Solving Unit Commitment Problem Based on New Stochastic Search Algorithm

H. A. Shayanfar *
Department of Elec. Engineering
College of Tech. and Engineering
South Tehran Branch
Islamic Azad University
Tehran, Iran

O. Abedinia
Electrical Engineering Department
Semnan University
Semnan,
Iran

N. Amjady
Electrical Engineering Department
Semnan University
Semnan,
Iran

hashayanfar@yahoo.com, oveis.abedinia@gmail.com, n_amjady@yahoo.com

Abstract— *Unit commitment problem is one of the large scale nonlinear hybrid integer programming problems which is considered in this paper. Thus, a new stochastic search algorithm has been implemented for solving the mentioned problem. For this purpose, Modified Invasive Weed Optimization (MIWO) has been proposed which is a bio-inspired numerical technique and inspired from weed colonization and motivated by a common phenomenon in agriculture that is colonization of invasive weeds. The proposed algorithm is tested on the power systems in the range of 10–140 generating units for a 24-hours scheduling period and compared to Quantum inspired Evolutionary Algorithm (QEA), Improved Binary Particle Swarm Optimization (IBPSO) and Mixed Integer Programming (MIP).*

Keywords: Unite Commitement, Invasiv Weed Optimization, Stochastic Search.

I. Introduction

Unit commitment (UC) aims to schedule the most cost-effective combination of generating units to meet forecasted load and reserve requirements, while adhering to generator and transmission constraints. Generally, UC is completed for a time horizon of one day to one week and determines which generators will be operating during which hours. This commitment schedule takes into account the inter-temporal parameters of each generator (minimum run time, minimum down time, notification time, etc.) but does not specify production levels, which are determined five minutes before delivery. The determination of these levels is known as economic dispatch and it is "the least-cost usage of the committed assets during a single period to meet the demand" [1-5].

The main purpose of optimal Unit Commitment Problem (UCP) for power system is to find the on/off state of each generating unit and the generation of every committed unit for a given horizon, under various operating constraints, consists of fuel constraints, multiple emission requirements, ramp rate limits, minimum up and down time limits and proper spinning reserves. Since the optimal commitment programming can save huge amount of costs and improve reliability of power system, many methods have been proposed to solve the UCP, such as Lagrange Relax (LR) [6], Dynamic Programming (DP) [7], and Genetic Algorithm (GA) [8]. However, they all have some disadvantages such as; the main problem of LR in the difficulty encountered in obtaining feasible solutions. DP is flexible but it may lead to "curse of dimensionality". The shortcoming of GA is massive calculations and it is difficult in dealing with nonlinear constraints.

This paper proposes a new stochastic algorithm to solve the UC problem. Moreover, we thought a new way to update the on/off status of the units in the form of probability. Meanwhile, the Lambda-iteration method is adopted to solve the economic dispatch problem. The Lambda-iteration method and the proposed modified IWO algorithm are run at the same time for the purpose of finding the solution that has the least total production cost. Furthermore, the correction method and several adjustment techniques are proposed to ensure that the solutions are diverse in the iterative process and satisfy all the constraints.

---

* Corresponding Author. E-Mail Address: hashayanfar@yahoo.com (H. A. Shayanfar)

II. Problem Definition

The formulation for the unit commitment is described in detail in this section. The objective of the UC problem is to minimize the total production cost consisting of the generation cost and the start-up cost of the generating units under the circumstance where, the operational constraints and the constraints of the generating units are satisfied in the scheduling period [9-10]. Where, it can be as;

$$F_T = \sum_{t=1}^{T}\sum_{i=1}^{NT}[C_i(P_i^t.u_i^t)+S_i u_i^t(1-u_i^{t-1})] \tag{1}$$

