A Novel Hybrid Algorithm Based on Combined BICA-BPSO for Solving the Optimal Electricity Procurement Problem of the Large Consumers

Mehdi Mehdinejad[a], Sayyad Nojavan[a,*], Kazem Zare[a], and Behnam Mohammadi-Ivatloo[a]
[a]Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran
Tel-Fax: +98 41 33300829, P.O. Box: 51666-15813
Email: m.mehdinejad92@ms.tabrizu.ac.ir, sayyad.nojavan@tabrizu.ac.ir, kazem.zare@tabrizu.ac.ir, bmohammadi@tabrizu.ac.ir

Received: December 2014 Revised: July 2015 Accepted: July 2015

ABSTRACT:
In restructured electricity markets, the consumers have various procurement strategies to supply their electricity demand from alternative resources such as self-generating facility, bilateral contracts and pool market purchase. A hybrid approach based on binary particle swarm optimization (BPSO) and binary imperialist competitive algorithm (BICA) is proposed in this paper to find optimal procurement for large consumers with multiple procurement options. The solution of these problems provides adequate information to obtain an electricity procurement problem for large consumers. Also, the results are compared with ICA and PSO methods. Test results show that the proposed hybrid approach is more effective and has higher capability in finding the optimum solutions in comparison with ICA and PSO methods. A case study is used to illustrate the efficiency of the proposed hybrid approach.

KEYWORDS: Electricity procurement strategy, large Consumers, binary imperialist competitive algorithm (BICA), binary particle swarm optimization (BPSO).

1. INTRODUCTION

Large electric consumers participate in the power market to meet its electricity demand at the minimum cost, buying from different trading floors via bilateral contracts and even utilizing its own generating units. The main problem facing any consumer is how to procure electric energy from different sources with the lowest cost [1] in the presence of the pool market price uncertainty environment.

There is considerable literature addressing consumer participation in energy market for purchasing of their demand. The consumers and retailers need to purchase their demand from power market that this problem is studied in [2]. The optimal response of a consumer to the pool prices is characterized in [3] in terms of load elasticity. Demand-side bidding and purchase allocation in two markets are discussed in [1] and [4], where the price volatility is modeled using a stochastic process. The profit maximization problem of a retailer for selling to the customers considering the risk assessment is studied in [5], where the uncertainty of load and price are modeled by probability distributions. The alternative energy procurement options in energy market are available for industrial customers are analyzed in [6]. Electricity procurement by large consumers is addressed in [7], where it is assumed that all required data are available without considering the load and price uncertainties. A mean-variance method is used to solve the previous problem in [8]. The problem is addressed again in [9] and solved through a scenario generation algorithm and a stochastic programming method. In [10], a distribution company is procured their electricity for minimizing the energy procurement cost. Furthermore, the tolling contracts as new energy source are used by consumer in [11]. A theoretical framework for selecting the forward-contract by Distribution Company for minimizing purchasing cost is proposed in [12], subject to a cost-exposure constraint. The alternative energy sources such as future contracts, call/put options, and interruptible contracts are reviewed in [13] that can use as new energy options. In particular, the role of these options in mitigating the market risks and structuring the hedging strategies for different agents are analyzed. In [14], real and contractual assets are analyzed to optimize the procurement cost considering the value-at-risk (VaR) constraint. A stochastic optimization model for determining the optimal forward loads and selling prices for a single retailer is proposed in [15]. In [16], a stochastic programming methodology is proposed to determine the purchasing power from forward contracts and power market, and optimal sale price from retailers to the customers based on the fixed pricing. In addition, strategies such as call options and self-production facilities are considered in [16]. In [17], a self-financed hedging portfolio consisting of a risk assessment using the VaR constraint is studied. Moreover, a technique based on Information Gap Decision Theory (IGDT) is proposed in [18, 19] to assess the different procurement strategies for large consumers to supply their demand from alternative energy sources, e.g., pool market, bilateral contracts, and even their own DG facilities. A fuzzy-based decision-making system for procurement of electricity from different sources is proposed in [20] that helps large consumer to select the best trade of between the profit and risk. Also, in [21], the second-order stochastic dominance is developed for mid-term scheduling problems of the large industrial consumers.

In this paper, the objective is to minimize energy procurement costs by adopting an optimal strategy for large consumers over a medium-term timeframe. Large consumers, alongside utilizing their existing production units, seek to fulfill future needs and manage price volatility and risks associated with pool market prices through bilateral contracts. The study focuses on a four-week planning period, with each day divided into three eight-hour intervals named valley, shoulder, and peak. This hypothesis is chosen to balance the computational load and the accuracy of problem-solving effectively. Moreover, the average pool market prices during these eight-hour periods are used as the pool price for each interval, while the total hourly demand across all hours within each period is calculated as the demand volume of the large consumer.

