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Economic/Emission dispatch including wind power using ABC-Weighted-Sum

Sebaa Haddi, Tarek Bouktir

Abstract— **This paper presents a mean of renewable energy integration by searching the best compromise setting of mix generation cost and thermal generation gas emissions by using one of best meta-heuristic based population technique ABC, followed by weighted sum technique. The study is done on a standard IEEE 30 bus test system. The total generation cost as well as the total emission of the entire system can be reduced clearly, by solving the EED load dispatch problem including, wind farms plants with the cost related to their stochastic nature, so that both operating cost of conventional sources and wind farms, and the emissions caused by the conventional ones, are solved by the proposed method; using ABCWS approach. Results for optimization of total cost as well as emission are then investigated in this paper.**

Index Terms—**EED problem, multi-objective optimization, ABCWS Algorithm.**

I. INTRODUCTION

The economic dispatch problem deals with finding the optimal allocation of electrical power output from available generators vector, by the computation of the minimum generation cost. The basically EED problem involves only the conventional thermal energy power generators, which use depletable sources of energy, as fossil fuels [1]. Due to the shortage of energy, the blackouts, and the environmental concerns worldwide, there is a need to exploit the alternative energy resources so called renewable; and their effective intelligent integration in existing power grids. One of the major difficulties in optimizing the operation of Smart Grid is the uncertainty associated with the weather profiles, unpredicted weather variations causes fluctuations in the power outputs of renewable energy sources, such as wind farms and solar panels, and such fluctuations can cause serious problems to the system operator, thus there are operational challenges to maintain the generation-load balance, especially in case of high level of renewable power penetration. One of the renewable sources that mean nowadays more widespread used, especially in the North Europe is the wind power, which is after the starting cost of land and capital prices, there is essentially no cost involved in the production of power from these sources, the same thing is seeing about solar energy [2].

On the other hand the operation of smart grids often requires optimizing conflicting objectives such as cost, risk level, environmental impact and reliability, due to gas emissions, and customer preferences. Since it is impossible to optimize every single objective independently, Pareto optimization can be used to find the optimal solution [3]. Pareto fronts contain a wealth of information, providing a set of solutions of good quality for the decision makers to choose according to their preferences.

Such approach is introduced in order to figure out the optimal amounts of the generated powers from the thermal units and wind farms, by minimizing the emission level and cost of generation simultaneously, which is known as economic emission dispatch (EED) problem, by searching the best compromise solution of the cost of generation power outputs and related gas emission, subject to operational equality and inequality constraints. [4]

In this work, the problem of EED considering availability of wind sources and seeking minimization of gas emission in a IEEE30 bus test system by using ABCWS multi-optimization technique to find the best compromise solution of the problem under study. For this purpose, this work is divided as follows; following the introduction, general problem formulation for economic emission dispatch problem including wind power is formulated in section two. Then in section three, a flowchart of ABCWS technique is given. Section four deals with the application of the proposed method on IEEE 30 bus test system with different scenarios; such as load varying level, Pareto front for different wind rates and results discussion, finally in section five a conclusion.

II. PROBLEM FORMULATION

A multi-objective problem seeks to find the best compromise solution between conflicting objectives and can be expressed by:

$$\textit{Minimize} \quad \left[f_1(P), f_1(P),...., f_T(P) \right]^T \tag{1}$$

$$\text{Subject to} \quad \begin{matrix} \Gamma(P) = 0 \\ \Psi(P) \leq 0 \end{matrix} \tag{2}$$

Where the overall objective function is the combined objectives function, Γ and Ψ are the equality and inequality constraints, respectively. P is the victor of decision variables.

The solution to the above problem is not unique, but a set of Pareto optimal set that constitute the non-dominated solution

Sebaa Haddi, Department of Electrical Engineering, Faculty of Technology University, Of Sétif 1, Algeria, +213 6 69 64 33 00.