Where, F is the total production cost; T the number of hours in the scheduling period; NT the number of generating units; and u_i^t on/off status of the unit i at hour t, 1 represents the on status of the unit i at hour t, 0 represents the off status of the unit i at hour t. $C_i(p_i^t)$ is the generation cost function of unit i. It is normally a quadratic polynomial represented by;

$$C_i(p_i^t) = a_i(p_i^t)^2 + b_i(p_i^t) + c_i \tag{2}$$

Where, p_i^t generation output of unit i at hour t; and a_i, b_i, c_i are parameters of unit i. S_i is the start-up cost of unit i which is related to the duration time of the off state of unit i. It can be expressed by:

$$S_i = \begin{cases} H_{SCi} & M_{DTi} < X_{OFFi}^t \le M_{DTi} + C_{SHi} \\ C_{SCi} & M_{DTi} + C_{SHi} < X_{OFFi}^t \end{cases} \tag{3}$$

Where, HSCi is hot start-up cost of unit i; CSCi the cold startup cost of unit i; Xt OFFi the duration time during which unit i keeps off status at hour t; CSHi cold start time of unit i; and MDTi the minimum down time of unit i.

Also, for the constrains;

1) System power balance constraint:

$$\sum_{i=1}^{N} u_i^t p_i^t = D^t \tag{4}$$

2) Thermal Generator Constraints:

a) Unit'smaximum up/down reserve contribution constraints:

$$US_i^{max}=d\%\times P_{i,r}^{\ max} \tag{5}$$
$$DS_i=d\%\times P_{i,r}^{\ max} \tag{6}$$

b) Unit's up/down spinning reserve contribution constraints:

$$US_i(t)=min\{\ US_i^{max}\ ,\ P_{i,r}^{\ max}\_\ P_{i,r}(t)\} \tag{7}$$
$$DS_i(t)=min\{\ DS_i^{max}\ ,\ P_i(t)\_\ P_{i,r}^{\ min}\} \tag{8}$$

c) Unit's ramping up/down capacity constraints:

$$UR_i(t)=min\{\ UR_i^{max}\ ,\ P_{i,r}^{\ max}\_\ P_i(t)\} \tag{9}$$
$$DR_i(t)=min\{\ DR_i^{max}\ ,\ P_i^{max}\_\ P_{i,r}^{\ min}\} \tag{10}$$

d) Unit generation limits:

$$P_i^{\min}(t)\times U_i(t) \le P_i(t) \le P_i^{\max}(t)\times U_i(t) \tag{11}$$

$$P_i^{\max}(t) = \begin{cases} \min\{P_{i,r}^{\max}, P_i(t-1)+UR_i^{\max}\} \\ \min\{P_{i,r}^{\max}, P_i(t-1)+SR_i\} \end{cases} \begin{matrix} if\ U_i(t)=U_i(t-1)=1 \\ \\ if\ U_i(t)=1, U_i(t-1)=0 \end{matrix} \tag{12}$$

$$P_i^{\min}(t) = \begin{cases} \min\{UR_i^{\max}, P_i(t-1)-DR_i^{\max}\} \\ P_{i,r}^{\min}\ if \quad U_i(t)=1, U_i(t-1)=0 \end{cases}$$

$$if \quad U_i(t) = U_i(t-1) = 1$$

e) Minimum up/down time constraints:

$$[t_{ON,i}(t\text{-}1)\text{-}T_{ON,i}]\times[U_i(t\text{-}1)U_i(t)]\ge 0 \tag{13}$$
$$[t_{OFF,i}(t\text{-}1)\text{-}T_{OFF,i}]\times[U_i(t\text{-}1)U_i(t)]\ge 0 \tag{14}$$

III. Modified Invasive Weed Optimization

Invasive Weed Optimization (IWO) is inspired from weed colonization and motivated by a common phenomenon in agriculture that is colonization of invasive weeds. Actually, the weeds have shown with adaptive nature and very robust which turns them to undesirable plants in agriculture. Since its advent IWO has found several successful engineering applications like tuning of robot controller [11], optimal positioning of piezoelectric actuators [12], development of recommender system [13], antenna configuration optimization [15], computing Nash equilibria in strategic games [16], DNA computing [17], and etc.

