The Dynamic Economic Dispatch including Wind Power Injection in the Western Algerian Electrical Power System

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Abstract: In this paper, we investigate the effect of the injection of wind farm energy in the western Algerian electrical power system on Dynamic Economic Dispatch (DED). DED is solved by Harmony Search algorithm (HS). HS is a newly-developed meta-heuristic algorithm that uses a stochastic random search. It is simple in concept, few in parameters and easy in implementation. The simulations are realized by considering first the western Algerian power system as it is (WA: 2003 data), then the western Algerian electrical power system with the injection of wind farm energy (Western Algerian power system + Wind energy WAW). The results are compared in production cost and harmful emissions (CO_2). After a theoretical introduction of the problem formulation and the harmony search algorithm, a description of the site and the wind farm is presented, followed by a discussion of the simulation results.

Keywords: optimization; harmony search; dynamic economic dispatch; wind power; CO_2 emission

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1 Introduction

The rise of environmental protection and the progressive exhaustion of traditional fossil energy sources have increased the interests in integrating renewable energy sources into existing power systems [1]. Wind power generation is becoming more and more popular while the large-scale wind farm is the mainstream one. It has the potential benefits of cutting the consumption of irreplaceable fuel reserves and reducing pollutants and harmful emissions as the demand for electricity has steadily rises due to industrial developments and economic growth in most parts of the world [2].

Economic dispatch is one of the most important optimization problems in power system operation and forms the basis of many application programs. The main objective of economic load dispatch of electric power generation is to schedule the committed generating unit outputs so as to meet the load demand at minimum operating cost while satisfying all unit and system constraints [3]. Because the output of wind power depends on the wind speed, which is related to climatological and micrometeorological parameters, wind behavior is quite distinct from conventional energy operation at their rated capacities [4].

In this paper we investigate the effect of introducing a wind power farm in to the western Algerian electrical power system. This can be expressed as a Dynamic Economic Dispatch (DED) problem solved with Harmony Search Algorithm [5].

2 Problem Formulation

2.1 Wind Farm Output Calculation

To simulate the wind farm as an equal wind turbine, all wind speeds and directions of wind turbines in one farm are assumed to be the same. The relationship between the wind turbine output P_W and the wind speed V_W can be expressed as a subsection function [4, 6, 7]:

$$P_W = \begin{cases} 0 & V_W < V_{CI} \\ \frac{1}{2} C_P .\rho.\pi.R_P^2.V_W^3 & V_{CI} \le V_W < V_R \\ P_R & V_R \le V_W < V_{CO} \\ 0 & V_W \ge V_{CO} \end{cases} \tag{1}$$

where C_P is the aerodynamic coefficient of turbine power, ρ is the air density (1,225 kg/m^3), R_P the turbine ray, V_{CI}, V_R and V_{CO} are respectively the cut-in, the rated and the cut-out wind speeds. P_R is the rated output of the wind turbine. The C_P coefficient cannot, theoretically, pass the limit of Betz (C_{p_limit}= 0.593) [8].

2.2 Economic Dispatch

In the practical cases, the total fuel cost may be represented as a polynomial function of real power generation [9]:

$$F(P_{Gi}^t) = \sum_{i=1}^{ng} (a_i \, {P_{Gi}^t}^2 + b_i \, P_{Gi}^t + c_i) \tag{2}$$

where F is the total fuel cost of the system at time t, P^t_{Gi} is real power output of the i-th unit at time t, ng is the number of generators including the slack bus, a_i, b_i and c_i are the cost coefficients of the i-th unit.

The daily total cost of active power generation may be expressed by:

$$G(P_{Gi}^t) = \sum_{t=1}^{24}\sum_{i=1}^{ng} F(P_{Gi}^t) \tag{3}$$

The Economic Dispatch Problem can be mathematically represented as:

Minimise $G(P_{Gi}^t)$ (4)

under constraints:

$$\sum_{i=1}^{ng} P_{Gi}^t + P_W^t - P_D^t - P_L^t = 0 \tag{5}$$

$$P_{Gi\min} \le P_{Gi}^t \le P_{Gi\max} \quad i = 1,..., ng \tag{6}$$

where P^t_L and P^t_D are the real power losses and the total demand at time *t*. P_{Gimin} and P_{Gimax} are the generation limit of the i-th unit.