Tarek Bouktir, Department of Electrical Engineering, Faculty of Technology University, Of Sétif 1, Algeria,

of the problem. The solutions that are non-dominated within the search space are denoted as Pareto optimal front [5].
A Pareto optimal solution is the best solution vector out of several numbers of solution vectors that could be achieved without disadvantaging other objectives.
In EED problem, Pareto optimal solution is the best generation schedule out of several sets of generation schedule that can be achieved without disadvantaging both fuel cost minimization objective and emission minimization objective.
The above multi-objective problem may be converted to a single objective optimization problem by introducing the price penalty factor, thus the total operating cost of the system is the cost of generation plus the implied cost of emission.
In this case the objective function is: [6]

$$\text{minimize } c = f_1 + p_{fng} \times f_{ng} \quad (\$/h) \tag{3}$$

By this bi-objective function a set of Pareto optimal solutions is achieved, and then non-dominated solutions can be generated using weighting factor "α", as follows:

$$\text{minimize } c = (\alpha) \times f_1 + (1-\alpha) \times p_{fng} \times f_{ng} \tag{4}$$

In this section, the economic emission dispatch seeks a balance between the fuel cost and gas emissions amount, this may be considered as a multi-objective problem, and may be formulated by:

$$\text{minimize } \left[C_{op}(P_{gi}, P_{wi}), \mathrm{E}(P_{gi}) \right] \tag{5}$$

Subject to;

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \tag{6}$$

$$0 \le P_{wi} \le P_{w,ri} \tag{7}$$

$$\sum_{i=1}^{M} P_{gi} + \sum_{i=1}^{N} P_{wi} = P_D \tag{8}$$

Where
Cop Combined operating cost of thermal units and wind farms.
E Emissions of thermal units
Pgi Output of i^{th} thermal generating unit
wi Scheduled output of ith wind farm
wri Rated output of i^{th} wind farm
PD System load including losses
M Number of thermal units
N Number of wind farms
As shown in [7], the combined operating cost can be formulated as;

$$C_{op} = \sum_{i=1}^{M} C_i(P_{gi}) + \sum_{i=1}^{N} C_{wi}(P_{wi}) + \sum_{i=1}^{N} C_{pi}(W_{i,ue}) + \sum_{i=1}^{N} C_{ri}(W_{i,oe}) \tag{9}$$

Where
Ci Operating cost for i^{th} thermal generating unit
Cwi Operating cost for ith wind farm
Cpi Penalty cost coefficient for not using all available power from ith wind farm due to under-generation
Cri Reserve cost coefficient due to the reserve capacities used to compensate the over-estimated wind power from the ith wind farm.

These quantities can be represented by;

$$C_i = a_i + b_i P_i + c_i P_i^2 \tag{10}$$

$$C_{wi} = d_i P_{wi} \tag{11}$$

$$\begin{aligned} W_{i,ue} &= (p_{wr,i} - p_{w,i}) \left[\exp\left(-\frac{v_{r,i}^{ki}}{c_i^{ki}}\right) - \exp\left(-\frac{v_{o,i}^{ki}}{c_i^{ki}}\right) \right] \\ &+ \left(\frac{p_{Wr,i} v_{\text{in},i}}{v_{r,i} - v_{in,i}} + p_{w,i} \right) \left[\exp\left(-\frac{v_{r,i}^{ki}}{c_i^{ki}}\right) - \exp\left(-\frac{v_{1,i}^{ki}}{c_i^{ki}}\right) \right] \\ &+ \left(\frac{p_{Wr,i} v_{in}}{v_{r,i} - v_{in,i}} \right) \left\{ \Gamma\left[1 + \frac{1}{k_i}, \left(\frac{v_{1,i}}{c_i} \right)^{ki} \right] - \Gamma\left[1 + \frac{1}{k_i}, \left(\frac{v_{r,i}}{c_i} \right)^{ki} \right] \right\} \end{aligned} \tag{12}$$

