Solving Unit Commitment With Wind Power Using Artificial Immune Evolutionary Programming Optimization Technique

Mohamad Fitri bin Ramli
Faculty of Electrical Engineering
MARA University of Technology
4050 Shah Alam, Selangor Darul Ehsan
e-mail: fitriramli89@gmail.com

Abstract — **This paper propose a solution to unit commitment problem with wind power using artificial immune evolutionary programming. The objective of this paper is to find the suitable generation scheduling which can minimize the operation cost with subjected to various constrain. The main idea of this paper is to integrate the use of Artificial Immune Evolutionary Programming as optimization technique towards Unit Commitment. Other than that, this paper also aiming to review the effect of addition wind power to the Unit Commitment problem solution. MATLAB programming language was used to execute the program using 10 set of generator data with several constrain like power balance, and generation limit .The process of Artificial Immune Evolutionary Programming including of initialization, cloning, cost calculation, mutation, sorting and combine and convergences test. The result are shown to verify the performance of Artificial Immune Evolutionary Programming technique**

Keywords: Unit Commitment, Artificial Immune Evolutionary Programming (AIEP), optimized, wind power generator

I. Introduction

Fluctuation of demand everyday will create problem for generating unit to fulfill the load or electricity demand. Theoretically, generating unit will run all the generators in order to meet with the specific demand, but that kind of strategy will oppose problem in the future and cause a lot of money. Therefore, an optimization is required. The problem facing with optimization is it required scheduling of the generators whereby it is also called as unit commitment.

A. Unit Commitment

Power system management can be categorized into several operations which are operational planning, improvement, expansion and last but not least optimization of power system. Optimization process is crucial part in the management because through optimization process, the power supply to the load or consumer can be always sufficient.

Unit commitment can be define as set of sequence determine which generator attached in the power system network to start up and which generator to shut down and for how long [1], [9]. Basically, the load in power system network is always changing during per day. Thus, the load needs to be predicted or forecasted in order to meet the demand.

Therefore, the concept of unit commitment is to minimize the cost like fuel cost, start up cost and shut down cost.

B. Evolutionary Programming (EP)

Evolutionary Programming (EP) is a mutation-based evolutionary algorithm which involves with the real parameter of the system [6]. This EP objective is to maximize or minimize fitness equation and can be presented using mathematical equation. There are several types of EP such as Meta EP and adaptive EP.

The algorithm of EP is encoded by the mutation strength (or variance of normal distribution) for decision variable and self-updating rule is used to update the mutation strength.

EP is conduct by sequences of operation. The schematic diagram below shows the overall EP algorithm in Figure 1:

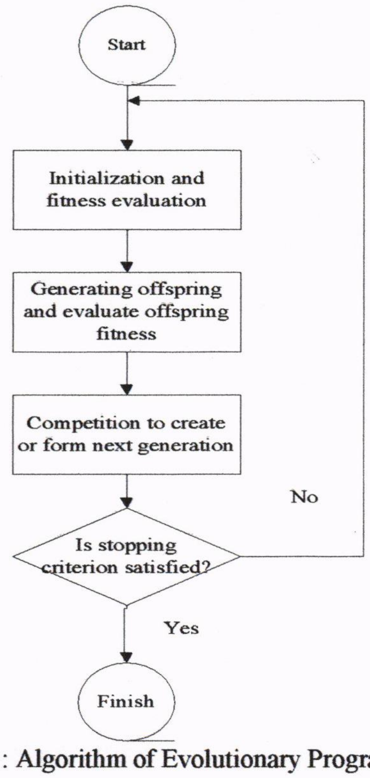

Figure 1: Algorithm of Evolutionary Programming (EP)

C. Artificial Immune System (AIS)

The natural immune system is an intricate biological system which resolute with the resistance of body against any harmful foreign entities. The main objective of immune system is to recognize all cells and molecules within the body and categorized it under self or non self [10]. When antigen or bacteria invades the human body only few of the immune system cells can recognize the invader peptides. The recognition with stimulate proliferation and differentiation of cells in producing matching clones or also known's as antibody[10]. This process will generate a large amount of antibody cells that specified for the antigen.

