A NOVEL METAHEURISTIC APPROACH TO SOLVE UNIT COMMITMENT PROBLEM IN THE PRESENCE OF WIND FARMS

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Key words: Metaheuristic, Unit commitment, Wind farm, Power system planning.

This paper solves unit commitment (UC) problem by a novel evolutionary algorithm based on tendency of a society to improve and promote quality of life in the presence thermal and wind units. The traditional objective function of UC problem has been modified by considering related parameters of wind farm. Main challenges in this stage are wind farm modeling and wind speed forecast which have been performed by reliable techniques. The aerology data of Tabriz metropolis in north west of Iran in 10 past years has been employed to obtain output power of wind farm. Simulations have been performed in 10, 20, 40 and 60-unit test system and results of the proposed technique compared with two other approaches. Other highlight of our work is presenting five novel indices to analyze the obtained results of simulations.

1. INTRODUCTION

The utilization of wind energy generation is increasing throughout the world and it is therefore important that these facilities be integrated in the existing generating capacity planning and operating protocols and procedures [1]. Day-ahead unit commitment (UC) solution methods seek to determine the status and output of all available generators. In a world with an increasing integration of renewable energy sources such as wind electric generators, the UC solution process must model and include wind energy generations too in the decision-making process [2].

By considering objective of our work, past lectures of UC problem have been classified based on solving UC problem in the presence of wind farm. For this, four categories are introduced; *i.e.* solving UC by considering uncertainty [3–6], economic dispatch [7–9], risk analysis [1, 2] and security-constrained [10, 11].

Main goal of Ref.[3] is to provide rapid (every 5 min.) look-ahead (up to 5 to 8 hours ahead) assessment of the resulting uncertainty ranges for the balancing

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Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **60**, *3,* p. 253–262, Bucarest, 2015

effort in terms of the required capacity, ramping capability, and ramp duration. Constantinescu *et al.* have proposed a computational `framework for integrating a state-of-the-art numerical weather prediction model in stochastic unit commitment/economic dispatch formulations that account for wind power uncertainty [4]. Authors in [5], have presented artificial neural network based a short term wind power forecaster into UC problem. In [6] the uncertain wind power output has been formulated as a chance-constrained two-stage stochastic program to guarantee the minimum usage of the wind power.

Authors in [7], a discrete neuron model and a continuous neuron model have been used to combine the UC and ED and solve this problem as simultaneous by hopfield neural network. In [8], a time series of observed and predicted 15-min average wind speeds at foreseen onshore- and offshore-wind farm locations have been used to assess the impacts of large-scale wind power on system operations from cost, reliability, and environmental perspectives. Tuohy *et al.* in [9], the stochastic optimization have suggested to analyze the effects of stochastic wind and load on the unit commitment and dispatch by comparing the costs, planned operation and performance of the schedules produced.

In [1], a double strategies technique has been suggested to minimize costs and handle risks introduced due to wind farm in UC and solved by a mixed integer linear programming (MILP). Ref. [2] develops the basic concepts of unit commitment risk analysis to include the inherent variability associated with wind power by developing short-term probability distributions of the wind speed and wind power output using auto-regressive moving average time series models.

In [10], a security-constrained UC (SCUC) algorithm has been proposed by considering initial dispatch and intermittency and volatility of wind in the subproblem. Authors of Ref.[11] have integrated an energy storage system and wind generation for SCUC and compressed air energy storage considered as an alternative solution to store energy.

In the presented paper, the UC problem has been solved by a novel algorithm by considering wind farm. This paper has been organized in seven sections. The UC problem in the presence and absence of wind farm has been formulated in Section 2. Basis of society progress (SP) algorithm and solving the UC problem by the SP algorithm have been presented in 3^{th} and 4^{th} sections, respectively. Simulation results and discussion about these are visible in Sections 5 and 6, respectively. This work has been concluded in Section 7.