$$\begin{aligned} W_{i,oe} &= (p_{w,i}) \left[1 - \exp\left(-\frac{v_{\text{in},i}^{ki}}{c_i^{ki}}\right) + \exp\left(-\frac{v_{o,i}^{ki}}{c_i^{ki}}\right) \right] \\ &+ \left(\frac{p_{wr,i} v_{\text{in},i}}{v_{r,i} - v_{in,i}} + p_{w,i} \right) \left[\exp\left(-\frac{v_{\text{in},i}^{ki}}{c_i^{ki}}\right) - \exp\left(-\frac{v_{1,i}^{ki}}{c_i^{ki}}\right) \right] \\ &+ \left(\frac{p_{wr,i} v_{in}}{v_{r,i} - v_{in,i}} \right) \left\{ \Gamma\left[1 + \frac{1}{k_i}, \left(\frac{v_{1,i}}{c_i} \right)^{ki} \right] - \Gamma\left[1 + \frac{1}{k_i}, \left(\frac{v_{\text{in},i}}{c_i} \right)^{ki} \right] \right\} \end{aligned} \tag{13}$$

Where
$W_{i,ue}$, $W_{i,oe}$ are expected value of wind power under and over estimation for ith wind turbine.
A_i, b_i and c_i Cost Coefficients of ith thermal unit.
d_i Cost coefficient of ith wind farm.
k_i and c_i Weibull PDF parameters of the ith wind turbine.
v_i, v_r and v_0 Cut-in, rated and cut-out wind speeds, are the wind speed for which the wind turbine starts the generation and for which wind turbine is disconnected from network.

For wind farms, the operating cost is considered linearly proportional to the power output. The imbalance cost due to over-generation or under-generation of wind farms is assumed to be linearly proportional to the difference between the actual and scheduled wind powers.

In case of under-estimation penalty, if the available wind output is more than what was specified, that power will be wasted, and the system operator must pay a cost to the wind power producer for this wasted capacity, so the penalty cost for not using all the available wind power will be linearly related to the difference between the available and actual wind power used.

If a certain amount of wind power is assumed and that power is not available at the assumed time, power must be purchased from another alternate source or load must shed, thus the reserve cost coefficient for the not availability of the assumed wind power is calculated. [8]

The incomplete gamma function is used for simplifying calculations of both (12) and (13).

The environmental emissions from thermal units can be expressed as in [9], by;

$$E=\sum_{i=1}^{M}\left[\alpha_i+\beta_i P_{gi}+\gamma_i P_{gi}^2+\xi_i \exp(\lambda_i P_{gi})\right] \quad \text{(t/h)} \qquad (14)$$

Where;

αi , βi , γi , ξi , and λi are coefficients of the i[th] generator's emission characteristic.

III. Used Algorithm

Artificial Bee colony (ABC) Is one of the most recently defined algorithms by Drv.Karaboga in 2005, motivated by the intelligent behavior of honey bees. ABC as an optimization tool provides a population based search procedure in which individuals called food positions are modified by the artificial bees with time and the bee's aim is to discover the places of food sources with high nectar amount and finally the one with the highest nectar. [10]

A. ABC Algorithm

The ABC algorithm follows the flow chart shown is based on the following 'bees' movements. [11]

a) Movement of employed Bees;

$$V_{ij}=X_{kj}+\varphi_{ij}\left(X_{ij}-X_{kj}\right) \qquad (15)$$

Where xi (i = 1, 2... N); is represented by a D-dimensional vector, where D is the number of parameters to be optimized. Vij is the new position of the employed bee k є {1, 2.., n}, and j є {1, 2.., D} are randomly chosen indexes. Øij is a random number between [0 1].

b) move of onlooker bees for selected sites and evaluation of fitness based on the probability function as;

$$P_i=\frac{fit_i}{\sum_{n=1}^{s} fit_n} \qquad (16)$$

Where; P_i defined the probability of the food source with respect to its fitness.

c) move of scout bees;

d) The following equation corresponds to their movement:

$$X_{ij}=X_{j\min}+rand(0,1)*\left(X_{i\max}-X_{j\min}\right) \qquad (17)$$

Where X_{ij} and j Є {1, 2… D} new food source, X_{jmax} and X_{jmin} are the minimum and maximum limits of the parameter to be optimized.