IWO is a meta-heuristic algorithm which mimics the colonizing behavior of weeds. In this algorithm, the process starts with initializing a population. It means that the population of initial solutions is randomly generated over the problem space. Then the population members produce seeds depending on their relative fitness in the population. In other words, the numbers of seeds for each member are beginning with the value of S_{min} for the worst member and increases linearly to S_{max} for the best member [15]. This technique can be summarized as:

A. *Initialization*

In this step, a finite number of weeds are initialized at the same element position of the conventional array which has a uniform spacing of "$\gamma/2$" between neighboring elements.

B. *Reproduction*

The individuals, after growing, are allowed to reproduce new seeds linearly depending on their own, the highest, and the lowest fitness of the colony (all of plants). The maximum (S_{max}) and minimum (S_{min}) number of seeds are predefined parameters of the algorithm and adjusted according to the structure of problem. The schematic seed production in a colony of weeds is presented in Fig. 1. In this figure, the best fitness function is the lower one [11].

C. *Spatial distribution*

The generated seeds are being randomly distributed over the d-dimensional search space by normally distributed random numbers with mean equal to zero; but varying variance. This step certifies that the produced seeds will be generated around the parent weed, and leading to a local search around each plant. However, the Standard Deviation (*SD*) of the random function is made to decrease over the iterations, which is defined as:

$$SD_{ITER} = \left(\frac{iter_{\max} - iter}{iter_{\max}}\right)^{pow}(SD_{\max} - SD_{\min}) + SD_{\min} \qquad (15)$$

SD_{max} and SD_{min}□ are the maximum and minimum standard deviation, respectively. This step ensures that the probability of dropping a seed in a distant area decreases nonlinearly with iterations, which result in grouping fitter plants and elimination of inappropriate plants.

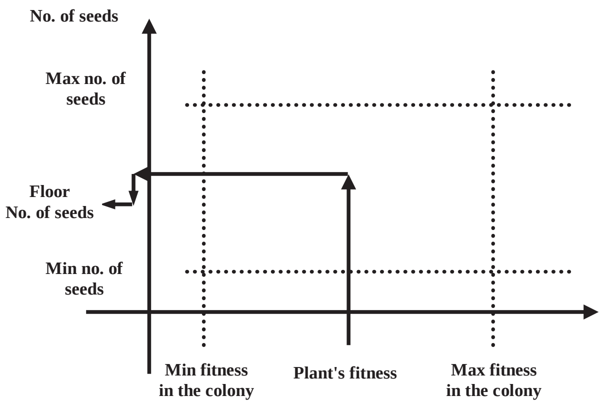

Figure 1. Schematic seed production in a colony of weeds

IV. Numerical Results

In this section the proposed algorithm has been tested over UC problem on the power system with 10, 20, 40, 60, 80, 100, 120 and 140 generating units in the 24-h scheduling period. The 10-unit data is presented in Table 1 and the power demand in the scheduling period is shown in Table 2. The 20, 40, 60, 80, 100, 120 and 140-units data are obtained by duplicating the 10-unit data, whereas, the power demand is proportional to the number of units. Furthermore, the spinning reserve is set to be 10% of the power demand.

Table. 1. Ten Unit System Data

Unit	P_{max}/MW	P_{min}/MW	a/(\$/MW^{2}h)	b/(\$/MW^{2}h)	c/(\$/h)	Min up/h	Min dn/h	Hot start cost/\$	Cold start cost/\$
1	455	150	0.00048	16.19	1000	8	8	4500	9000
2	455	150	0.00031	17.26	970	8	8	5000	10000
3	130	20	0.002	16.6	700	5	5	550	1100
4	130	20	0.00211	16.5	680	5	5	560	11200
5	162	25	0.00398	19.7	450	6	5	900	1800
6	80	20	0.00712	22.26	370	3	3	170	340
7	85	25	0.00079	27.74	480	3	3	260	520
8	55	10	0.00413	25.92	660	1	1	30	60
9	55	10	0.00222	27.27	665	1	1	30	60
10	55	10	0.00173	27.79	670	1	1	30	60

Table. 2. Load Demand

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

Parameters are set as follows: the number of population size 5; the it_{max} is equal to 100, *dim* is considered 1, P_{max} is 5, S_{max} is 25, S_{min} is 0. The program is written in MATLAB R2011a and executed on a 2.5 GHz CPU with 4-GB RAM personal computer. In order to have a comprehensive understanding of the proposed method, 50 trials are done on every test system.