2. FORMULATION

2.1. TRADITIONAL UC PROBLEM

Main goal in UC process is minimizing total cost. Objective function of UC problem consists of three terms: operation cost, *OC*, start up cost, *SuC*, and shut down cost, *SdC* (Eq.(1)),

$$OF = \text{Min}\sum_{i=1}^{NG}\sum_{t=1}^{NT}\{OC + SuC + SdC\}, \tag{1}$$

where NG and NT are the number of generating units and time periods under study (24 hours), respectively. Operation cost (OC) is the most important part of UC problem. The OC is comprised of two parts, the thermal unit costs which is indicated as OC_t in equation (2) and OC_w which will be discussed later on. This term is function of production cost, PC, maintenance cost, MC, and emission cost, EC. This is zero if the unit isn't involved in the production,

$$OC_T = \begin{cases} PC + MC + EC & \text{if production} = 1 \\ 0 & \text{if production} = 0 \end{cases}, \tag{2}$$

where PC_{ci} is defined as a quadratic function which has been illustrated using a curve

$$PC_{ci} = \alpha_i + \beta_i P_{it} + \gamma_i P_{it}^2, \tag{3}$$

where α_i, β_i and γ_i are cost factors. P_{it} is output of unit i at instant t. MC has two terms: first term is constant maintenance cost of unit i at instant t, CM_{it}, and second term is incremental maintenance cost, IM_i

$$MC_{ci} = CM_{it} + IM_{it} \times P_{it}. \tag{4}$$

Behavior of EC is expressed similar to PC,

$$EC_{ci} = \omega_i + \lambda_i P_{it} + \mu_i P_{it}^2, \tag{5}$$

where ω_i, λ_i and μ_i are emission factors. To start up thermal units, some fuel should be consumed which do not product any effective power, cost due to this energy is called Start up Cost (SuC). In this section, a step by step technique used by transition hour, h_i^{off}, (transition from OFF to ON) from hot to cold startup to describe time dependent SuC.

$$SuC_{it} = \begin{cases} H_{\text{cost}_{it}}; & T_i^{off} \le Z_i^{off} \le h_i^{off} \\ C_{\text{cost}_{it}}; & Z_i^{off} > h_i^{off} \end{cases}, \tag{6}$$

where the first and second scenarios are hot and cold startups of unit i at time t, respectively. T_i^{off} is the minimum stop time of unit i and Z_i^{off} is the time duration in stop of unit i at time t. Eqs. (7) defines transition hour and cold startup cost,

$$h_i^{off} = T_i^{off} + \left(c - \text{Cost} - \text{hour}_i\right), \tag{7}$$

where second term is duration of cold startup of unit i.

$$C_{Cost_{it}} = I\left(1 - I_{(t-1)}\right)\left[\delta_i + \Omega_i\left(1 - \exp\frac{-Z_{it}^{off}}{t_i}\right) + \theta_i\right], \tag{8}$$

where δ_i and Ω_i are constant values (consist of costs of crew and maintenance in startup) and boiler startup costs, respectively. θ_i and *it* are farm startup cost and thermal time constant of unit *i*. I_{it} determines partnership status of unit *i* at time *t*; if unit state is ON, I_{it}=1; if not I_{it}=0. Finally, hot startup cost is obtained by Eq. (9),

$$H_{Cost_{it}} = \delta_i + (C_{ti} \times f_{ci}) Z_{it}^{off}, \tag{9}$$

where $C_{hi}=C_{ti}f_{ci}$. C_{ti} and f_{ci} are hot startup cost at each hour and fuel cost, respectively. This cost for each unit is a constant value which, in standard systems, is equal to zero. This cost is calculated using Eq (10),

$$SdD_{it} = K_i P_{it} \left(1 - I_{it}\right) I_{i(t-1)}, \tag{10}$$

where K_i is shut down incremental cost.

2.2. WIND FARM COST

The presence of wind farm applies fix, *FC*, and varying, *VC*, costs on network. The fix cost has been determined based on NET cost while varying cost is function of output power of wind farm,

$$OC_W = \text{Min}\{FC + VC\}, \tag{11}$$

where OC_w is wind farm cost. The used wind power plant output power calculation technique is same proposed method in [12].

3. SOCIETY PROGRESS (SP) ALGORITHM

The proposed society progress algorithm could be classified as a revolutionary algorithm. This algorithm produces the primary population randomly and then by applying three operators it reaches the optimal solution. These operators are designed and formulated based on tendency of each individual to upper his position in society.