B. MO-ABCWS technique: multiobjective ABC Weighted Sum optimization [12]

The following figure.1, presents a flowchart for the proposed approach, used in this study.

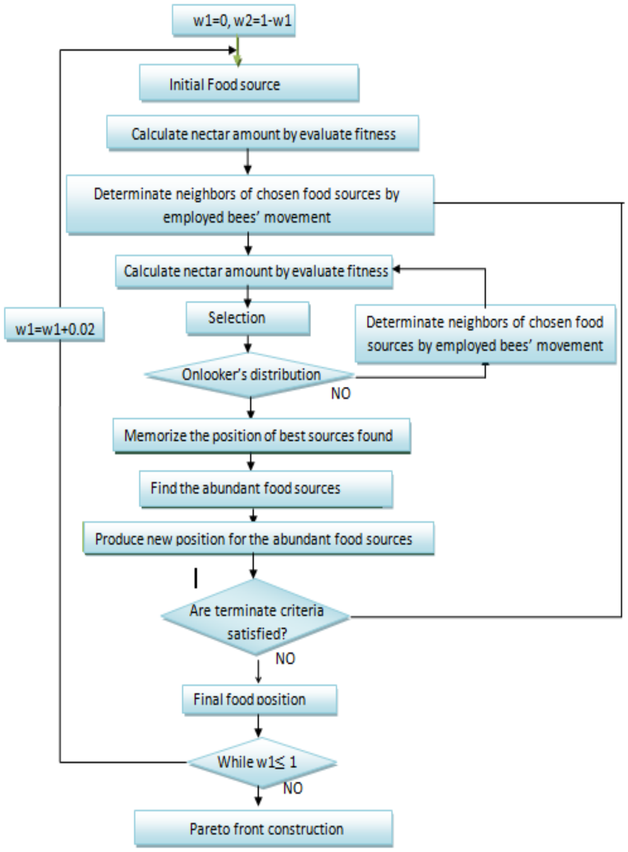

Fig. 1. Flowchart for ABCWS

IV. Application on IEEE30 Bus System

A mathematical equivalent model of the system under application is indicated in figure. 7. The parameters of generators cost and limits are indicated in table I, and in table II, wind generation ones are depicted.

TABLE I. IEEE30 BUS COST COEFFICIENTS AND POWER GENERATION LIMITS

N°	a	b	c.10^{-4}	P^{min}(MW)	P^{max}(MW)
P_{g1}	0	2.00	37.5	50	200
P_{g2}	0	1.75	175	20	80
P_{g3}	0	1.00	625	15	50
P_{g4}	0	3.25	83	10	35
P_{g5}	0	3.00	250	10	30
P_{g6}	0	3.00	250	12	40

In table I and II, are depicted the cost parameters and power limits of conventional sources and renewable sources rated characteristics, used in this study, as well as the power limits of generators, but the rated powers of the wind turbines are changeable between 4 and 6.5MW.

TABLE II. USED WIND FARMS PARAMETERS

N°	Wind 1	Wind 2
Direct cost	d1=1.0 $/h	d_2=1.1$/h
Vi (m/s)	5	5
Vr (m/s)	15	15

N°	Wind 1	Wind 2
Direct cost	d1=1.0 \$/h	d_2=1.1\$/h
Vi (m/s)	5	5
V_0 (m/s)	45	45
Shape factor k	2	2
Scale factor c	10	10
Penalty factor k_{pi}	2	2
Reserve factor k_{ri}	4	4

V. Results and Discussions

In this section, simulations where carried out using MATLAB software have been conducted on IEEE 30-bus power system shown in Fig.8. In 30-bus test system, bus 1 is considered as slack bus, while bus 2, 3, 5,8,11 and 13 are taken as generator buses and other buses are load buses. Different scenarios of renewable energy source are considered in order to perform such computation; as given by the following cases;

First Scenario: system without considering of wind generation.

Second Scenario: system considering of wind generation.