1.1. Procedure and contributions

A review of past studies indicates that the issue of energy procurement for large consumers using a hybrid approach based on BICA-BPSO has not been explored. This presents as a novel and valuable idea. In this context, the innovative contributions of this paper can be summarized as follows:

1. Development of a metaheuristic approach based on BICA-BPSO to achieve an optimized strategy for suppling the electricity demand of large consumers.
2. Comparison of the outcomes of the proposed hybrid approach with the ICA and PSO algorithms, affirming the efficacy of the proposed approach in comparison to these methods .

1.2. Paper organization

The structure of this paper is outlined as follows: Section 2 delineates a model for the procurement cost function applicable to large consumers. Section 3 provides an overview of the ICA and PSO methods. The hybrid approach utilizing BICA-BPSO is detailed in Section 4. Section 5 discusses the results obtained from numerical simulations, offering an in-depth evaluation and comparison with the ICA and PSO methods. The paper concludes with Section 6, which summarizes the key findings and implications.

2. MODEL FORMULATION

The electricity procurement cost function faced by a large consumer is as following:

$$\underset{P_{l,i},P_{p,i},E_{h,i}^{DG}}{Minimize} \sum_{l}^{B}\sum_{i=1}^{T}\lambda_{l,i}\,P_{l,i}+\sum_{i=1}^{T}\lambda_i\,P_{p,i} + \sum_{i=1}^{T}(A_{dg}\times P_{dg,i}^2 + B_{dg}\times P_{dg,i} + C_{dg}) \quad (1)$$

This equation represents the power procurement cost for a large consumer. The cost function is composed of three terms. The first term models the cost of power purchase through bilateral agreements, while the second term expresses the cost/revenue of trading with the pool ($P_{p,i}$ is free variable). Finally, the third term of this objective function reflects the operational cost of power generation by the DG owned by the large consumer. Large consumer as operator face the following constraints to optimize proposed objective function:

$$\sum_{l=1}^{B}P_{l,i}+P_{dg,i}+P_{p,i}=D_i \quad ; \; i=1,...,T \quad (2)$$

$$P_{l,i}^{\min}s_l \le P_{l,i} \le P_{l,i}^{\max}s_l \quad ; \quad i=1,...,T \quad l=1,...,B \quad (3)$$

$$P_{dg}^{\min} \le P_{dg,i} \le P_{dg}^{\max} \quad ; \quad i=1,...,T \quad (4)$$

$$P_{dg,i}+P_{p,i} \ge 0 \quad i=1,...,T \quad (5)$$

$$P_{l,i} \ge 0 \quad i=1,..T,\; l=1,..B \quad (6)$$

Power balance between the demand and the power exchanged with the pool market, self-generation, and bilateral contracts is illustrated by Equation (2). Each bilateral contract that a large consumer forms with major producers has minimum and maximum limits. This limitation is depicted in Equation (3). Furthermore, this actor must consider the production constraints of its own generating unit in suppling its demand. This constraint is represented by Equation (4). In this context, the large consumer must optimize its objective function, ensuring that the sum of the electricity traded in the pool and the electricity generated by its own DG (Distributed Generation) is non-negative for all time periods. Equation (5) demonstrates this constraint. It is also worth noting that the power procured from bilateral contracts, as indicated in Equation (6), must be positive.

3. BACKGROUND OF ICA AND PSO METHODS

In this section, the background of PSO and ICA methods are presented in below subsections.

3.1. Background of Particle Swarm Optimization

The PSO optimization algorithm is one of the most fundamental metaheuristic optimization algorithms, introduced in [22]. This algorithm falls under the category of population-based algorithms and is inspired by the collective intelligence inherent in particles (birds). Its efficiency in various complex problems has been established. However, due to the random nature of this algorithm, there is a possibility of it getting trapped in local optima. In this algorithm, each bird must adjust its velocity based on its own personal best solution and the global best solution of the group to reach a new position in the search space. Accordingly, the position and velocity of a particle in the search space are updated by the following relationships.

$$X_i^{t+1} = X_i^t + V_i^{t+1} \quad (7)$$

$$V_i^{t+1} = wV_i^t + C_1 rand()(pbest_i^t - X_i^t) + C_2 rand()(gbest - X_i^t) \quad (8)$$

In these equations, X_i^t represents the position, V_i^{t+1} the velocity, and $pbest_i^t$ the best personal experience of the i-th particle. Conversely, $gbest$ models the best group experience, $rand()$ represents a random number between zero and one, w denotes a weighting coefficient between zero and one, and C_1 and C_2 models two positive acceleration constants. The movement of particle is shown in Fig. 1.