Since the best solution of the 10-unit system of the proposed method is the same as that of QEA, the units' power output of the best solution can be seen in [18].The best solution of the 20-unit system is presented in Table 3

Table. 3. Unit Output of the 20 Unit System's Best Solution

Hour	Generating unit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	455	455	245	245	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	455	455	295	295	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	455	455	383	383	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0
4	455	455	455	455	0	0	0	0	40	44	0	0	0	0	0	0	0	0	0	0
5	455	455	455	455	0	0	130	0	25	25	0	0	0	0	0	0	0	0	0	0
6	455	455	455	455	130	0	130	130	25	24	0	0	0	0	0	0	0	0	0	0
7	455	455	455	455	130	130	130	130	45	45	0	0	0	0	0	0	0	0	0	0
8	455	455	455	455	130	130	130	130	30	39	0	0	0	0	0	0	0	0	0	0
9	455	455	455	455	130	130	130	130	97.5	98	98	20	20	0	0	0	0	0	0	0
10	455	455	455	455	130	130	130	130	162	163	162	33	33	0	0	0	0	0	0	0
11	455	455	455	455	130	130	130	130	162	163	162	98	98	98	10	0	0	0	0	0
12	455	455	455	455	130	130	130	130	162	163	162	98	80	25	10	0	0	0	0	0
13	455	455	455	455	130	130	130	130	162	163	98	65	80	25	10	10	10	10	0	0
14	455	455	455	455	130	130	130	130	97.5	87	33	65	33	25	10	10	10	10	10	10
15	455	455	455	455	130	130	130	130	30	38	25	20	25	25	0	0	0	0	0	0
16	455	455	310	334	130	130	130	130	25	32	25	20	0	0	0	0	0	0	0	0
17	455	455	260	260	130	130	130	130	25	25	30	25	0	0	0	0	0	0	0	0
18	455	455	360	360	130	130	130	130	25	25	33	33	0	0	0	0	0	0	0	0
19	455	455	455	455	130	130	130	130	30	30	105	30	0	0	0	0	0	0	0	0
20	455	455	455	455	130	130	130	130	162	167	105	25	0	0	0	0	0	0	0	0
21	455	455	455	455	130	130	130	130	105	105	105	25	30	25	0	0	10	10	10	0
22	455	455	455	455	0	0	130	0	105	105	0	25	33	25	0	10	0	0	0	0
23	455	455	433	433	0	0	0	0	25	24	0	0	0	0	0	0	0	0	0	0
24	455	455	345	345	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

and 4, which have never been illustrated in detail before. We can see that the generation cost in the scheduling period is 1114874 and the start-up cost is 8400 MW/$, so the total production cost is 1123292. Also, the convergence trend of proposed method over different case studies has been presented in Fig. 2.