A. Figures and Tables

The obtained results are depicted in the following tables; and figures. ABC-WS is used to identify the Pareto front and the associated power outputs of thermal and wind units; the simulation results are depicted in the following tables and figures.

TABLE III POWER GENERATION, COST ,POWERS

PLoad=2.834 (p.u)	Single cost without wind (\$/h)	Single emission without wind (t/h)
Pg1 (MW)	176.1203	59.4241
Pg2(MW)	48.8047	72.7623
Pg3(MW)	21.5691	50.0000
Pg4(MW)	21.4000	35.0000
Pg5(MW)	12.1759	30.0000
Pg6(MW)	12.0000	40.0000
Total gen. (MW)	293.044	287.186
Fuel cost (\$/h)	802.806	955.577
Real power loss (MW)	9.439	4.002
Total emissions(t/h)	0.328	0.194
Pwind (MW)	-	-

Table III shows the results for the extreme cases when α=1; and α=0 where the multi-objective equation (4), becomes a single objective equation.

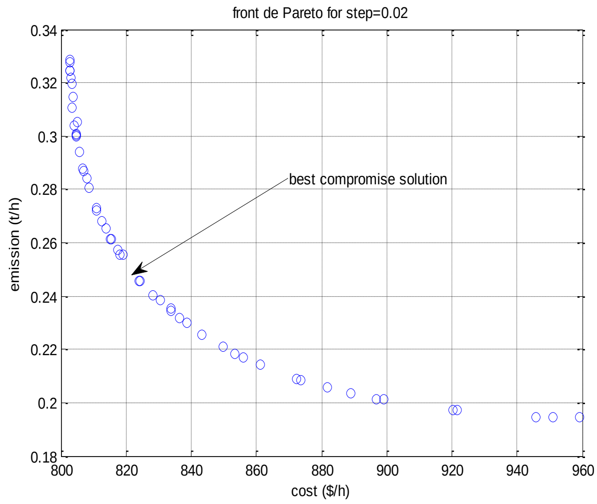

Fig. 2. Pareto Front without Wind power

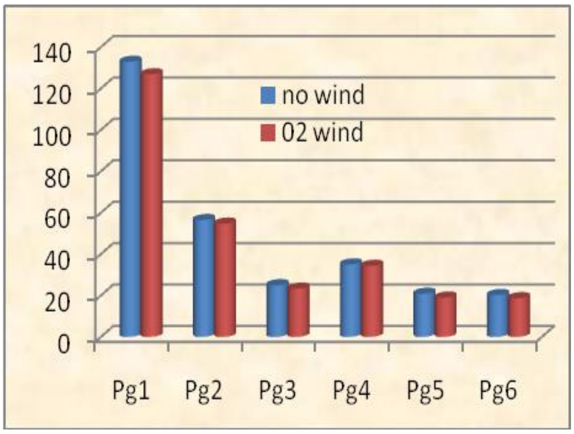

Fig. 3.Generation output profile with and without wind farm

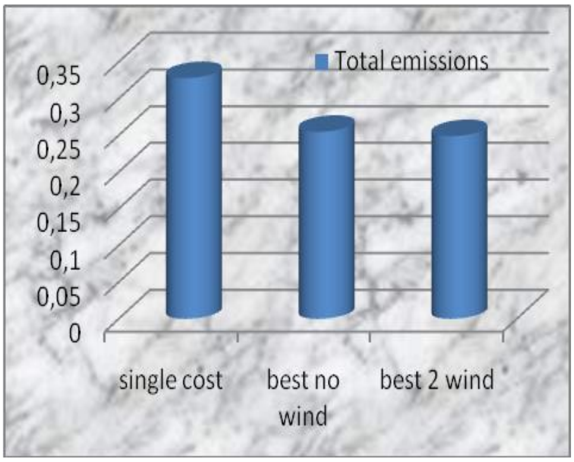

Fig. 4.Total emission levelswith and without Wind

By investigation of figures 2 and 5 we see clearly that the insertion of renewable source reduce significantly the amount of power generated by conventional sources, as well as total real loss of the entire system figure 4, table VI, shows that, the best tradeoff solution is obtained, in presence of wind sources, in the rated capacity for each wind farm is taken as 6.5MW.