The process known as clonal expansion [10]. The clonal expansion of immune system will attribute in destroying and neutralizing the antigen cells and also retains some of these cells in immunological memory, so that any subsequent exposure will lead to rapid immune response (second response)[10]. These biolological principical are mimicked and incoporated into algorithm known as Artificial Immune System (AIS). AIS develop base on three major immunological principle which is hypermutation, receptor edition and cellular memory.

D. Artificial Immune Evolutionary Progamming (AIEP)

Artificial Immune Evolutionary Pragamming is an adaptive optimization technique whereby its search methodolgy base on clonal selection model of immune system.

The alogrithm of this technique it works on set of candidate solution which called as population, cloning process, mutate, runs through computational iteration and provide an optimal solution.

E. Wind Power

Wind power is one of the renewable energy available nowdays. The basic mechanism of wind power by converting kinetic energy into electrical energy [4]. It provides a clean electricity and emission free. Nevertheless, the use of wind power in Malaysia electricity is not yet uncovers and monopolized. The depletion and fluctuate prize of coal and gas give a chance to wind power generation to compete in electricity business. Given with proper care in design, deployment, operation and maintenance, wind power can compete with gas and coal power plant

In the UC problem, determination of generator sequence is important because it can affect the total operation cost. The wind power electrical generation does not have an operational because the source is free. Therefore, the use of renewable energy is applicable in order to minimize the operation or production cost of the system

II. Unit Commitment Problem Formulation

The objective or purpose of solving UC problem is to minimize the cost production and determine the power scheduling in order to meet the specific demand at the specific time with satisfying set of operational constrain. Mainly the costs involving with UC problem are the cost generating power and the other is start up cost. Therefore standard UC problem formulation is to minimize these costs. Constrains are including power balance and generation limit constrain. The objective function of UC can be written in terms of N generating units and T hours:

$$\text{Min F } (P_i^t, U_i^t) = \sum_{t=1}^{T}\sum_{i=1}^{N}[Fi(P_i^t) + ST_i^t(1 - U_i^{t-1})].U_i^t \quad (1)$$

With subjecting to constrain:

1. Power balance constrain

$$P_{load}^t - \sum_{i=0}^{n} P_i^t - \mathrm{U}_\mathrm{i}^\mathrm{t} = 0 \quad (2)$$

   Total power generated by the generator at one time must be same as the demand which been varied from time to time

2. Spinning Reserves constrain

$$P_{load}^t + R^t - \sum_{i=1}^{N} P_i^{max} U_i^t \leq 0 \quad (3)$$

   Additional power to support for any unit loss to prevent a far drop in system frequency in case of unexpected outage or sudden increase in demand.

3. Generation limits constrain

$$P_i^{min} \leq P_i^t \leq P_i^{max} \quad (4)$$

   Power generated by the generator must be in the range of minimum and maximum output limit, power produced must not exceed or below the limit.

Where,

$F_i(p)$ is cost of producing p units of power by unit i

ST_i is startup cost

P_{load}^t is load at time t(demand)

R^t is power reserve at time t (unit failure case)

P_i^t is amount of power produce by unit I at time t

U_i^t is control variable of unit I at time t
t =1, 2,3,….N and i= 1,2,3,….N

III. Test System Data

A. 10 unit generators test system

The data used is a set of 10 generators with 24 hours operating time obtained from IEEE in order to solve UC problem.

TABLE 1
FORECASTED DEMAND AND RESERVE FOR 10 UNIT 24- PERIOD SYSTEM

Hour	Forecasted Demand (MW)	Forecasted Reserve (MW)
1	700	70
2	750	75
3	850	85
4	950	95
5	1000	100
6	1100	110
7	1150	115
8	1200	120
9	1300	130
10	1400	140
11	1450	145
12	1500	150
13	1400	140
14	1300	130
15	1200	120
16	1050	105
17	1000	100
18	1100	110
19	1200	120
20	1400	140
21	1300	130
22	1100	110
23	900	90
24	800	80

TABLE 2
UNIT DATA (10 UNITS' 24-HOURS PERIOD SYSTEM)

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Pmax (MW)	455	455	130	130	162
Pmin (MW)	150	150	20	20	25
a ($/MW^{2}h)	1000	970	700	680	450
b ($/MW^{2}h)	16.19	17.26	16.60	16.50	19.70
c ($/h)	0.00048	0.00031	0.00200	0.00211	0.00398
ST	4500	5000	550	560	900