The real power losses are a function of real power injection P^t_i and reactive power Q_i and voltage nodes [10, 11]. Their expression is given by:

$$P_L(P_{Gi}^t) = \sum_{\substack{i=1\\j=1}}^{n} [a_{ij}(P_i^t P_j^t + Q_i Q_j) + b_{ij}(Q_i P_j^t - P_i^t Q_j)] \tag{7}$$

where $a_{ij} = \frac{r_{ij}}{|V_i|.|V_j|}\cos(\theta_{ij})$, $b_{ij} = \frac{r_{ij}}{|V_i|.|V_j|}\sin(\theta_{ij})$,and r_{ij} are the real components of bus impedance matrix.

The voltage nodes V_i (in module $|V_i|$ and phase θ_i) and the reactive power injection are assumed constant. In this case, the power transmission losses can be expressed in terms of active power generations by assuming that the demand for power remains constant during dispatch period. This expression is given by:

$$P_L(P_{Gi}^t) = \sum_{\substack{i=1\\j=1}}^{n} a_{ij} P_{Gi}^t P_{Gj}^t - 2\sum_{\substack{i=1\\j=1}}^{n} (b_{ij} Q_j + a_{ij} P_{Di}^t) P_{Gi}^t + K^t \tag{8}$$

where

$$K^t = \sum_{\substack{i=1\\j=1}}^{n} [a_{ij}(P_{Di}^t P_{Dj}^t + Q_i Q_j) + b_{ij}(P_{Di}^t Q_j - Q_i P_{Dj}^t)]$$

3 The Harmony Search Algorithms

The HSA is inspired by the musical process of searching for a perfect state of harmony [5]. The optimization process, represented in Figure 1, is directed by four parameters:

1) Harmony Memory Size (HMS) is the number of solution vectors stored in Harmony Memory (HM).

2) Harmony Memory Considering Rate (HMCR) is the probability of choosing one value from HM and (1-HMCR) is the probability of randomly generating one new feasible value.

3) Pitch Adjusting Rate (PAR) is the probability of choosing a neighboring value of that chosen from HM.

4) Distance bandwidth (bw) defines the neighborhood of a value as [x^j ± bw*U(0,1)]. U(0,1) is a uniform distribution between 0 and 1.

Another intuitively important parameter is the Number of Iterations (NI) which is the stop criterion of many versions of HSA [12].

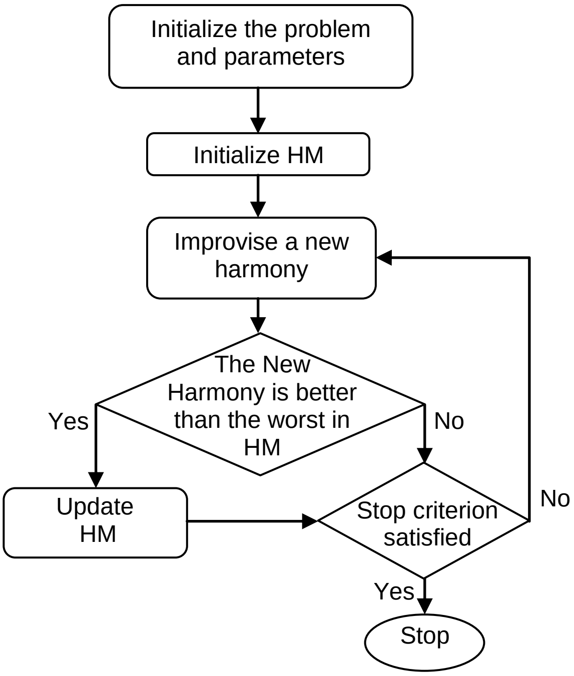

Figure 1

Optimization procedure of HSA

4 Application

4.1 Description of the Test System

The test system used in this paper is the western Algerian electrical power system 220 kV. The single-line diagram of this system is shown in Figure 2 and the detailed data are given in Reference [13]. The system is composed of 14 nodes with 3 power plants that are: power plant of "*Mersat El Hadjadj*" (node 1), power plant of "*Ravin Blanc*" (node 4) and power plant of "*Tiaret*" (node 3).