Table. 4. Cost of the 20-Unit System's Best Solution

Hour	Generation cost	Start-up cost	Spinning reserve	On/off status
1	27363.24	0	420	11110000000000000000
2	29109.00	0	320	11110000000000000000
3	33111.24	900	280	11110000100000000000
4	37194.44	900	240	11110000110000000000
5	39456.23	560	274	11110001001110000000
6	44277.22	2220	332	11110000000000000000
7	46000.23	0	233	11110000000000000000
8	48302.45	1100	363	11111111111111000000
9	53768.98	1200	309	11111111111111100000
10	60087.54	640	302	11111111111111110000
11	63782.45	120	312	11111111111111111000
12	67687.34	120	322	11111111111111111111
13	61112.34	0	301	11111111111111110000
14	53834.98	0	302	11111111111111000000
15	48287.87	0	260	11111111111100000000
16	43034.48	00	564	11111111111000000000
17	41284.98	0	665	11111111111000000000
18	44635.66	0	464	11111111111000000000
19	47827.45	0	254	11111111111000000000
20	61004.42	640	289	11111111111000111000
21	53456.98	0	279	11111111111000110000
22	44438.87	0	232	11111111111000000100
23	34537.23	0	180	11100001111000000000
24	30012.45	0	220	11100011101000000000

The best, worst and mean values of the total production cost, together with the mean computation time by MIP [18], QEA [19], IBPSO [20] and proposed method for various test systems are shown in Table 5.

Table. 5. Comparison of Simulation Results for Different Systems

Unit	Algorithm	Cost			Mean time
		Best	Worst	Mean	
10	MIP	564647			2
	QEA	563938	564672	563969	19
	IBPSO	563977	565312	564155	27
	Proposed	563933	564222	563945	2
20	MIP	1123908			5
	QEA	1123607	1125715	1124689	28
	IBPSO	1125216	1125730	1125448	55
	Proposed	1123287	1124078	1123768	9
40	MIP	2243020			11
	QEA	2245557	2248296	2246728	43
	IBPSO	2248581	2249302	2248875	110
	Proposed	2242880	2244572	2243581	30
60	MIP	3361614			29
	QEA	3366676	3372007	3368220	54
	IBPSO	3367865	3368779	3368278	172
	Proposed	3361681	3364101	3363112	50
80	MIP	4483194			38
	QEA	4488470	4492839	4490126	66
	IBPSO	4491083	4492686	4491681	235
	Proposed	4482013	4486732	4484502	70
100	MIP	5601857			47
	QEA	5609550	5613220	5611797	80
	IBPSO	5610293	5612265	5611181	295
	Proposed	5601272	5608321	5604172	99
120	Proposed	6722630	6732536	6726624	115
140	Proposed	7891535	7905537	7898747	132

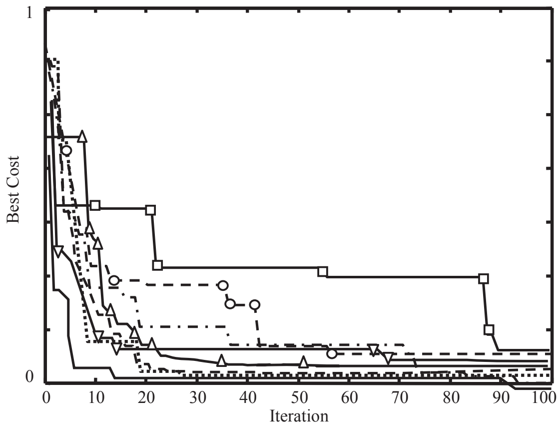

Figure 2. Fitness convergence, Solid; 10 unit, Dashed; 20 unit, Dotted; 40 unit, Dashed-Dotted; 60 unit, Upward-pointing triangle; 80 unit, Downward-pointing triangle; 100 unit, Circul-pointing; 120 unit, Square-pointing; 140 unit

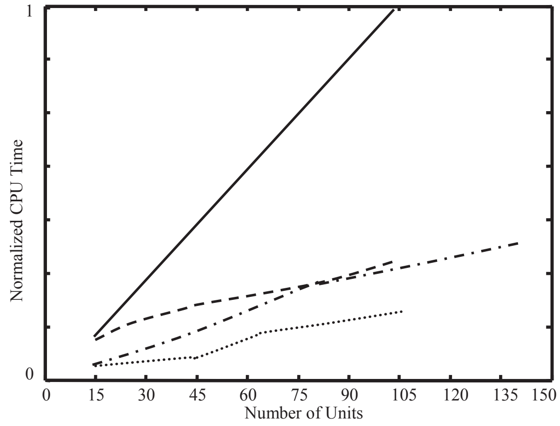

Figure 3. Comparison of different algorithms computation time, Solid; IBPSO, Dashed; QEA, Dotted; MIP, Dashed-Dotted; Proposed