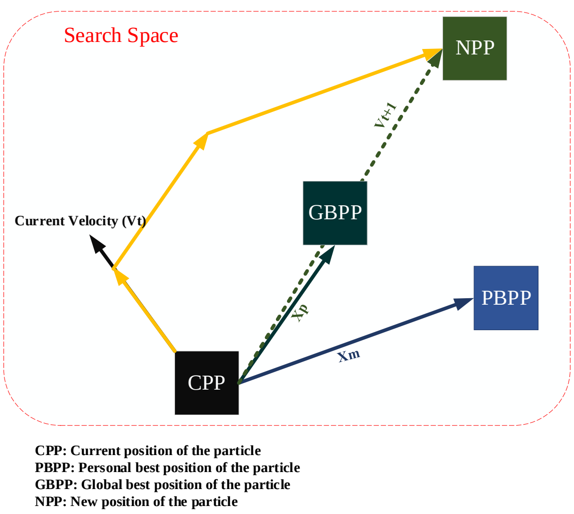

Fig. 1. Particle swarm optimization principle (PSO).

3.2. Background of Imperialist Competitive Algorithm

In the realm of optimization algorithms, the Imperialist Competitive Algorithm (ICA) [23] stands out as a key tool. This algorithm, operating on principles akin to genetic algorithm and Particle Swarm Optimization (PSO), commences with a set of initial solutions, conceptualized here as 'countries'. These countries evolve and improve over time within the algorithmic process. The foundation of this algorithm is built on three main components: Assimilation, competition among empires, and revolution. These elements enable the algorithm to derive optimal solutions for various problems, drawing inspiration from real-world social and political structures, through a systematic and repeatable process. Consequently, the algorithm seeks the continuous improvement of these 'countries' within the search space of the problem, ultimately striving to find the best possible solution. The fundamental procedures of the algorithm are concisely outlined in Algorithm 1. For a more comprehensive understanding and additional details, readers are encouraged to study reference [23]. Furthermore, the dynamics of each colony within the algorithm are visually depicted in Fig. 2.

Algorithm 1. Imperialist competitive algorithm [23]

```
Initialize and Evaluate the empires
while Stop condition is not satisfied do
    Assimilation of the colonies toward their pertaining imperialist
    if there is a colony in an empire which has a lower cost than the imperialist
        Exchange the positions of that colony and of the imperialist
    end if
    Compute the total cost of all empires
    Imperialistic competition
    if there is an empire with no colony then
        Eliminate empires which have no any colonies
    end if
end while
```

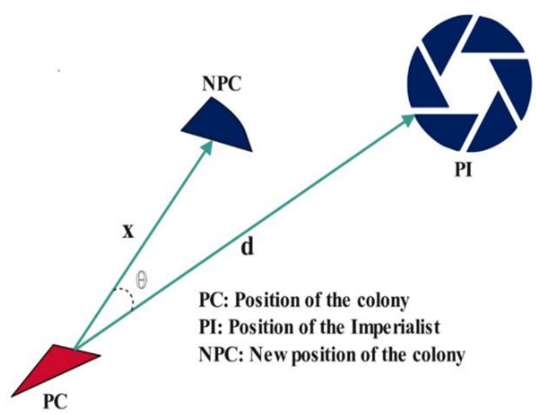

Fig. 2. Movement of colonies toward their relevant imperialist.

4. PROPOSED HYBRID APPROACH BASED ON BICA-BPSO

This section introduces the proposed hybrid methodology, which integrates the Binary Imperialist Competitive Algorithm (BICA) and Binary Particle Swarm Optimization (BPSO), as referenced in [24]. In other words, this paper employs the hybridized approach of BICA and BPSO to enhance optimization performance. In the standard ICA, there are only two types of countries: imperialists and colonies. In the proposed hybrid algorithm (BPSO-BICA) we added another type of country called 'independent' country. Independent countries do not fall into the category of empires, and are anti-imperialism. In addition, they are united and their shared goal is to get stronger in order to rescue colonies and help them join independent countries. These independent countries are aware of each other positions and make use of swarm intelligence in PSO for their own progress.
Based on these definitions, the steps of the proposed algorithm are succinctly outlined as follows:

Proposed algorithm

- 1: Initialize and evaluate the empires and independent countries
- 2: while Stop condition is not satisfied steps do
- Step1: Assimilation of the independent countries similar to ICA background[24];
    - Update best personal experience of independent countries
- Step2: Movement of colonies of every emperor similar to PSO background [24];
    - choose imperialist of every empire as gbest of its colonies
    - move every colony based on its gbest, best individual experience, and current position
    - Update the best personal experience of every colony
    - Attitude of colonies toward their own imperialist
    - Update best personal experience of every colony
- Step3: Movement of imperialists of every emperor similar to PSO background[24];
    - Update best personal experience and $gbest_{imp}^{tot}$ of imperialists
    - Update best personal experience and $gbest_{imp}^{tot}$ of imperialists
- Step4: Revolution similar to ICA background [23];
- Step5: Assimilation between imperialists and independent countries similar to ICA background [23];
- Step6: Comparison of imperialist with the best colony similar to ICA [23];
- Step7: Competition for independency [23];
- Step8: Competition to colonize independent countries [23];
- 3: if there is a colony in an empire which has a lower cost than the imperialist then
- 4: Exchange the positions of that colony and of the imperialist
- 5: end if
- 6: Compute the total cost of all empires
- 7: Imperialistic competition
- 8: if there is an empire with no colony then
- 9: Eliminate empires which have no any colonies
- 10: end if
- 11: end while

The proposed algorithm flowchart is dedicated in Fig. 3 [24].

