Optimization Hydro-thermal-wind-PV solar using MOPSO algorithm applied to economic/environmental dispatch

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Abstract
The dynamic economic emission dispatch (DEED) is an important subject in electrical power systems network and is one of the most popular multi-objectives non-linear optimization problems. This paper presents an application of multiple-objective particle swarm optimization algorithm MOPSO to solve dynamic economic emission dispatch problems. The valve point effect loading (VPEL), the ramp rate limit RRL of generation units, transmission powers losses and an equilibrium of power system are considered into count. The proposed MOPSO algorithm is applied in economic emission dispatch to find the best solutions of hydro plant, thermal units, wind and PV solar generation scheduling powers and then calculate the cost, emission functions for SOx and NOx gas pollution, and combined the three function. Case studies and simulation results are discussed, analyzed and compared in this work. The proposed algorithm was examining on ten-unit test power systems. All simulations results are thorough on the MATLAB-Simulink space.

Keywords: Economic emission dispatch problem; ramp rate; solar power; energy storage; wind power; hydro plant; MOPSO; power systems; transmission losses; valve point effect.

1. INTRODUCTION
Along with economic dispatch, the allocation of emissions has become a key issue under several conditions. It consists to minimize CO, CO2, NOx and SO2 [1 - 2]. However, due to the dynamic nature of the today network loads, it’s required to schedule the thermal unit outputs power in real time according to the variation of demand power during a certain time period [3]. To solve this modified EED problem known as dynamic economic emission dispatch (DEED), several mathematical formulations have been suggested in the literature [3 ,4]. In the most references, the DEED dispatch is taken in consideration as dynamic problem of optimization having the same objectives as static optimization problem EED over a time period of one day, subdivided on definite intervals time of one hour with respecting the constraints imposed by generator ramp-rate limits (RRL) [3]. Therefore, at an hour, the operational decision may be influenced by that taken at a previous hour.

Other constraints such as valve-point loading effects (VPLE) have been considered in some few works [5 - 9]. However, incorporating VPLE in the fuel cost function makes it with ripples and the problem will be with multiple minima. Therefore, the DEED problem becomes highly nonlinear with non-convex fitness functions.

A considerable amount of research works has been suggested for solving this kind of problems. Classical methods like DP [10], LP [11], LI [12] and interior point [13] methods have been used to solve the static EED. However, several criticisms have been addressed to these techniques as they are iterative and require an initialization step. That can cause the convergence property for the search process into optimum local. Moreover, they may fail to solve the dynamic case including above constraints.

Currently, metaheuristics search algorithms are classified on different groups in terms on methodology of optimization, view the high efficiency and good performance in solving complex optimization problems. Swarm intelligence based in EA were assumed that they are the most used algorithms.

Among metaheuristic-based optimization techniques, genetic algorithm [14], PSO [6], SA [15 - 16], artificial bee colony (ABC) [9], tabu search [17], DE [18] and bacterial foraging [19] have been suggested for solving the EED problem.

Traditional algorithms, they are criticized in later works [20]. Whereas their efficiencies are sensitive to the form of problem constraints and the number of units. Most of above research works presented in the literature have concentrated only about static EED problem except a few of them, where the DEED multi-objective problem is taken into consideration. In addition, RRL constraints were not considered during transition from the last hour of the current day to the first hour of the next day.

The role of best optimal dispatch production scheduling of a thermal-renewable power system of generation pointing modest economic and minimization of emission as a benefit is necessary actually in order to swelling the demanded power generation, escalating the total fuel price and high pollution rate [21]. Optimization scheduling of power plant production is of large importance to electric interest systems. With the low misfit cost of power hydroelectric, the problem of minimizing the transition cost of a hydrothermal system basically reduces to that of minimize the fuel cost for thermal plants user the diver’s constraints on the hydraulic and power system grid [22].

A coal-fired power plant releases ton of ash, tons of toxic heavy metals, arsenic, mercury, cadmium, uranium, tons of thorium, soot and fine particles that escape to the atmosphere each year.
Tons of CO2 and tons of nitrogen oxide (NOx). Thus, everyone is currently oriented towards the use of renewable energies by the integration of these different forms in electrical networks [21]. Electricity production is responsible for 35% of CO2 emissions linked to human activity worldwide. Fortunately, renewable energies, or green energies, have experienced a real boom since the 2000s. These new energy production sectors should in future represent a greater share of use because of the environmental impact of renewable energy [22].