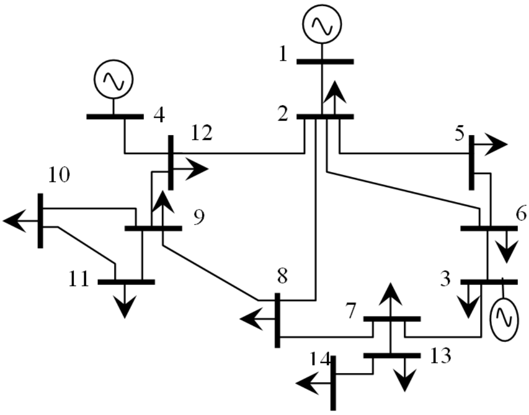

Figure 2

Topology of western Algerian electrical power system

Figure 3 (February 3, 2003) represents the daily load curve. The values of the Load Scaling Factor (LSF) are given in Figure 4 with a maximum value of 1.35 for the maximum load of 782 MW.

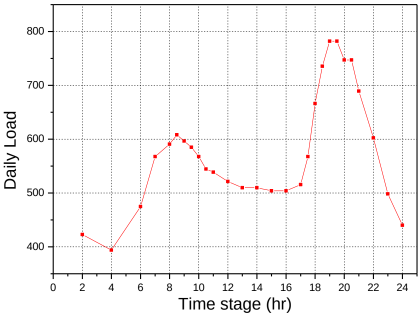

Figure 3

Daily Load

The coefficients of the transmission losses according to the powers generated for to the maximum load are:

$$a_{ij}=\begin{bmatrix} 0.00546 & -0.00052 & 0.00392 \\ -0.00052 & 0.01035 & -0.00137 \\ 0.00392 & -0.00137 & 0.01479 \end{bmatrix},\ -2\sum_{\substack{i=1\\ j=1}}^{n=1}(bijQ_j+aijP_{Dj})=\begin{bmatrix} -0.02296 \\ 0.01680 \\ -0.03629 \end{bmatrix},\ K=0.1032$$

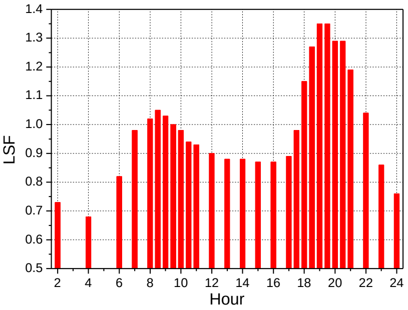

Figure 4
Load Scaling Factor

The cost functions [14, 15] providing the quantity of the fuel in Nm^3/h necessary to the production are:

$$F(P_{G1}^t)=0.85\,{P_{G1}^t}^2+150P_{G1}^t+2000$$

$$F(P_{G3}^t)=0.4\,{P_{G3}^t}^2+75P_{G3}^t+850$$

$$F(P_{G4}^t)=1.7\,{P_{G4}^t}^2+250P_{G4}^t+3000$$

Under the constraints:

$$30\le P_{G1}^t\le 510\text{MW}$$

$$25\le P_{G3}^t\le 420\text{MW}$$

$$10\le P_{G4}^t\le 70\text{MW}$$

$$\sum_{i=1}^{ng}P_{Gi}^t+P_W^t-P_D^t-P_L^t=0$$

4.2 Description of the Wind Farm

Figure 5 represents the map of the wind speed in Algeria to an altitude of 50 meters.