5. NUMERICAL SIMULATION

In this part, the numerical simulations are studied to show the capability of the proposed approach to find the optimality solution of procurement cost function of large consumer.
In the proposed problem, the each day is divided into three load levels denoted as valley, shoulder and peak, as presented in Table 1. Multiple bilateral contracts are available in power market whose should be selected by decision maker of large consumer at the beginning of the study horizon. The maximum and minimum quantity of energy along with energy price of twelve bilateral contracts is presented in Table 2. According the Table 2, two contracts are available for each week while four contracts are available for the entire month. Also, six contracts are available for peak periods and all load level. Table 4 presented the data of self-production unit. Furthermore, the Fig. 4 shows the load profile of large consumer. Finally, the Fig. 5 shows the pool market prices in the study horizon.
The proposed algorithm is implemented using the MATLAB 7.0 software and the computing time for solving the problem and finding the optimality solution is in 60 seconds in a PC with Intel(R) Core(TM) i3-2330M CPU 2.20GHz 2GB RAM.

The proposed hybrid approach is applied to minimize objective function (1) subject to constraints (2) to (6) considering the estimated pool market prices. The energy procurement cost using the proposed hybrid approach is $ 10,015,354. The numerical results show that large consumer should be procured 1.8255 % of electricity needs from the self-production unit, 20.5521 % from bilateral contracts and 77.6224 % from the pool market.

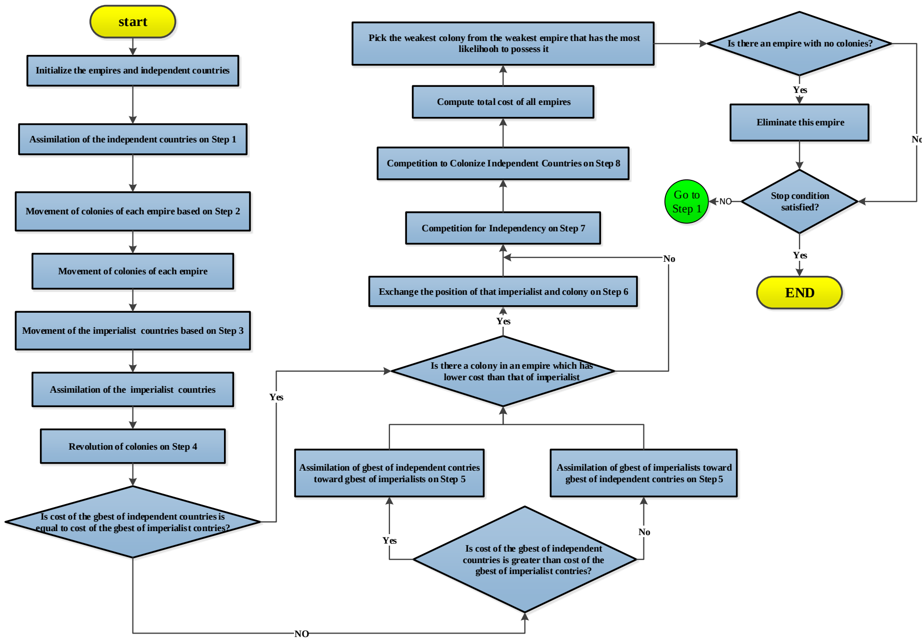

Fig. 3. Proposed Hybrid Methodology Flowchart.

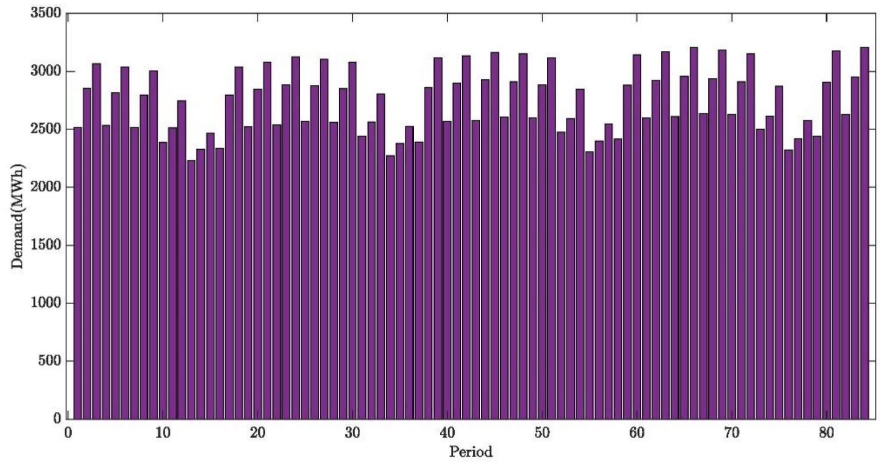

Fig 4. Consumer Load Profile over Study Horizon [24].