	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
Pmax (MW)	80	85	55	55	55
Pmin (MW)	20	25	10	10	10
a ($/MW^{2}h)	370	480	660	665	670
b ($/MW^{2}h)	22.26	27.74	25.92	27.27	27.79
c ($/h)	0.00172	0.00079	0.00143	0.00222	0.00173
ST	170	260	30	30	30

B. 1 Unit Wind Power Generator

For the purpose of this research, one unit wind power generator was added and the effect of wind power to the UC problem was reviewed. The data of the generator is accumulated from the National Renewable Energy Laboratory (NREL) Colorado, U.S.[15]

TABLE 3
WIND POWER GENERATOR FOR 24 HOURS OPERATION

Hours	Power (MW)	Hours	Power (MW)
1	62	13	35
2	35	14	42
3	28	15	42
4	16	16	65
5	38	17	42
6	25	18	28
7	35	19	52
8	28	20	78
9	56	21	84
10	48	22	82
11	36	23	84
12	52	24	72

IV. METHODOLOGY

Figure above shows the complete cycle of AIEP optimization technique. The process involves with initialization, cloning, cost calculation, mutation, sorting and combine and lastly the convergences test.

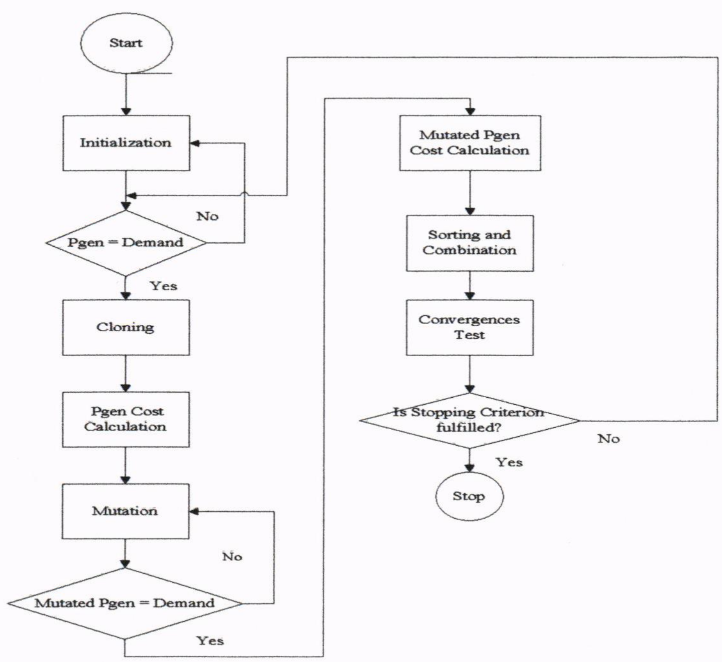

Figure 2: Flowchart of AIEP

A. Initialization Process

In order to solve the UC problem, the initialization process must be executed whereby determining the on and off scheduling for the 10 generators system and determine the total cost. The determination of on and off scheduling is done by randomly.

B. Cloning Process

The value of generated power,Pgen of each population have been evaluated. Cloning the Pgen in the population will give a rise to temporary population of clones.

C. Cost Calculation Process

The total cost is equivalent to the cost of generating power plus with the startup cost of generator. The power produced must be same as demand and at the same time full filling the generation limits constrain of the generators as stated above

D. Mutation Process

Mutation is a process of generate offspring value from the clone Pgen, whereby the value produce in the mutation process must not be the same as cloned Pgen. The value mutated Pgen must also same as demand and does not violate the generation limits constrain of the generators.

E. Sorting and Combine Process

The total cost obtained from the cloning process and mutation process will be combine and sort accordingly. It can be done by in cascade or cascode form. The sorting process can be done with sorting out from the minimum value to maximum value or from maximum value to minimum value depending on the optimization objective.

F. Convergences Test

The test itself determines the stopping criterion and the accuracy of this test can be determine by the user. If the stopping citerion is fullfilled under some condition, the search will be stop.

V. Result and Discussion

In order to determine the efficiency of the technique in solving UC problem, two subjected factor was introduced which is the number of population need to be use and the number of trial need to be run. Thus, those factors are classified into cases which are case 1 and case 2.