We can see that the best solution of the proposed algorithm is better in most of the test systems and the best solution of proposed algorithm is very close to that of the MIP method in the 60-unit test system. From Fig. 3, it can seen that the proposed method is faster than the proposed method in all the test systems and QEA algorithm in 10, 20, 40 and 60-unit test systems. Although the calculation time of the proposed method is longer than that of the MIP method, the calculation time of the proposed method increases almost linear with the number of the units, which means that it has the capacity of solving large-scale UC problems.

V. Conclusions

In this paper, a new stochastic search algorithm has been implemented for solving the unit commitment problem. Thus, Modified Invasive Weed Optimization (MIWO) has been implemented over this problem which is a bio-inspired numerical technique and inspired from weed colonization and motivated by a common phenomenon in agriculture that is colonization of invasive weeds. The simulation results show that the total production cost of proposed method is less expensive than those of the other methods in the range of 10–100 generating units. In addition, the CPU time of this method increases almost linear with the size of the units, which is favorable for the large-scale power systems.

References

[1] C. D. Yue, C.M. Liu, and M. L. L. Eric, “A transition toward a sustainable energy future: Feasibility assessment and development strategies of wind power in Taiwan,” Energy Pol., Vol. 29, pp. 951–963, 2001.

[2] T. J. Chang,Y.T.Wu,H.Y.Hsu, C. R. Chu, and C.M. Liao, “Assessment of wind characteristics and wind turbine characteristics in Taiwan,” Renew. Energy, Vol. 28, pp. 851–871, 2003.

[3] A. G. Bakirtzis and P. S. Dokopoulos, “Short term generation scheduling in a small autonomous system with unconventional energy sources,” IEEE Trans. Power Syst., Vol. 3, No. 3, pp. 1230–1236, Aug. 1988.

[4] C. Brunetto and G. Tina, “Optimal hydrogen storage sizing for wind power plants in day ahead electricity market,” Renewable Power Generation, Vol. 1, No. 4, pp. 220–226, Dec. 2007.

[5] S. Chakraborty, M. Weiss, and M. G. Simoes, “Distributed intelligent energy management system for a single-phase high-frequency AC microgrid,” IEEE Trans. Ind. Electron., Vol. 54, No. 1, pp. 97–109, Feb. 2007.

[6] A. Merlin, and P. Sandrin, “A new method for unit commitment at Electricite de France”, IEEE Transactions on Power Applied Systems, Vol. PAS-102, pp. 1218-1255, 1983.

[7] W. L. Snyder, Jr., H. D. Powell, Jr., and J. C. Rayburn, “Dynamic programming approach to unit commitment”, IEEE Transactions on Power Systems, Vol. 2, No. 2, pp. 339-350, 1987.

[8] S. A. Kazarlis, A. G. Bakirtzis, and V. Petridis, “A genetic algorithm solution to the unit commitment problem”, IEEE Transactions on Power Systems, Vol. 11, No. 1, pp. 83-92, 1996.

[9] J. Juban, L. Fugon, and G. Kariniotakis, “Uncertainty estimation of wind power forecasts”, in Proceedings of the European Wind Energy Conference EWEC08, Brussels, Belgium, 2008.

[10] A. Tuohy, P. Meibom, E. Denny, and M. O’Malley, “Unit commitment for systems with significant wind penetration”, IEEE Transactions on Power Systems, Vol. 24, pp. 592–601, 2009.

[11] A. R. Mehrabian and C. Lucas, “A novel numerical optimization algorithm inspired from invasive weed colonization,” Ecological Informatics, Vol. 1, pp. 355-366, 2006.

[12] H. Sepehri-Rad and C. Lucas, “A recommender system based on invasive weed optimization algorithm,” in Proc.