The map shows that the sites with the maximum wind speeds are those of *Adrar* (west south) and *Tiaret* (west north, in square) with a speed approaching 9 m/s and a recovered power density around 3.4 MWh/m^2 [16].

The site of *Tiaret* is chosen for the implant of the wind farm. This one is supposed composed of 20 identical wind turbines with 40 meters blades.

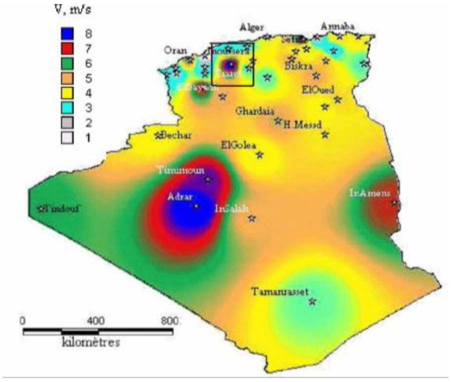

Figure 5

Atlas of wind speed at 50 m

Due to a lack of data, we use the curve of variation of the wind speed of February 03, 2010 [17]. This curve, after interpolation, is represented by Figure 6. The variations of the power produced by the wind farm, the production of the thermal power plants and the total demand with respect to the time stage are illustrated in Figure 7.

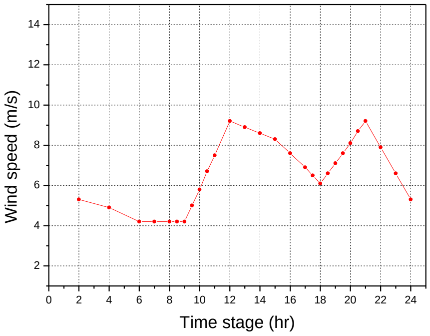

Figure 6

Daily variation of the wind speed

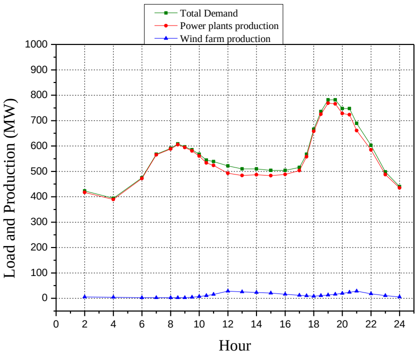

Figure 7

Power production and Load demand

4.3 Carbon Dioxide Emission

For the combustion, the emission of carbon dioxide can be calculated with good precision from a balance of the carbon contained in the fuel. The Lower Heating Value or Net Calorific Value (NCV) and the content in carbon of the fuel, necessary to this calculation, can be measured accurately.

The calculation of carbon dioxide emissions related to energy use of fuels includes five steps [18]:

a) determination of the amount (ton) of fuel consumed during a time T,

b) calculation of energy consumption from the quantity of fuel consumed and the NCV of the fuel,

c) calculation of the potential carbon emissions from energy consumption and carbon emission factors,

d) calculation of actual carbon oxidized from oxidation factors (correction for incomplete combustion),

e) conversion of carbon oxidized to CO_2 emissions.

Being of type H, The Algerian gas has the following characteristics:

$$\begin{cases} NCV = 49.6\ Gj/t \\ Density \quad \rho = 0.78\ Kg/m^3 \\ Carbon\ emission\ \ factor = 15.5\ Kg/Gj \\ Oxidation\ \ factor = 0.995 \end{cases}$$

For determining the amount of fuel consumed in one hour, it is necessary to convert the flow from Nm^3/h to m^3/h. The law of boyle-mariotte-lussac permits us to write, to equal pressures:

$$\frac{Nm^3/h}{273} = \frac{m^3/h}{(273+c^o)}, \tag{9}$$

which becomes for c°=20° : $m^3/h = 1.07\ Nm^3/h$

4.4 Results

The simulations are realized by considering first the western Algerian electrical power system as it is (WA), then the western Algerian electrical power system with the injection of wind farm energy (WAW).The results of the production cost, for the two cases WA and WAW are shown in Figure 8 and detailed in Table 1 and Table 2.