Therefore the SP algorithm could be defined by five following steps:

Step 1. Generating initial population ($R^G_{i,j}$): In this step, the two dimension initial population is generated as follows:

$$R_{i,j}^G = \text{rand}_i \times \left(b_{\max} - b_{\min}\right) + b_{\min}, \quad i \in [1,\ P], \quad j \in [1,\ V], \tag{12}$$

where *P* and *V* are the number of population and variable, respectively. Search space within initial population is limited by upper and lower bound value; i.e. *bmax* and *bmin*, respectively. rand_1 is a uniformly random value in range of [0,1].

Step 2. Selection: The best generation (R_{best}) is selected based on best fitness value. The following operators have been applied on the vector.

Step 3. Mutation: In this step, the selected vector is mutated by considering the special talents among the population. Main goal is mutation based on the best generation; for this, the selected vector (R_{best}) has been used in first iteration. Mutation rate (MR) is applied to the operator to restrict range of the mutated generation.

$$R_i^{G+1} = \begin{cases} R_i^G & \text{itr} = 1 \\ R_i^G + MR \times \text{rand}_3 \times \text{Min}\left\{R_i^G, \left[1 - R_i^G\right]\right\} & \text{if} \quad \text{itr} > 1 \end{cases}, \tag{13}$$

where itr and rand_2 are the number of iteration and a random value between [0,1], respectively.

Step 4. Migration: The migration operator has been used to trend to the best solution and escape from local optimum point,

$$R_i^{G+1} = R_i^G + (1 - MR) \times \text{rand}_3 \times \left(R_{best} - R_i^G\right). \tag{14}$$

Step 5. Termination criteria: The iterative process terminates even when difference between solutions is smaller than a fixed threshold or quantity of iteration reaches its predefined number. Second criterion was used for termination of algorithm in this study. Fig. 1 shows Pseudocode of the SP algorithm.

```
Import values of population size, generation, variable number.
 while termination criteria is not satisfied  {
    for j=1 to NP; j++{
       generating initial population based on
       R_{i,j}^G = rand_1 × (b_max − b_min)
          for G=1 to generation{
             selecting the best vector from population
             if itr=1
             R_i^{G+1} = R_i^G
             else
             R_i^{G+1} = R_i^G + MR×rand_3 ×Min{R_i^G, [1 − R_i^G]} }%End of mutation operator
              %start migration operator
              Eq.(14)} % End for migration operator
              }    %End while
```

Fig. 1 – Pseudocode of the SP algorithm.

4. SOLVING UNIT COMMITMENT PROBLEM BY SOCIETY PROGRESS ALGORITHM

In this paper, the SP algorithm has been suggested to solve UC problem. This work is carried out in nine steps.

Step *i*. The required data to run SP algorithm are defined, these data are number of iteration, number of population, mutation.

Step *ii*. The system data are applied, these data are minimum and maximum powers emission factors, up and down times and costs of cold start and hot start (for thermal units) and low and high cut speeds, nominal and existing speeds, nominal output power, emission factors, OMVCW and OMFCW stand for operation maintenance variable cost wind and operation maintenance fixed cost wind, respectively.

Step *iii*. The SP algorithm is initialized to generate initial population, randomly.

Step *iv*. The objective function and theirs constrains are analyzed.

Step *v*. The minimum average production cost is computed of all units and economic dispatch carried out based generated and consumed powers.

Step *vi*. Determining how many units can be started up based on minimum downtime.

Step *vii*. The last units are selected for stopping from the priority list.

Step *viii*. If the maximum number of hours is reached, a new vector improvised; otherwise a unit is increased to the number of hour and process repeated from Step v.

Step *ix*. If the maximum iteration number is reached, a unit is increased to the number of iteration and process repeated from Step iv.

5. CASE STUDIED

Simulation has been carried out in two scenarios; without and with wind farm. The 10, 20, 40 and 60 generating units have been employed as test systems. For the system with 20 generating units, the data of the 10 generating unit system was duplicated and the load data was multiplied by 2. For problems with more than 20 generating units, the problem data were scaled appropriately [14]. In SP algorithm, Mutation rate and the numbers of population and iteration are 0.2,12 and 500, respectively. Simulations have been carried out by SONY VAIO Corei5, 2.3 GHz.

5.1. WITHOUT WIND FARM

Table 1 presents comparison of costs of proposed method with integer coded genetic algorithm (ICGA) and lagrangian relaxation (LR) techniques [15–16]. All values of Table 1 is in $.