The Clean Air Act 1990 aims to reduce greenhouse gases and acid rain. It requires that fossil fuel power plants must decrease its (NOx) emission level and (SO2) quantity [23]. Though these approaches previous have obtain simultaneously emission and total fuel cost, the scheduling problem is ultimately optimization problem of single objective both inevitable flaws. The results of optimization are critical to the balances which are difficult to be resolved. The Pareto best group cannot be acquired in one test by using different metering. To overcome the disadvantages mentioned above, many authors have developed strength pareto evolutionary algorithm-2 (SPEA 2) [24] and non-dominated sorting genetic algorithm-II.

The main contributions of this work are summarized as follows:

• an application of multiple- objective particle swarm optimization algorithm MOPSO to solver dynamic economic emission dispatch problems in electrical power system including hydro-thermal-wind-PV solar energy. In addition, a search for the optimal solution of the various separate and combined objective functions such as the cost, emission functions for SOx and NOx gas pollution in power systems.
• All above constraints were considered simultaneously in the DEED problem.

\[
F_u = \sum_{t=1}^{T} \left[ \sum_{g=1}^{N_g} f_{g,t} (P_{g,t}) \right] + \sum_{k=1}^{N_w} K_{w,k} \times P_{w,k,t} + \sum_{m=1}^{N_{PV}} K_{PV,m} \times P_{PV,m,t} \right] \tag{1}
\]

Equation (2) give the expression of the total fuel cost for thermal plant, taking into count the valve-point effect (VPE) [26].

\[
f_{g,t} (P_{g,t}) = a_g + b_g P_{g,t} + c_g P_{g,t}^2 + d_g \times \sin \left[ e_g \times \left( P_{g,t}^{\min} - P_{g,t} \right) \right] \tag{2}
\]

2.1. NOx emission function

In reference [27], the NOx emissions is given by the following equation:

\[
E_{NOX} = \sum_{t=1}^{T} \sum_{g=1}^{N_g} \left[ a_{ng} + b_{ng} P_{g,t} + c_{ng} P_{g,t}^2 \right] \tag{3}
\]

2.1.3. SOx emission function

The equation (4) that represent the expression of SOx emission is given by [27]:

\[
E_{SOX} = \sum_{t=1}^{T} \sum_{g=1}^{N_g} \left[ a_{sg} + b_{sg} P_{g,t} + c_{sg} P_{g,t}^2 \right] \tag{4}
\]
2.2. Constraints of the problem

 Depending on the size of the electrical network, in other words its complexity, the study of the switching of units can be conditioned by several constraints. In fact, in this context two constraints to be respected the spinning reserve constraints and demanded power of load [28].

- Generating unit ramp-rate limits

Violation of unit ramp rates will shorten the life for power production facilities. Thus, the ramp rate limits must be shown when the power demanded for electric charge changes [29].

\[
\begin{align*}
P_{g,t} & - P_{g,t-1} \leq UR_g \\
P_{g,t-1} & - P_{g,t} \leq DR_g
\end{align*}
\]

For \( g \in N_g \) et \( t = 2, 3, \ldots, T \) (5)

If unit ramp speed limits are considered into account, actual generated power limits (5) can be obtain the variation as equation (6):

\[
\max \left( p_{\min}^g , P_{g,t-1} - DR_g \right) \leq P_{g,t} \leq \min \left( p_{\max}^g , P_{g,t-1} + UR_g \right)
\]

- Real power balance equation:

\[
T = 24 \sum_{t=1}^{T} \left[ \sum_{g=1}^{N_g} P_{g,t} + \sum_{j=1}^{N_h} P_{h,j,t} + \sum_{m=1}^{N_{PV}} P_{PV,m,t} + \sum_{k=1}^{N_w} P_{w,k,t} + P_{bat,t} \right] = P_{Dt} + PL_t
\]

(7)

Or the total power losses of the transmission line PLt can be calculated by using B-coefficient stated as equation number (8)

\[
P_{Lt} = \sum_{t=1}^{T} \sum_{g=1}^{N_g} P_{g,t} B_{gj} P_{j,t} \quad ; t = 1, 2, \ldots, T
\]

(8)

The hydroelectric generation [30] is a function of reservoir and discharge water rate given by the following expression:

\[
P_{h,j,t} = C_{1,j} V_{h,j,t}^2 + C_{2,j} Q_{h,j,t}^2 + C_{3,j} V_{h,j,t} + C_{4,j} Q_{h,j,t} + C_{5,j} V_{h,j,t} + C_{6,j}
\]

For \( j \in N_{h,t} \) et \( t = 1, 2, \ldots, T \) (9)

The output power [31] for the kth generated power of wind unit for given speed and time t has the following expression:

\[
P_{\text{win}} = \begin{cases} 
0, & \text{for } v_{\text{win}},t \leq v_{\text{in}}, \text{and } v_{\text{win}},t > v_0 \\
pr \left( \frac{v_{\text{win}},t - v_{\text{in}}}{v_r - v_{\text{in}}} \right), & \text{for } v_{\text{in}} \leq v_{\text{win}},t \leq v_r \\
pr, & \text{for } v_r \leq v_{\text{win}},t \leq v_0
\end{cases}
\]