Table 1

Production costs (WA case)

time(hr)	Cost (Nm^3/h)	P_{G1}(MW)	P_{G3}(MW)	P_{G4}(MW)	P_L(MW)
2	94,939.463	100.726	302.774	20.938	1.579
4	85,895.721	92.58	286.017	16.864	1.566
6	112,235.482	115.428	332.947	28.292	1.674
7	146,253.725	141.711	386.65	41.439	2.127
8	155,422.338	148.315	400.097	44.743	2.311
8.5	162,475.972	153.278	410.19	47.225	2.471
9	157,756.749	149.969	403.461	45.57	2.362
9.5	153,077.708	146.62	396.731	43.894	2.193
10	146,253.725	141.711	386.65	41.439	2.127
10.5	137,352.701	135.121	373.214	38.143	1.974
11	135,168.813	133.476	369.856	37.32	1.94
12	128,716.808	128.544	359.785	34.853	1.849
13	124,498.056	125.261	353.073	33.211	1.796
14	124,498.056	125.261	353.073	33.211	1.796
15	122,413.518	123.62	349.718	32.39	1.772
16	122,413.518	123.62	349.718	32.39	1.772
17	126,599.384	126.902	356.429	34.032	1.822
17.5	146,253.725	141.711	386.65	41.439	2.127
18	187,636.984	185.498	420	63.338	2.688
18.5	223,575.384	248.624	420	70	2.965
19	252,192.443	295.355	420	70	3.355
19.5	252,192.443	295.355	420	70	3.355
20	230,370.734	260.288	420	70	3.044
20.5	230,370.734	260.288	420	70	3.044
21	198,755.638	202.065	420	70	2.746
22	160,108.117	151.623	406.825	46.397	2.416
23	120,345.149	121.98	346.363	31.57	1.75
24	100,559.131	105.62	312.83	23.387	1.6

Table 2

Production costs (WAW case)

time (hr)	Cost (Nm^3/h)	P_{G1} (MW)	P_{G3} (MW)	P_{G4} (MW)	P_L (MW)
2	93,215.571	99.216	299.611	20.183	1.583
4	84,590.505	91.388	283.516	16.268	1.57
6	111,322.561	114.708	331.364	27.932	1.713
7	145,207.921	140.956	385.077	41.061	2.124
8	154,346.252	147.56	398.523	44.364	2.306
8.5	161,377.042	152.522	408.616	46.846	2.465
9	156,673.062	149.213	401.887	45.191	2.357
9.5	151,277.129	145.345	394.076	43.256	2.186
10	143,467.912	139.7	382.443	40.429	2.017
10.5	133,250.207	132.06	366.826	36.61	1.967
11	129,473.321	129.183	360.897	35.17	1.932
12	118,527.727	120.626	343.25	30.888	1.845
13	115,399.179	118.095	338.103	29.622	1.796
14	116,274.976	118.796	339.566	29.973	1.796
15	115,067.226	117.809	337.576	29.48	1.773
16	116,755.205	119.159	340.396	30.156	1.773
17	122,287.385	123.562	349.453	32.359	1.82
17.5	142,393.989	138.913	380.818	40.038	2.115
18	183,848.594	180.017	420	60.595	2.746
18.5	217,686.873	238.179	420	70	3.01
19	243,833.352	282.314	420	70	3.374
19.5	241,981.121	279.362	420	70	3.38
20	219,244.474	240.974	420	70	3.122
20.5	216,679.09	236.358	420	70	3.142
21	185,327.934	182.175	420	61.669	2.938
22	152,910.221	146.592	396.35	43.877	2.38
23	116,654.701	119.059	340.258	30.107	1.751
24	98,790.598	104.11	309.667	22.631	1.603

The total quantity of CO_2 emitted is shown in Figure 9 and detailed in Table 3, while Figure 10 plots the CO_2 emitted by every power plant.