Table 1

Comparison of cost of different methods in the absence of wind farm

Case	Units	Methodes			Case	Units	Methodes		
		LR	ICGA	SP			LR	ICGA	SP
1	10	565825	566404	565768	2	20	1130660	1127244	1122986
3	40	2258503	2254123	2243968	4	60	3394066	3378108	3375081

By focusing on values of Table 1, the propsed algorithm presents better solution respect to other techniques.

5.2. WITH WIND FARM

In this subsection, the UC problem has been solved in the presence of wind farm. Fig. 2 shows aerology data of Tabriz metropolis in the 10 past years which this data has been employed to obtain output power of wind farms. Where *y* stand for year.

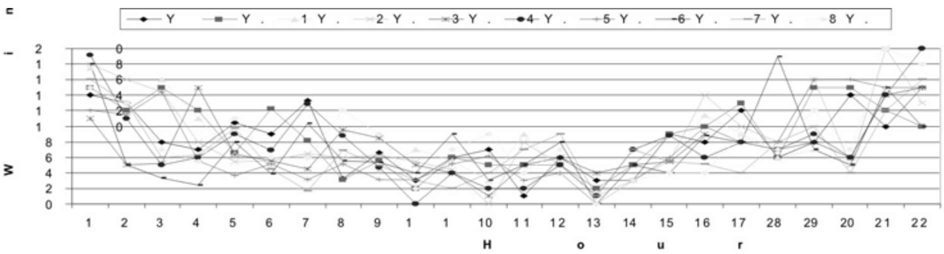


Fig. 2 – Changes of wind speed in the ten past years (m/s) in Tabriz metropolis.

By considering the data and placing to Eq.(14) the nominal values and constant coefficients of wind farm obtains as listed in Table 2. where, OMVCW and OMFCW are operation maintenance variable cost wind and operation maintenance fixed cost wind in \$/MW, respectively. Also *V's* and P_r are in m/s and M*W*, respectively. By applying data of wind farm in UC problem, the results of Table 3 obtain which in this Table, *U* and *W* have been illustrated unit and wind farm, respectively.

Table 2

Nominal values and constant coefficients of wind farm

V_o	V_{ci}	V_r	P_r	*a*	*b*	*c*	OMVCW	OMFCW
25	2.5	14	32	0.0952	–0.0604	0.0089	6.193	0

Table 3

Results of simulation on 10-unit by SP algorithm in the presence of wind farm (in MW)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
U.1	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455
U.2	230	275	350	450	370	455	394	455	455	455	455	455	455	455	455	310	260	360	455	455	455	455	455	335
U.3	0	0	0	0	0	130	123	130	130	130	130	130	130	130	130	130	130	130	130	130	130	0	0	0
U.4	0	0	0	0	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	0	0
U.5	0	0	25	25	25	44	25	25	78	162	162	162	162	100	30	25	25	25	30	162	75	0	0	0
U.6	0	0	0	0	0	0	0	0	20	30	71	80	23	20	0	0	0	0	0	20	25	20	0	0
U.7	0	0	0	0	0	0	0	0	25	25	25	25	25	0	0	0	0	0	0	25	25	25	0	0
U.8	0	0	0	0	0	0	0	0	0	10	10	43	10	10	0	0	0	0	0	10	10	10	10	10
U.9	0	0	0	0	0	0	0	0	0	0	10	10	0	0	0	0	0	0	0	0	0	0	0	0
U.10	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0
W	15	20	20	20	20	16	16	12	7	3	2	1	1	0.2	0.3	4	8	9	15	20	20	20	20	20

6. DISCUSSION AND ANALYSIS

6.1. RATIO OF THE COST SYSTEM WITH/WITHOUT STARTUP COST

Main objective of this index is studying impact of wind farm on system costs by with/without startup cost in four test system; *i.e*. 10, 20, 40 and 60. Table 4 shows the results of this index.

Table 4

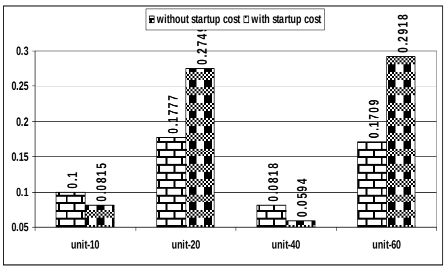
Comparison of costs ($) system with/without wind farm

unit	Without wind farm		With wind farm	
	without startup	with startup cost	without startup cost	with startup cost
10	559887	565768	559327	565307
20	1115566	1122986	1113587	1119907
40	2236489	2243968	2234661	2242635
60	3363921	3375081	3358181	3365261

By focusing values of Table 4, it is clear that system cost increase by considering startup cost, this increment in without wind farm is 1.05, 0.6651, 0.3344 and 0.3318 % for 10 to 60 units, respectively, in with wind farm is 1.0691,0.5675,0.3568 and 0.2108 % for 10 to 60 units, respectively. Fig.3a has been presented ratio of startup cost of with wind farm to without wind farm in percentage.