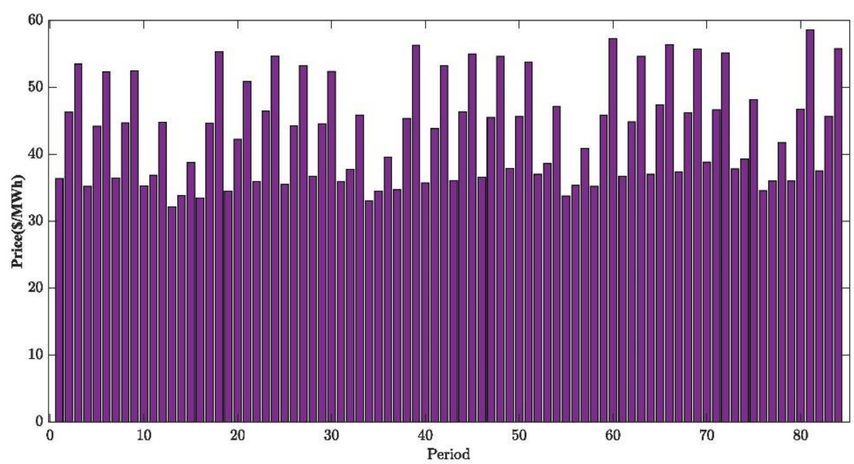

Fig 5. Projected Pool Market Price Data across Study Horizon [24].

Table 1. Categorization of Daily Load Levels [24].

H	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
V	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
S	×	×	×	×	×	×	×	×	✓	✓	×	×	×	×	✓	✓	✓	✓	×	×	×	×	✓	✓
P	×	×	×	×	×	×	×	×	×	×	✓	✓	✓	✓	×	×	×	×	✓	✓	✓	✓	×	×

H: Hours of the day V: Valley S: Shoulder P: Peak

Table 2. Specifications of Bilateral Contracts [24]

Contracts	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
Min. (MW)	10	15	10	15	15	10	15	10	15	10	15	10
Max. (MW)	35	25	35	25	50	40	50	40	50	40	50	40
Price ($/MWh)	41.97	47.15	53.75	51.1	34.77	44.16	56.02	48.44	46.37	60.97	52.65	63.58

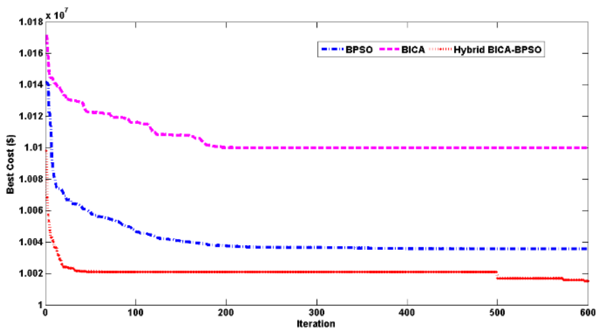

Fig. 6. Comparison of the Objective Function Across Iterations for Three Different Methods.

Table 3: Usage Periods of Bilateral Contracts [24].

Contracts	Usage period					Validity level		
	Month	Week				V	S	P
		ONE	TWO	TREE	FOUR			
C_1	✓	×	×	×	×	✓	✓	✓
C_2	✓	×	×	×	×	×	×	✓
C_3	✓	×	×	×	×	✓	✓	✓
C_4	✓	×	×	×	×	×	×	✓
C_5	×	✓	×	×	×	✓	✓	✓
C_6	×	✓	×	×	×	×	×	✓
C_7	×	×	✓	×	×	✓	✓	✓
C_8	×	×	✓	×	×	×	×	✓
C_9	×	×	×	✓	×	✓	✓	✓
C_{10}	×	×	×	✓	×	×	×	✓
C_{11}	×	×	×	×	✓	✓	✓	✓
C_{12}	×	×	×	×	✓	×	×	✓

Furthermore, the Tables 5-7 presented the purchasing energy from pool market, self-production unit and bilateral contracts using the conventional ICA, PSO and proposed hybrid approach, respectively.