The results show a difference between the costs of production and the CO_2 emissions. The daily production cost for the WA case is around 4,338,332.219 Nm^3/d and around 4,187,864.128 Nm^3/d for the WAW case, which represents a difference of 150,468.091 Nm^3/d.

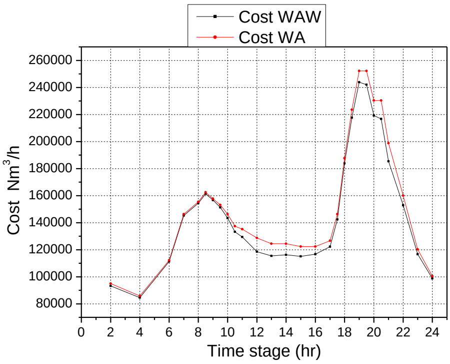

Figure 8

Production Cost

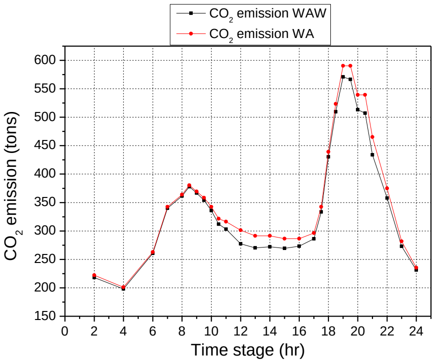

Figure 9

CO$_2$ Emissions

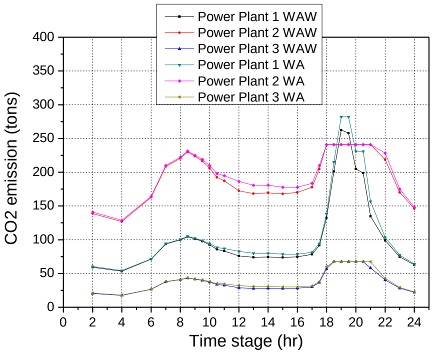

Figure 10

CO$_2$ emissions by power plants

The daily CO_2 emissions for the WA case are about 10,155.682 tons/d and around 9,803.448 tons/d for the WAW case, which represents a gain of 352.234 tons/d.

This gain is important considering that it is a winter day and therefore not very windy. Assuming that the wind has the same performance during a minimum of 80% of the year, the annual minimum amount of CO_2 the atmosphere that can be saved is of the order of 103,000 tons.

Table 3

Detailed CO_2 emissions

time (hr)	WA-CO_2 (tons)	WAW-CO_2 (tons)
2	222.246	218.210
4	201.075	198.019
6	262.734	260.597
7	342.368	339.920
8	363.831	361.312
8.5	380.343	377.770
9	369.296	366.759
9.5	358.342	354.127
10	342.368	335.847
10.5	321.531	311.928
11	316.419	303.086
12	301.316	277.464
13	291.440	270.140
14	291.440	272.190
15	286.560	269.363
16	286.560	273.314
17	296.359	286.265
17.5	342.368	333.333
18	439.243	430.375
18.5	523.372	509.587
19	590.362	570.794
19.5	590.362	566.458
20	539.279	513.233
20.5	539.279	507.228
21	465.271	433.838
22	374.800	357.950
23	281.718	273.079
24	235.401	231.261

Conclusion

In this paper, we study the effect of the injection of wind farm energy in the western Algerian electrical power system on cost and on the environment.

The dynamic environmental economic dispatch problem is solved via the Harmony Search Algorithm. The HSA is a meta-heuristic that uses a stochastic random search which is simple in concept, few in parameters and easy in implementation. Moreover, it does not require any derivative information.

The simulation results are very conclusive, since we showed that a minimum annual quantity of 103,000 tons of CO_2 emissions can be restricted with a relatively small wind farm. Those emissions are equivalent to the emissions of more than 340,000 average vehicles of which the CO_2 emission factor is equal to 0.2 kg/km [18] and traveling 1,500 km per year.

We recall here that the CO_2 is a gas with notorious greenhouse effect and an average lifespan in the atmosphere of 100 years.

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