6.2. RESPECT OF GENERATED POWER BY EACH UNIT

One contribution of the presence of wind farm in power system helps to traditional power plant to generate consumed power. Figure 3b illustrates respect of generated power of traditional units in with wind farm to without wind farm. By focusing Fig. 3b, in more cases the generated power by traditional units of with wind farm is less than related value of without wind farm. The generated power of the first unit is constant in the presence and absence of wind farm. Maximum reduction has been happen in 9th unit of 60 unit system and 3rd unit of 40 unit system.



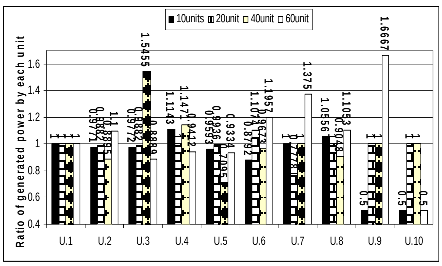


Fig. 3 – Values of first and second indices: a.) respect of generated power by each unit; b.) respect of generated power by each unit.

6.3. PERCENTAGE OF GENERATED POWER BY EACH UNIT

The presence of wind farm helps to the generated power by traditional units. This concept has been highlighted by percentage of generated power by each unit index. The results of this index have been listed in Table 5.

Table 5

Percentage of generated power by each unit

	case	U.1	U.2	U.3	U.4	U.5	U.6	U.7	U.8	U.9	U.10	W
10	Without	40.2952	35.7189	7.6753	8.1550	14.8155	1.2240	0.8303	0.3063	0.0738	0.0369	0
	With	40.2952	35.6626	7.1707	8.6347	5.7836	1.2987	0.7380	0.4908	0.0738	0.0369	1.1076
20	Without	40.2952	38.1550	6.7159	8.6347	6.6642	1.3247	0.8303	0.3506	0.0738	0.0369	0
	With	40.2952	37.7031	6.7159	8.5793	5.9788	1.4670	0.6458	0.3506	0.0738	0.0369	0.9933
40	Without	40.2952	39.6371	5.2768	8.1550	7.7352	1.5461	0.7380	0.3875	0.1476	0.0369	0
	With	40.2952	35.2583	8.1550	9.3542	5.4881	1.4955	0.7380	0.3506	0.1476	0.0369	0.7509
60	Without	40.2952	33.5793	8.6347	8.1550	7.1480	1.6974	0.7380	0.3506	0.1107	0.0738	0
	With	40.2952	36.9373	7.6753	7.6753	6.6723	2.0295	1.0148	0.3875	0.1845	0.0369	0.9933

By considering results of Table 5, in more cases the generated power of traditional units reduce in the presence of wind farm respect to absence wind farm. Maximum percentage of the generated power by wind turbine in 20 unit system obtains.

6.4. ADAPTATION OF THE GENERATED POWER WITH SYSTEM LOAD

The consumed load by the system is 27100 MW while the generated power by generators is usually more than this value. The adaptation of the generated power with system load index is introduced to discuss about difference between the consumed load and generated power. In all systems, except 60-unit system, the presence of wind farm reduces difference between the generated and consumed powers.

7. CONCLUSION

In this paper, the SP has been suggested to solve UC problem by considering wind farm in power systems. For this, the traditional UC problem has been modified for the presence of wind farm. Other contribution of this work is proposing novel five indices to analyze and discuss the obtained results from simulations on four test systems; *i.e.* 10, 20, 40 and 60-unit systems. The data of wind speed in the ten past years (m/s) in Tabriz metropolis have been employed to obtain output power of wind farm. Priority of the proposed technique to solve UC problem has been confirmed by comparing its results with the related results of integer coded genetic algorithm and lagrangian relaxation techniques.

Received on February 14, 2014

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