Moreover, the results of proposed hybrid approach in comparison with conventional ICA and PSO methods are presented in Table 8. According to Table 8, the energy procurement cost using the proposed hybrid approach is lower than the conventional ICA and PSO methods. Also, the proposed hybrid approach is more efficient and the results are optimality in comparison with conventional ICA and PSO methods. Finally, the convergence of the proposed hybrid approach in comparison with conventional ICA and PSO methods are shown in Fig. 6. According to Fig. 6, the proposed hybrid approach reached the optimality solution in less iteration in comparison with conventional ICA and PSO methods. Also, the convergence of the proposed hybrid approach is faster in comparison with ICA and PSO methods.

Table 4. Information on the DG Facility [24]/

Capacity (MW)	$A_{dg}\,(\$/MW^2h)$	$B_{dg}\,(\$/MWh)$	$C_{dg}\,(\$)$
100	0.02	34	0

6. CONCLUSION

In this paper, the mid-term energy procurement problem of large consumers is considered. The power market, self-production unit and bilateral contracts are used as available alternative energy sources by large consumer' decision maker. The four weeks is considered as mid-term time horizon and each day is divided into three eight-hour periods, namely peak, shoulder and valley. For solving the energy procurement cost optimization, a hybrid approach based on BICA-BPSO is proposed in this paper. Using the proposed hybrid approach, the energy purchasing from power market and self-production unit are determined. Also, some of available bilateral contracts are selected and set by decision maker of large consumer. Furthermore, in the numerical simulation, the results of proposed hybrid approach are compared with conventional ICA and PSO methods. The comparison results show that proposed approach is more efficient. Also, the results are optimality in comparison with conventional ICA and PSO methods. Finally, the convergence of the proposed hybrid approach is faster in comparison with conventional ICA and PSO methods.

NOMENCLATURES:

D_i	**Load at time i [MW]**
$P_{l,i}^{\max}$	**Maximum power pertaining to contract l at time i [MW]**
$P_{l,i}^{\min}$	**Minimum power pertaining to contract l at time i [MW]**
A_{dg}, B_{dg}, C_{dg}	**Coefficients of operation cost function of self-generating facility**
T	**Number of time periods [hours]**
λ_i	**Forecasted pool market price at time i [\$/MWh]**
$\lambda_{l,i}$	**Energy price of contract l at time i [\$/MWh]**

Variables:

$P_{dg,i}$	**Procured power from the self-generating facility at time i [MW]**
$P_{P,i}$	**Procured power from the pool at time i [MW]**
$P_{l,i}$	**Procured power from the bilateral contract l at time i [MW]**
$P_{b,i}$	**Total procured electricity from bilateral contracts at time period i [MW]**
s_l	**Binary variable, which is equal to 1 if the bilateral contract l is selected and 0 otherwise.**

Indices:

i	Time (hour) index
l	Bilateral contract index

Constants:

B	Number of bilateral contracts
N	Number of production blocks of the self-generating facility

Table 5. Comparison of Energy Procurement Outcomes from Pool Markets Using Three Different Methods.

Methods	Proposed Method			ICA method			PSO method		
/Day	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
1	1838.01	2084.71	1568.75	1818.01	2076.71	1768.75	1784.01	2076.71	1568.75
2	1853.67	2139.25	1539.18	1833.67	2119.25	1735.18	1853.67	2139.25	1535.18
3	1837.26	2043.26	1528.18	1817.26	2014.26	1783.18	1781.26	2014.26	1503.18
4	1704.69	1833.98	1246.61	1684.69	1813.98	1446.61	1680.69	1766.98	1246.61
5	1548.37	1647.68	968.15	1548.37	1647.68	1168.15	1528.37	1647.68	968.15
6	1653.97	2022.78	1547.12	1653.97	2096.78	1739.12	1653.97	2016.78	1539.12
7	1766.28	2099.16	1584.89	1840.28	2066.16	1778.89	1820.28	2066.16	1578.89
8	2260.27	2606.58	2040.80	2260.27	2506.58	2304.80	2260.27	2606.58	2024.80
9	2289.91	2574.76	2019.62	2269.91	2494.76	2203.62	2259.91	2494.76	2003.62
10	2280.16	2473.28	1997.05	2260.16	2553.28	2181.05	2215.16	2473.28	1981.05
11	2069.64	2194.52	1762.02	2141.64	2264.52	1986.02	2119.64	2284.52	1706.02
12	1991.80	2079.21	1443.35	1991.80	2099.21	1627.35	1991.80	2099.21	1527.35
13	2036.09	2478.43	2032.06	2112.09	2558.43	2216.06	2112.09	2478.43	2016.06
14	2288.10	2619.59	2051.44	2268.10	2519.59	2235.44	2288.10	2519.59	2035.44
15	2298.15	2626.40	2416.05	1878.15	2146.40	2185.05	2252.15	2646.40	2385.05
16	2324.83	2597.75	2394.21	1864.83	2129.75	2170.21	2264.83	2629.75	2370.21
17	2317.30	2606.86	2379.18	1897.30	2106.86	2139.18	2317.30	2506.86	2339.18
18	2196.56	2315.22	2089.44	1776.56	1815.22	1868.44	2125.56	2215.22	2068.44
19	2025.67	2098.32	1796.67	1625.67	1698.32	1568.67	2025.67	2092.32	1768.67
20	2089.59	2545.79	2373.29	1717.59	2098.79	2163.29	2114.59	2498.79	2363.29
21	2297.03	2597.76	2406.17	1897.03	2143.76	2189.17	2253.03	2543.76	2389.17
22	2273.36	2674.92	2424.86	2311.36	2574.92	2624.86	2331.36	2574.92	2424.86
23	2357.34	2556.07	2404.74	2337.34	2556.07	2604.74	2276.34	2556.07	2404.74