A. Case 1: Trial Analysis

The objective of trial analysis is to determine the best number of trial for the program to converge. The analysis was done on one population which population 6 (Pop 6) while varying the trial from 1 to 10. The trial was run using the AIEP optimization technique only.

TABLE 4
TOTAL OPERATIONAL COST FOR 10 UNITS TEST SYSTEM USING AIEP ONLY FOR 6 POPULATIONS

		Cost($)			
Trial	Pop	Worst	Average	Best	Time(h)
1		63689	63457	63276	3.6
5		63084	63057	63034	5.7
10	6	63201	62986	62895	17.8

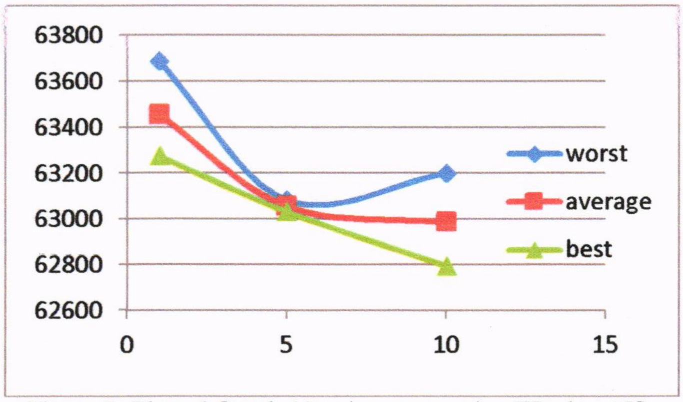

Figure 3: Plotted Graph 10 unit system using EP plus AIS with different trial

The result is plotted into a graph as shown as Figure 3. Base from the observing, convergences occur at trial no 5. Thus, number of trial equal to 5 is chosen for the next experiment or analysis.

B. Case 2: Population Analysis

The population analysis is to determine the suitable population in generating the minimum cost. Base on the theory, increasing value of population will resulting a better cost. Therefore, the analysis is begin with 3 types of population which are 6, 8 and 12. These populations is chosen because of cloning process in the program, whereby the total population used will multiply by 2 and creating a new population. For example, population 6 will create 12 populations in the end of the program.

TABLE 5
TOTAL OPERATIONAL COST FOR 10 UNITS TEST SYSTEM USING AIEP

Trial	Pop	Cost($) Worst	Average	Best	Time (h)
	6	63084	63057	63034	5.6
	8	63547	63353	62986	7.4
5	12	64036	63858	62985	13.1

TABLE 6
TOTAL OPERATIONAL COST FOR 10 UNIT SYSTEM WITH USING AIEP WITH WIND POWER.

Trial	Pop	Cost($)			Time (h)
		Worst	Average	Best	
	6	60078	60056	58931	7.6
	8	60192	60027	59707	12.4
5	12	59748	59657	59415	20.6

Base from Table 5 and 6, it shows the total cost of generating power with the minimum number of trial and varying numbers of population. The total cost is categorized into 3 parts which is worst, average and best. The worst cost produces a high operational whereby the best cost provide a minimum operational cost for the system.

C. Best power generation using AIEP optimization technique

Sample of best power generation and total operation cost can be seen in Table 7 and 8. Both of the tables indicate power scheduling for 24 hours period of generation. Number '1' in those table represent generators that are working and still on operating condition. Meanwhile, number '0' represent the generators in idle form which does not in working or generating condition. Base from the observation of both tables, the most and available generator is unit 1 and 2 whereby the generators have a wide generation limit and its working as base unit.

In Table 7, 10 unit thermal generator working in order to fulfill the total load demand by hour. The generation power varies from one unit of generator from the other in order to get an optimal solution

Meanwhile in Table 8, 9 unit thermal generator and 1 unit wind power working. The selection of thermal generators working is by how much is the cost production. If the cost of production is very high, it is recommended for shut down. Therefore, unit 10 is selected for shut down purpose.

