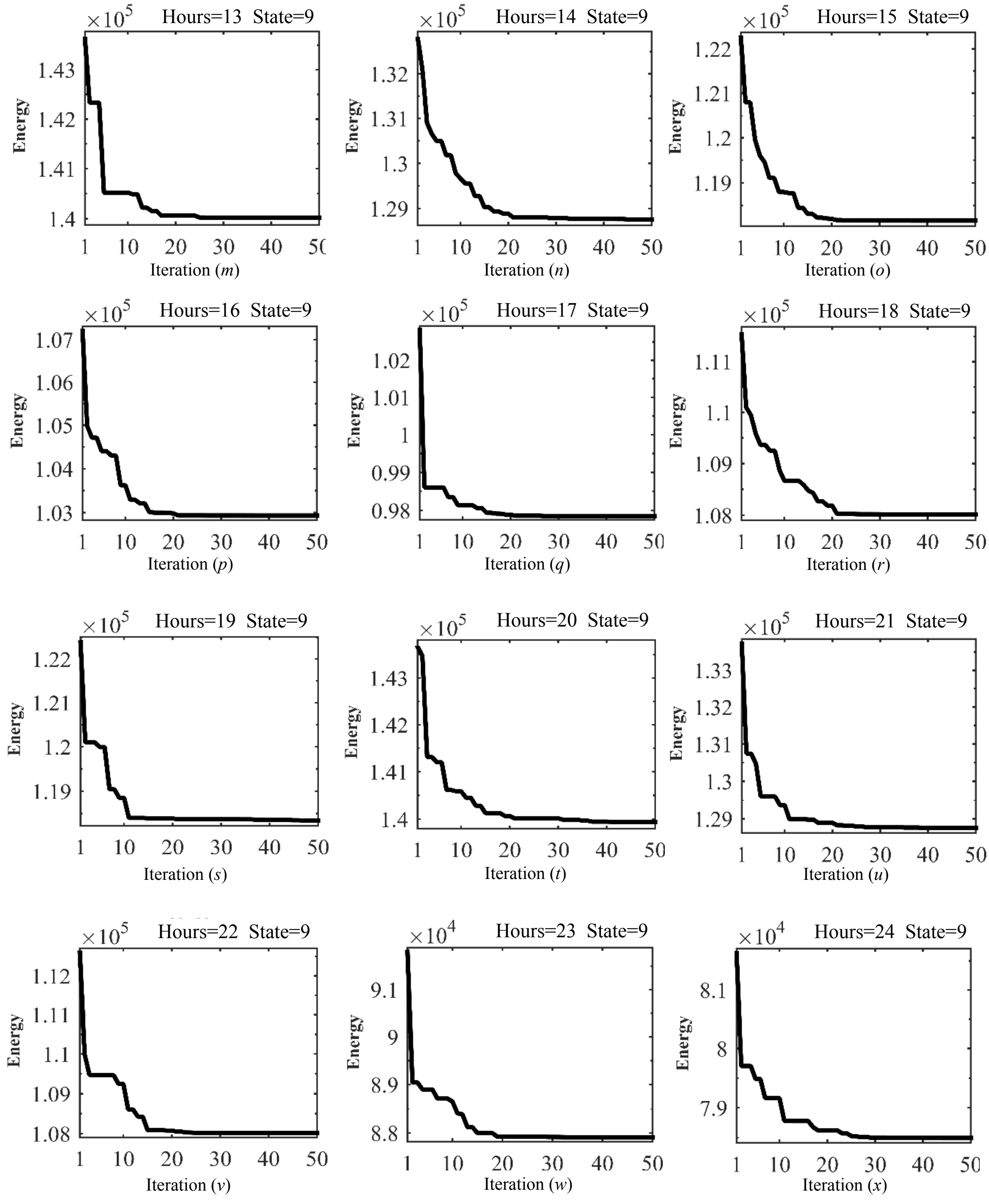


Fig. 1. The access trend to the electrical energy economical distribution\ within the energy grid by applying PSO

Discussion and conclusion. In the present article, a new approach in energy studies was introduced. In this view, the maximum effort was made to arrive at the suitable planning of energy carriers based on the final energy consumption. This planning was done such that it showed energy carriers beside each other as a system and neglected their planning independent view.

The energy grid modeling started from the lowest energy level of the final energy consumption and went to the highest level of the energy initial carriers step by step in a matrix shape. In this modelling, some factors like the energy grid losses, the electrical energy distribution among units, and the petroleum refinement were taken into account. After a matrix form energy grid modelling, the energy grid was designed based on the 24 hour information of Iran energy balance sheet and the standard electrical grid since there was no available authentic information of energy grid.