24	2345.49	2550.22	2390.84	2245.49	2531.22	2570.84	2345.49	2631.22	2370.84
25	2221.70	2275.49	2094.61	2201.70	2314.49	2291.61	2127.70	2234.49	2091.61
26	2023.72	2102.80	1797.63	2043.72	2118.80	1997.63	2023.72	2138.80	1797.63
27	2062.37	2559.23	2398.37	2142.37	2524.23	2598.37	2162.37	2524.23	2398.37
28	2345.76	2624.26	2434.75	2325.76	2572.26	2627.75	2345.76	2572.26	2427.75

Table 6: Comparison of Energy Procurement Outcomes from the DG Unit across Three Methods.

Methods	**Proposed hybrid approach**			**ICA method**			**PSO method**		
day	**Level 1**	**Level 2**	**Level 3**	**Level 1**	**Level 2**	**Level 3**	**Level 1**	**Level 2**	**Level 3**
1	0	92	100	20	100	100	54	100	100
2	0	0	96	20	20	100	0	0	100
3	0	71	75	20	100	20	56	100	100
4	0	0	100	20	20	100	24	67	100
5	0	0	100	0	0	100	20	0	100
6	0	94	92	0	20	100	0	100	100
7	74	67	94	0	100	100	20	100	100
8	0	0	100	0	100	20	0	0	100
9	0	20	100	20	100	100	30	100	100
10	0	100	100	20	20	100	65	100	100
11	92	90	60	20	20	20	42	0	100
12	0	20	100	0	0	100	0	0	0
13	76	100	100	0	20	100	0	100	100
14	0	0	100	20	100	100	0	100	100
15	0	20	69	20	100	100	46	0	100
16	0	32	76	60	100	100	60	0	100
17	0	0	60	20	100	100	0	100	100
18	0	0	79	20	100	100	71	100	100
19	0	20	72	0	20	100	0	26	100
20	48	53	90	20	100	100	23	100	100
21	20	46	83	20	100	100	64	100	100
22	58	0	100	20	100	100	0	100	100
23	0	100	100	20	100	100	81	100	100
24	0	81	80	100	100	100	0	0	100
25	0	59	97	20	20	100	94	100	100
26	20	36	100	0	20	100	20	0	100
27	100	65	100	20	100	100	0	100	100
28	0	48	93	20	100	100	0	100	100

Table 7. Comparison of Results for Energy Procurement through Bilateral Contracts Using Three Methods.

Contracts	Method		
	Hybrid	ICA	PSO
C_1	✓	✓	✓
C_2	✓	✓	✓
C_3	×	×	×
C_4	✓	×	✓

C_5	✓	✓	✓
C_6	✓	✓	✓
C_7	✗	✗	✗
C_8	✓	✓	✓
C_9	✗	✓	✗
C_{10}	✗	✗	✗
C_{11}	✗	✗	✗
C_{12}	✗	✗	✗

Table 8. Analysis of the Proposed Hybrid Approach Outcomes in Comparison with ICA and PSO Methods.

Results	Proposed Method	ICA	PSO
Objective function ($)	10015354	10100009	10035793
Percent procurement from pool (%)	77.6224	76.0410	77.1217
Percent procurement from bilateral contracts (%)	20.5521	21.8124	20.6006
Percent procurement from DG units (%)	1.8255	2.1466	2.2777

REFERENCES

[1] Houmin, Y., Houzhong, Y., **"Optimal energy purchase in deregulated California energy markets,"** *IEEE Power Eng. Soc. Winter Meeting 2* pp. 1249-1254, 2000.

[2] Kirschen Daniel, S., **"Demand-side view of electricity markets,"** *IEEE Trans. Power Syst.* Vol. 18 (2), pp. 520- 527, 2003.

[3] Daryanian, B., Bohn, R. E., Tabors, R. D., **"Optimal demand-side response to electricity spot prices for storage-type customers,"** *IEEE Trans Power Syst*. Vol. 4 (3), pp. 897-903, 1998.

[4] Lin, Y., Guan, X., **"Purchase allocation and demand bidding in electric power markets,"** *IEEE Trans. Power Syst.* Vol. 18 (1), pp. 106-112, 2003.