D. Comparison of cost between population size and between case

TABLE 9
COST DECREMENT BETWEEN EP PLUS AIS AND EP PLUS AIS WITH WIND

Pop	Case	Cost($)		
		worst	average	best
	AIEP only	63234	63157	63034
	AIEP+ wind	60078	60056	58931
6	reduction(%)	4.9	4.9	6.5
	AIEP only	63547	63353	62986
	AIEP+ wind	60192	60027	59707
8	reduction(%)	5.2	5.2	5.2
	AIEP only	64036	63858	62895
	AIEP+ wind	59748	59657	59415
12	reduction(%)	6.6	6.5	5.5

TABLE 10
AVERAGE REDUCTION OF COST BASE ON NO OF POPULATION

No of population	Average reduction (%)
6	5.4
8	5.2
12	6.2

The total cost in every population shows a slight decrement which resulting a lower and minimal cost compared with the initial cost. From the observation, by increasing the population will resulting a high decrement value in the total cost, whereby population 12 give an average reduction of total operating cost by 6.2 percent.

Base on the finding that can be obtain from the result, the implement of wind power can reduce the total cost of generating power, wind power does not have operational cost but can provide electrical power.

VI. CONCLUSION AND RECOMMENDATION

This paper present Artificial Immune Evolutionary Programming (AIEP) to solve Unit Commitment with Wind Power

The purpose of this paper to minimize the operational cost in producing electric power and to see the effect of wind power in UC problem and operational cost. The technique was developed and tested into 10 units generators test system and 1 unit wind power generator. The result of the technique shows that the operational cost has been reduced. Hence, the using renewable energy into the power system is highly recommended

For future development, AIEP will be combine with other optimization technique such as Particle Swarm and Ant colony. Furthermore, the usage of different kind or combination of renewable energy like solar power and ocean wave into the system will be encouraged.

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TABLE 7:
UC SCHEDULING USING AIEP WITHOUT WIND POWER. POPULATION = 12.TRIAL=5. TOTAL COST =62895$

Unit	Power (MW)																							
	Hour																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	264	268	333	215	445	440	397	410	449	442	447	445	419	431	394	386	343	341	435	447	444	447	232	308
2	287	317	354	351	452	387	412	422	419	430	450	438	443	433	420	333	262	378	396	433	444	316	403	322
3	20	77	0	128	29	98	0	95	96	129	78	128	102	34	52	46	25	0	80	122	94	37	0	0
4	20	0	123	113	0	0	41	99	61	123	93	86	118	94	0	50	114	61	128	103	68	118	83	44
5	0	0	40	46	36	90	161	88	155	136	137	133	106	102	160	108	112	162	0	104	112	0	0	38
6	26	0	0	0	0	65	0	0	0	0	63	78	76	66	79	54	21	47	51	55	55	53	53	21
7	37	59	0	0	0	0	0	0	73	51	27	60	49	78	0	0	75	38	64	59	0	71	61	48
8	19	0	0	21	38	20	51	47	13	31	52	43	27	10	0	40	26	30	0	27	32	18	0	0
9	27	0	0	28	0	0	51	0	24	12	50	54	36	17	54	22	22	43	28	34	0	0	36	0
10	0	29	0	48	0	0	37	39	10	46	53	35	24	35	41	11	0	0	18	16	51	40	32	19
Total Pgen	700	750	850	850	950	1100	1150	1200	1300	1400	1450	1500	1400	1300	1200	1050	1000	1100	1200	1400	1300	1100	900	800

TABLE 8:
UC SCHEDULING USING AIEP WITH WIND POWER. POPULATION = 12. TRIAL = 5.TOTAL COST =59415$

Unit	Power (MW)																							
	Hour																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	216	290	262	433	382	393	340	363	386	452	455	436	443	386	450	302	299	326	426	440	409	452	447	333
2	303	225	411	441	407	244	401	443	428	432	436	417	428	436	233	296	362	424	414	434	339	426	174	354
3	0	0	0	0	0	107	0	130	123	45	62	113	75	102	84	21	63	35	100	75	127	70	0	0
4	0	64	37	51	59	29	128	63	111	74	119	118	128	82	94	118	108	57	0	92	84	0	120	24
5	103	109	0	0	0	126	97	0	57	130	130	120	114	72	127	100	110	45	74	157	147	34	0	0
6	0	0	0	0	62	44	75	79	42	77	47	75	71	72	51	27	20	38	55	20	0	0	0	24
7	0	30	80	0	0	85	50	0	74	73	76	82	69	31	66	53	0	61	84	69	38	44	36	0
8	22	0	0	0	23	0	0	44	0	39	52	37	29	54	47	37	0	44	0	0	48	0	21	0
9	0	0	35	11	33	49	27	53	29	35	41	55	11	27	10	37	0	45	0	43	32	0	26	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(wind)	62	35	28	16	38	25	35	28	56	48	36	52	35	42	42	65	42	28	52	78	84	82	84	72
Total Pgen	700	750	850	950	1000	1100	1150	1200	1300	1400	1450	1500	1400	1300	1200	1050	1000	1100	1200	1400	1300	1100	900	800