In the proposed planning, the dynamic planning method and the particle swarm optimization algorithm were used. Indeed, particle swarm optimization algorithm was used along with the electrical energy economical distribution; hence, the dynamic planning program was utilized in order to access the proper strategy of mixing energy carriers along with the study period.

The proposed planning done on the authentic-based designed energy grid was implemented and its results were represented.

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Received 14.06.2018

M. Dehghani[1], Candidate of Power Engineering, M.Sc.,
Z. Montazeri[2], Candidate of Power Engineering, M.Sc. Student,
A. Ehsanifar[1], Candidate of Power Engineering, M.Sc.,
A.R. Seifi[1], Doctor of Power Engineering, Professor,
M.J. Ebadi[3], Doctor of Applied Mathematics, Assistant Professor,
O.M. Grechko[4], Candidate of Technical Science, Associate Professor,
[1] Department of Power and Control,
Shiraz University,
Shiraz, I.R. Iran,
e-mail: adanbax@gmail.com, ali.ehsanifar2020@gmail.com, seifi@shirazu.ac.ir
[2] Department of Electrical Engineering,
Islamic Azad University of Marvdasht,
Marvdasht, I.R. Iran,
e-mail: Z.montazeri2002@gmail.com
[3] Faculty of Marine Science,
Chabahar Maritime University,
Chabahar, Iran,
e-mail: ebadi@cmu.ac.ir
[4] National Technical University «Kharkiv Polytechnic Institute»,
2, Kyrpychova Str., Kharkiv, 61002, Ukraine,
e-mail: a.m.grechko@gmail.com

Appendix (Tables A.1–A.11)

Table A.1. Unit Information

Row	Power plant	Capacity of unit (MW)		Efficiency	Constant cost	Priority
		Min	Max			
1	Thermal	150	455	0.368	1	1
2	Thermal	150	455	0.345	2	2
3	Combined Cycle	20	130	0.455	3	3
4	Thermal	20	130	0.317	4	4
5	Gas	25	162	0.3	5	5
6	Combined Cycle	20	80	0.47	6	6
7	Thermal	25	85	0.35	7	7
8	Thermal	10	55	0.35	8	8
9	Combined Cycle	10	55	0.5	9	9
10	Gas	10	55	0.25	10	10

Table A.2. The time information of energy networks

Row	Power plant	MUT	MDT	Cold start	Initial conditions
1	Thermal	8	8	5	8
2	Thermal	8	8	5	8
3	Combined Cycle	5	5	4	–5
4	Thermal	5	5	4	–5
5	Gas	6	6	4	–6
6	Combined Cycle	3	3	2	–3
7	Thermal	3	3	2	–3
8	Thermal	1	1	0	–1
9	Combined Cycle	1	1	0	–1
10	Gas	1	1	0	–1

Table A.3. The cost of setting up units

Row	Power plant	Hot start	Cold start
1	Thermal unit	4500	9000
2	Thermal unit	5000	10000
3	Combined Cycle unit	550	1100
4	Thermal unit	560	1120
5	Gas unit	900	1800
6	Combined Cycle unit	170	340
7	Thermal unit	260	520
8	Thermal unit	30	60
9	Combined Cycle unit	30	60
10	Gas unit	30	60

Table A.4. Matrix *Tp*

Petroleum	0
Liquid gas	0.032
Fuel oil	0.293
Gas oil	0.293
Kerosene	0.099
Gasoline	0.157
Plane fuel	0
Other products	0.058
Natural gas	0
Coke gas	0
Coal	0
Non-commercial fuels	0
Electricity(power)	0

Table A.5. Conversion matrix input energy to power plants

Power plant	Thermal unit	Combined Cycle unit	Gas unit
Fuel oil	0.254	0	0
Gas oil	0.003	0.082	0.166
Natural gas	0.743	0.918	0.834

Table A.6. Domestic supplies of energy carriers

Row	Energy carrier	Energy (boe)
1	Petroleum	10513
2	Liquid gas	0
3	Fuel oil	0
4	Gas oil	0
5	Kerosene	0
6	Gasoline	0
7	Plane fuel	0
8	Other products	0
9	Natural gas	4026.4
10	Coke gas	26.6
11	Coal	40
12	Non-commercial fuels	161
13	Electricity (power)	0

Table A.7. Heating value[15] and energy rates[16]

Energy carrier	Heating value	Energy rates
Petroleum	38.5 MJ/lit	48 dollar/boe
Liquid gas	46.15 MJ/kg	374 dollar/tone
Fuel oil	42.18 MJ/kg	180 dollar/tone
Gas oil	43.38 MJ/kg	350 dollar/tone
Kerosene	43.32 MJ/kg	500 dollar/tone
Gasoline	44.75 MJ/kg	450 dollar/tone
Plane fuel	45.03 MJ/kg	555 dollar/tone
Natural gas	39 MJ/m^3	237 dollar/1000m^3
Coke gas	16. 9 MJ/kg	157 dollar/tone
Coal	26.75 MJ/kg	61 dollar/tone