[5] Gabriel, S. A., Conejo, A. J., Plazas, M. A., Balakrishnan, S., **"Optimal price and quantity determination for retail electric power contracts,"** *IEEE Trans. Power Syst*. Vol. 21 (1), pp. 180–187, 2006.

[6] Talati, S., Bednarz, J., **"Deregulation and opportunities for industrial customers,"** *IEEE Trans. Power Ind. Appl.* Vol. 34 (6), pp. 1378-1386, 1998.

[7] Conejo, A. J., Fernandez-Gonzalez, J. J., Alguacil, N., **"Energy procurement for large consumers in electricity markets,"** *IEE Proc. Gener. Trans. Dist.* Vol. 152 (3), pp. 357-364, 2005.

[8] Conejo, A.J.,Carrión, M., **"Risk constrained electricity procurement for a large consumer,"** *IEE Proc. Gener. Trans. Dist*. Vol. 153 (4), pp. 407-413, 2006.

[9] Carrión, M., Philpott, A. B., Conejo, A. J., Arroyo Jose, M., **"A stochastic programming approach to electric energy procurement for large consumers,"** *IEEE Trans. Power Syst*. Vol. 22 (2), pp. 744-754, 2007.

[10] Woo, C. K., Horowitz, I., Horii, B., Karimov, R., **"The Efficient Frontier for Spot and Forward Purchases: An Application to Electricity,"** *Journal of the Operational Research Society* Vol. 55 (11) pp. 1130-1136, 2004.

[11] Woo, C. K., Horowitz, I., Olson, A., Horii, B., **"Baskette, Efficient Frontiers for Electricity Procurement by an LDC with Multiple Purchase Options,"** *OMEGA* Vol. 34 (1), pp. 70-80, 2006.

[12] Woo, C. K., Karimov, R., Horowitz, I., "**Managing Electricity Procurement Cost and Risk by a Local Distribution Company,"** *Energy Policy*, Vol. 32 (5) pp. 635-645, 2004.

[13] Deng, S. J., Oren, S. S., **"Electricity derivatives and risk management,"** *Energy Journal* Vol. 31 (6-7), pp. 940-953, 2006.

[14] Kleindorfer, P. R., Li, L., **"Multi-period VaRconstrained portfolio optimization with applications to the electric power sector,"** *Energy Journal* Vol. 26 (1), pp. 1-26, 2005.

[15] Gabriel, S. A., Conejo, A. J., Plazas, M. A., Balakrishnan, S., **"Optimal price and quantity determination for retail electric power contracts,"** *IEEE Trans. Power Syst*. Vol. 21 (1), pp. 180–187, 2006.

[16] Hatami, A. R., Seifi, H., Sheikh-El-Eslami, M. K., **"Optimal selling price and energy procurement strategies for a retailer in an electricity market,"** *Electric Power Systems Research* Vol. 79 (1), pp. 246-254, 2009.

[17] Oum, Y., Oren, S., "VaR constrained hedging of fixed price load-following obligations in competitive electricity markets," Risk and Decision Analysis 1 (1) (2009) 43-56.

[19] Zare, K., Parsa Moghaddam, M., Sheikh-El-Eslami, M. K., **"Demand bidding construction for a large consumer through a hybrid IGDT-probability methodology,"** *Energy* Vol. 35, pp. 2999-3007, 2010. [19] Zare, K., Conejo, A. J., Carrion, M., Sheikh-ElEslami, M. K., **"Multi-market energy procurement for a large consumer using a risk-aversion procedure,"** *Electric Power Systems Research* Vol. 80, pp. 63-70, 2010.

[20] Zarif, M., Javidi, M. H., Ghazizadeh, M. S., **"Selfscheduling approach for large consumers in competitive electricity markets based on a probabilistic fuzzy system,"** *IET Gener. Transm. Distrib.*, Vol. 6, No. 1, pp. 50–58, 2012.

[21] Zarif, M., Javidi, M. H., Ghazizadeh, M. S., **"Selfscheduling of large consumers with second-order stochastic dominance constraints,"** *IEEE Trans. Power Syst*, Vol. 28, No. 1, pp. 289-299, Feb. 2013.

[22] James, Kennedy, and Eberhart Russell. **"Particle swarm optimization."** *In Proceedings of 1995 IEEE International Conference on Neural Networks*, pp. 1942-1948, 1995.

[23] Gargari EA, Lucas C. **"Imperialist competitive algorithm: an algorithm for optimization inspired by imperialistic competition,"** *In: Proc. IEEE Congr. Evolutionary Computation*, 2007.

[24] Nojavan S, Mehdinejad M, Zare K, MohammadiIvatloo B. **"Energy procurement management for electricity retailer using new hybrid approach based on combined BICA–BPSO,"** *International Journal of Electrical Power & Energy Systems*., Vol. 73, pp. 411-9, 2013.