VIII. REFERENCES

[1] M. Bavafa, H. Monsef, and N. Navidi, "A New Hybrid Approach for Unit Commitment Using Lagrangian Relaxation Combined with Evolutionary and Quadratic Programming," in *Power and Energy Engineering Conference, 2009. APPEEC 2009. Asia-Pacific*, 2009, pp. 1-6.

[2] W. Chengjian, Y. Susu, and H. Zhenya, "A modified evolutionary programming," in *Evolutionary Computation, 1996., Proceedings of IEEE International Conference on*, 1996, pp. 135-138.

[3] E. J. Contreras-Hernandez and J. R. Cedeno-Maldonado, "A Sequential Evolutionary Programming Approach to Profit-Based Unit Commitment," in *Transmission & Distribution Conference and Exposition: Latin America, 2006. TDC '06. IEEE/PES*, 2006, pp. 1-8.

[4] T. Dang, "Introduction, history, and theory of wind power," in *North American Power Symposium (NAPS), 2009*, 2009, pp. 1-6.

[5] M. Elhadef, S. Das, and A. Nayak, "A novel artificial-immune-based approach for system-level fault diagnosis," in *Availability, Reliability and Security, 2006. ARES 2006. The First International Conference on*, 2006, p. 8 pp.

[6] D. B. Fogel, L. J. Fogel, and J. W. Atmar, "Meta-evolutionary programming," in *Signals, Systems and Computers, 1991. 1991 Conference Record of the Twenty-Fifth Asilomar Conference on*, 1991, pp. 540-545 vol.1.

[7] W. Gao, "Study on genetic algorithm and evolutionary programming," in *Parallel Distributed and Grid Computing (PDGC), 2012 2nd IEEE International Conference on*, 2012, pp. 762-766.

[8] L. Gwo-Ching and T. Ta-Peng, "Hybrid immune genetic algorithm approach for short-term unit commitment problem," in *Power Engineering Society General Meeting, 2004. IEEE*, 2004, pp. 1075-1081 Vol.1.

[9] W. Jianhui, M. Shahidehpour, and L. Zuyi, "Security-constrained unit commitment with volatile wind power generation," in *Power & Energy Society General Meeting, 2009. PES '09. IEEE*, 2009, pp. 1-1.

[10] K. Lakshmi, S. Vasantharathna, and C. Muniraj, "Clonal Selection based Artificial Immune System to solve the Unit Commitment Problem in restructured electricity sectors," in *Power and Energy (PECon), 2010 IEEE International Conference on*, 2010, pp. 259-263.

[11] P. J. Luickx, E. D. Delarue, and W. D. D'Haeseleer, "Effect of the generation mix on wind power introduction," *Renewable Power Generation, IET,* vol. 3, pp. 267-278, 2009.

[12] M. Moghimi Hadji and B. Vahidi, "A Solution to the Unit Commitment Problem Using Imperialistic Competition Algorithm," *Power Systems, IEEE Transactions on,* vol. 27, pp. 117-124, 2012.

[13] C. C. A. Rajan and M. R. Mohan, "An evolutionary programming method for solving the unit commitment problem," in *Power Engineering Society General Meeting, 2004. IEEE*, 2004, p. 1149 Vol.1.

[14] R. L. R. Singh and C. C. A. Rajan, "A hybrid approach based on PSO and EP for proficient solving of Unit Commitment Problem," in *Utility Exhibition on Power and Energy Systems: Issues & Prospects for Asia (ICUE), 2011 International Conference and*, 2011, pp. 1-7.

[15] Y.-H. Wan, "Wind Power Behavior:Analyses of Long-Term Wind Power Data," september 2004.

[16] W. Zhen-dong, C. Hao-zhong, Y. Liang-zhong, and M. Bazargan, "Research on unit commitment considering wind power accommodation," in *Power and Energy Society General Meeting, 2012 IEEE*, 2012, pp. 1-7.