TABLE IV POWER GENERATION, COST, AND OTHER BENEFITS POWER

PLoad=2.834 p.u	Case 1:best solution without wind	Case 2 : with 02 wind farms at bus 10 and bus 24
Pg1	132.8814	126.819
Pg2	56.4650	54.691
Pg3	24.9566	23.314
Pg4	35.0000	34.322
Pg5	20.8344	18.995
Pg6	20.2018	18.697
Total gen.	290.339	276.838
Fuel cost ($/h)	818.5513	775.184
Real power loss (MW)	6.813	6.43
Total emissions	0.2548	0.249
Pwf1 (MW)	-	Pw1 = 6.5
Pwf2 (MW)	-	Pw2 = 6.5

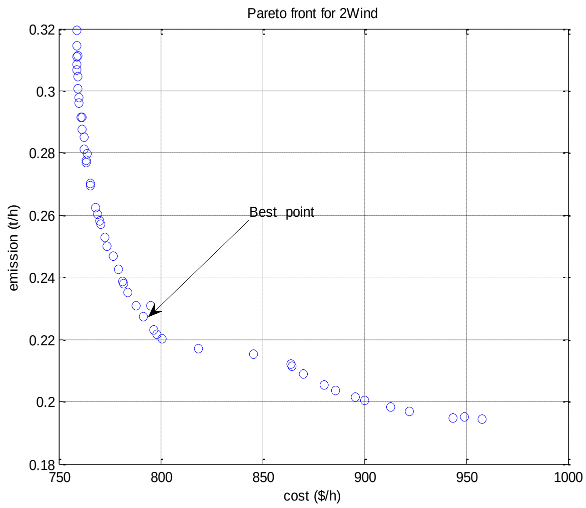

Fig. 5.Pareto Front in presence of wind Farms and for base Load

Table IV also presents the best solution vector without and with the penetration of wind power sources, and by the integration of more renewable source the total conventional outputs of generation power can be changed; the total cost as well as the total loss of the power system are reduced; in the case of two wind farms can see that the amount of the related emission in lower than the case without wind.