IEEE Congress on Evolutionary Computation, pp. 4297 – 4304, 2007.

[13] A. R. Mehrabian and A. Yousefi-Koma, "Optimal positioning of piezoelectric actuators of smart fin using bio-inspired algorithms," Aerospace Science and Technology, Vol. 11, pp. 174 – 182, 2007.

[14] B. Panida, B. Chanwit, O. Weerakorn, "Optimal congestion management in an electricity market using particle swarm optimization with time-varying acceleration coefficients", Computers and Mathematics with Applications, Vol. 3, pp. 1-10, 2010.

[15] N.G. Pavlidis, K.E. Parsopoulos, and M.N. Vrahatis, "Computing Nash equilibria through computational intelligence methods," J. of Computational and Applied Mathematics, Vol. 175, No. 1, pp. 113–136, 2005.

[16] B. Dadalipour, A. R. Mallahzadeh, Z. Davoodi-Rad, "Application of the invasive weed optimization technique for antenna configurations," in Proc. Loughborough Antennas and Propagation Conf., Loughborough, pp. 425-428, Mar. 2008.

[17] X. Zhang, Y. Wang, G. Cui, Y. Niu, and J. Xu, "Application of a novel IWO to the design of encoding sequences for DNA computing," Computers and Mathematics with Applications, 2008.

[18] TW. Lau, CY. Chung, KP. Wong, Quantum-inspired evolutionary algorithm approach for unit commitment. IEEE Trans Power Syst., Vol. 24, No. 3, pp. 1503–1512, 2009.

[19] KA. Juste, H. Kita, E. Tanaka, An evolutionary programming solution to the unit commitment problem. IEEE Trans Power Syst., Vol. 14, No. 4, pp. 1452–1459, 1999.

[20] YW. Jeong, JB. Park, SH. Jang, A new quantuminspired binary PSO: Application to unit commitment problems for power systems. IEEE Trans Power Syst., Vol. 25, No. 3, pp. 1486–1495, 2010.

Biographies

Heidar Ali Shayanfar received the B.S. and M.S.E. degrees in Electrical Engineering in 1973 and 1979, respectively. He received his Ph. D. degree in Electrical Engineering from Michigan State University, U.S.A., in 1981. Currently, he is a Full Professor in Electrical Engineering Department of Iran University of Science and Technology, Tehran, Iran. His research interests are in the Application of Artificial Intelligence to Power System Control Design, Dynamic Load Modeling, Power System Observability Studies, Smart Grids, Voltage Collapse, Congestion Management in a Restructured Power System, Reliability Improvement in Distribution Systems and Reactive Pricing in Deregulated Power Systems. He has published more than 495 technical papers in the International Journals and Conferences proceedings. He is a member of Iranian Association of Electrical and Electronic Engineers and IEEE.

Oveis Abedinia received the B.S. and M.Sc. degrees in Electrical Engineering in 2005 and 2009, respectively. Currently, he is a Ph. D. student in Electrical Eng. Department, Semnan University, Semnan, Iran. His areas of interest in research are Application of Artificial Intelligence to Power System and Control Design, Load and Price Forecasting, Restructuring in Power Systems, Heuristic Optimization Methods. He has two industrial patents, authored of one book in Engineering area in Farsi and more than 70 papers in international journals and conference proceedings. Also, he is a member of Iranian Association of Electrical and Electronic Engineers (IAEEE) and IEEE.

Nima Amjady (SM'10) was born in Tehran, Iran, on February 24, 1971. He received the B.Sc., M.Sc., and Ph.D. degrees in electrical engineering from Sharif University of Technology, Tehran, Iran, in 1992, 1994, and 1997, respectively. At present, he is a Professor with the Electrical Engineering Department, Semnan University, Semnan, Iran. He is also a Consultant with the National Dispatching Department of Iran. His research interests include security assessment of power systems, reliability of power networks, load and price forecasting, and artificial intelligence and its applications to the problems of power systems.