Table A.8. Electrical load demand

Hour	1	2	3	4
Load	700	750	850	950
Hour	5	6	7	8
Load	1000	1100	1150	1200
Hour	9	10	11	12
Load	1300	1400	1450	1500
Hour	13	14	15	16
Load	1400	1300	1200	1050
Hour	17	18	19	20
Load	1000	1100	1200	1400
Hour	21	22	23	24
Load	1300	1100	900	800

Table A.9. Final energy consumption

Hour	1	2	3	4	5	6	7	8
Residential, commercial, general	1570.19	1682.347	1906.66	2130.973	2243.129	2467.442	2579.599	2691.755
Industrial	738.9593	791.7421	897.3078	1002.873	1055.656	1161.222	1214.005	1266.787
Transportation	998.4982	1069.819	1212.462	1355.105	1426.426	1569.069	1640.39	1711.711
Agriculture	131.1437	140.5111	159.2459	177.9807	187.3481	206.0829	215.4503	224.8177
Other	9.816144	10.5173	11.9196	13.32191	14.02306	15.42537	16.12652	16.82768
Non-energy	334.9268	358.8502	406.6969	454.5436	478.4669	526.3136	550.2369	574.1603
Hour	9	10	11	12	13	14	15	16
Residential, commercial, general	2916.068	3140.381	3252.537	3364.694	3140.381	2916.068	2691.755	2355.286
Industrial	1372.353	1477.919	1530.701	1583.484	1477.919	1372.353	1266.787	1108.439
Transportation	1854.354	1996.996	2068.318	2139.639	1996.996	1854.354	1711.711	1497.747
Agriculture	243.5526	262.2874	271.6548	281.0222	262.2874	243.5526	224.8177	196.7155
Other	18.22998	19.63229	20.33344	21.03459	19.63229	18.22998	16.82768	14.72422
Non-energy	622.007	669.8537	693.777	717.7004	669.8537	622.007	574.1603	502.3903
Hour	17	18	19	20	21	22	23	24
Residential, commercial, general	2243.129	2467.442	2691.755	3140.381	2916.068	2467.442	2018.816	1794.503
Industrial	1055.656	1161.222	1266.787	1477.919	1372.353	1161.222	950.0906	844.5249
Transportation	1426.426	1569.069	1711.711	1996.996	1854.354	1569.069	1283.783	1141.141
Agriculture	187.3481	206.0829	224.8177	262.2874	243.5526	206.0829	168.6133	149.8785
Other	14.02306	15.42537	16.82768	19.63229	18.22998	15.42537	12.62076	11.21845
Non-energy	478.4669	526.3136	574.1603	669.8537	622.007	526.3136	430.6202	382.7735

Table A.10. Matrix T12

	Residential and commercial	Industrial	Transportation	Agriculture	Other	Non-energy
Petroleum	0	0	0	0	0	0
Liquid gas	0.051	0.013	0.01	0	0	0
Fuel oil	0.023	0.212	0.014	0	0	0
Gas oil	0.055	0.087	0.363	0.689	0	0
Kerosene	0.141	0.002	0	0.018	0	0
Gasoline	0.002	0.002	0.573	0.003	0	0
Plane fuel	0	0	0.031	0	0	0
Other products	0	0	0	0	0	0.402
Natural gas	0.564	0.521	0.007	0	0	0.497
Coke gas	0	0.021	0	0	0	0
Coal	0.0003	0	0	0	0	0.101
Non-commercial fuels	0.064	0	0	0	0	0
Electricity(power)	0.102	0.142	0.0004	0.29	1	0

Table A.11. Matrix T23

Petroleum	1	0	0	0	0	0	0	0	0	0	0	0	0
Liquid gas	0	1	0	0	0	0	0	0	0	0	0	0	0
Fuel oil	0	0	1	0	0	0	0	0	0	0	0	0	0
Gas oil	0	0	0	1	0	0	0	0	0	0	0	0	0
Kerosene	0	0	0	0	1	0	0	0	0	0	0	0	0
Gasoline	0	0	0	0	0	1	0	0	0	0	0	0	0
Plane fuel	0	0	0	0	0	0	1	0	0	0	0	0	0
Other products	0	0	0	0	0	0	0	1	0	0	0	0	0
Natural gas	0	0	0	0	0	0	0	0	1.1601	0	0	0	0
Coke gas	0	0	0	0	0	0	0	0	0	1	0	0	0
Coal	0	0	0	0	0	0	0	0	0	0	1	0	0
Non-commercial fuels	0	0	0	0	0	0	0	0	0	0	0	1	0
Electricity(power)	0	0	0	0	0	0	0	0	0	0	0	0	1.3158