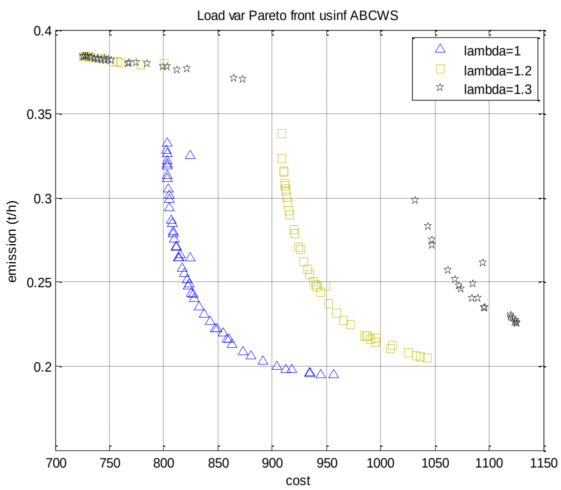

Fig. 6. Pareto Fronts for different demand levels

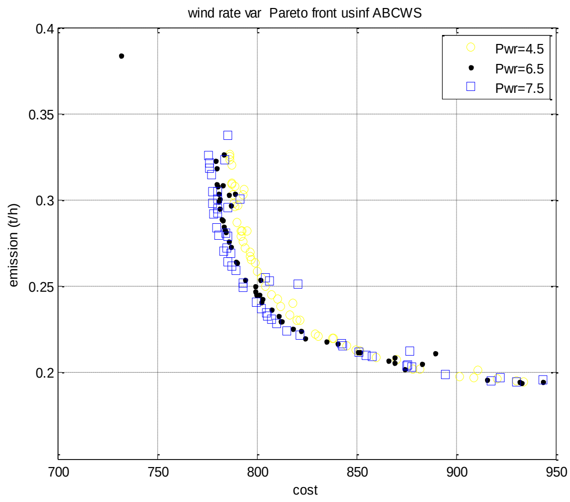

Fig. 7. Pareto Front for different winf power rates

As seen in fig. 6 by the increase of load the emission of gazes as well as generation cost increase, with the insertion of the wind farm source, it can be observed from table IV that the total generation cost as well as the total active loss of the power system, are reduced comparing with the standard case; without any renewable source, then by keeping the load demand at certain level and increasing the capacity of wind farms gradually in order to study the impact of wind power installed capacity on the emissions and the total generation cost, we get the curve of Pareto fronts shown in figure 7,

By investigating fig. 7, we can see that the increase of wind rated power or the wind capacity, can significantly enhance the generation cost and decrease the amount of gas emissions.

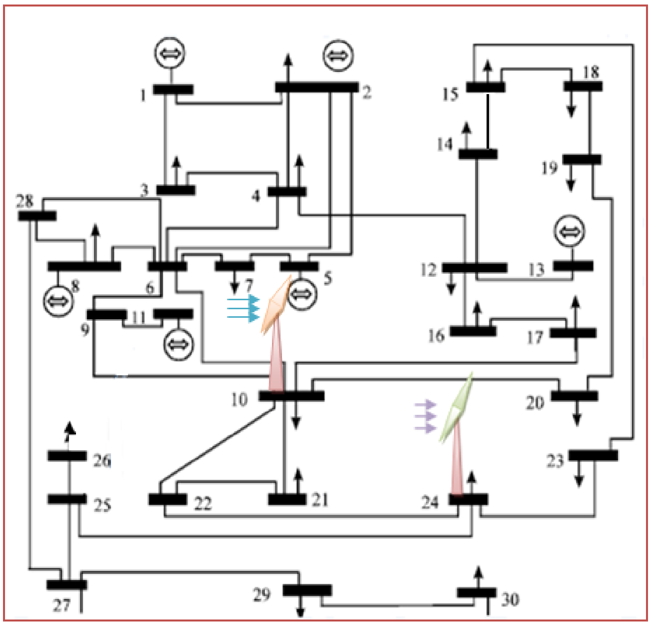

Fig. 8. IEEE 30 Bus test System

VI. Conclusion

In this paper, the fuel cost objective function of the IEEE30 bus system is optimized considering different operating conditions of the power system under study; in first time we consider the system without any renewable source; then the penetration of wind farms in the IEEE-30 bus can reduce efficiently the total active loss, as well as the total generation cost of the power system. By the integration of more wind farms in addition to conventional power sources these different performances are enhanced enough. ABC technique is employed among other métha-heuristic methods for calculation purpose because of its sure and fast characteristics, less computational time in combination weighted sum method in order to achieve the best compromise solution of the problem, and gives good performances, for the optimal integration of renewable sources as wind farms regarding both gas emission and cost reduction in stochastic environment.

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Sebaa Haddi: was born in Ain Lahdjar Sétif Algeria, follows his study in the University of Ferhat Abbes Sétif 1, has got his B.S degree in Electrical Engineering Power system from Sétif University (Algeria) in 1997, and his MSc degree in 2009 in the field of electrical network, now he prepares for the Doctorate degree in the Department of Electrical Engineering, of the university of Sétif, his area of interest is the optimization in power system, optimal integration of renewable sources, Facts device Electric Vehicles etc.

Tarek Bouktir: Prof. Tarek Bouktir was born in Ras El-Oued, Algeria in 1971. He received the B.S degree in Electrical Engineering Power system from Sétif University (Algeria) in 1994, his MSc degree from Annaba University in 1998, his PhD degree in power system from Batna University (Algeria) in 2003. His areas of interest are the application of the meta-heuristic methods in optimal power flow, FACTS control and improvement in electric power systems, Multi-Objective Optimization for power systems, and Voltage Stability and Security Analysis. He is the Editor-In-Chief of Journal of Electrical Systems (Algeria), the Co-Editor of Journal of Automation & Systems Engineering (Algeria).