(10)

The output power [32] from PV cell has the following equation.

\[
P_{PV,m,t}(G) = \begin{cases} 
\frac{G^2}{G_{\text{std}} \cdot R_c} & \text{for } 0 < G < R_c \\
\frac{G}{G_{\text{std}}} & \text{for } G > R_c
\end{cases}
\]

(11)
Real power generation limit

\[
P_{g,\min} \leq P_{g,t} \leq P_{g,\max}; \text{For } g \in N_g, t \in T
\]

\[
P_{h,j,\min} \leq P_{h,j,t} \leq P_{h,j,\max}; \text{For } j \in N_h, t \in T
\]

\[
P_{w,k,\min} \leq P_{w,k,t} \leq P_{w,k,\max}; \text{For } j \in N_w, t \in T
\]

Constraints of Hydraulic system

All constraints of the hydraulic equipment include equations of the water balance for each hydroelectric unit in addition to the limits on the storage and rejection targets of the reservoirs [31]:

- Physical limitations on reservoir storage volumes and discharge rates,

\[
v_{h,j,\min} \leq v_{h,j,t} \leq v_{h,j,\max}; \quad j \in N_h, t \in T
\]

\[
Q_{h,j,\min} \leq Q_{h,j,t} \leq Q_{h,j,\max}; \quad j \in N_h, t \in T
\]

- Hydro reservoir system has the following equation of continuity:

\[
V_{h,j}(t+1) = V_{h,j,t} + I_{h,j,t} - Q_{h,j,t} - S_{h,j,t}
+ \sum_{l=1}^{R_{w,j}} \left( Q_{h,l}(t-\tau_{lj}) + S_{h,l}(t-\tau_{lj}) \right); \quad j \in N_h, t \in T
\]

Energy storage system ESS

Equation (16) represents the maximum discharge and charge and battery capacity:

\[
-P_{b,\max} \leq P_{bt} \leq P_{b,\min}
\]

Pbt: positive in discharging Pd
Pbt: negative in charging Pc.

* If the ESS is charging (Pb(t) < 0)
* If the ESS is discharging (Pb(t) > 0)
* If the ESS is idle (Pb(t) = 0)

3. MULTIOBJECTIVE FUNCTION

The formulation of optimization in this case of multi-objective function CDEED dispatch is given by equation (17).

\[
\text{Min } F(P_{g,t}) = \left[ F_{u}(P_{g,t}), F_{NOX}(P_{g,t}), F_{SOX}(P_{g,t}) \right]
\]

Determine the optimal dispatch of active energy production which gives the minimization of two contradictory objectives functions of total fuel cost and emissions quantity while respecting several equality and inequality constraints [32].
The CDEED is considered as an optimization of a single objective function using the weighting method as [33]:

$$Min F = w F_U + (1 - w)(p_f NO_X E NO_X + p_f SO_X E SO_X)$$

(18)

Where $p_f$ is the price penalty factor is as flows:

$$p_f NO_X (P_{ig}^{max}) = \frac{F_{ug,i}t(P_{ig}^{max})}{E NO_X (P_{ig}^{max})} \text{$/ton}$

(19)

$$p_f SO_X (P_{ig}^{max}) = \frac{F_{ug,i}t(P_{ig}^{max})}{E SO_X (P_{ig}^{max})} \text{$/ton}$

(20)

Where $0 \leq w \leq 1$ is the weighting factor.
If $w = 1$, minimizing only the cost.
If $w = 0$, minimizing only the emission.
If $w = 0.5$ minimizing simultaneously the economic and emission.

4. MOPSO approach

4.1. Overview

Several scientific researches use a lot of times Particle swarm optimization and consider them as very efficient and robust methods which can be applied or used for nonlinear optimization problems and more particularly for electrical systems [34]. In fact, these algorithms ignore several conditions such as differentiability and continuity, whether for the objective functions to be optimized or these constraints to be respected. This algorithm is introduced by Eberhart and Kennedy [35] as an optimization tool for non-linear optimization problems.

4.2. MOPSO Algorithm

It is at random, the initialization of all the particles in the research space for the MOPSO approach. A position and velocity are assigned For each particle in the decision research space. The proposed MOPSO approach is well detailed with these different steps in the reference [35].

4.3. Front pareto and best compromise solution

Decision maker (DM) can assume vague or imprecise objectives for each objective function. Fuzzy sets are defined by equations called functions of membership. The DM is able to give the best evaluation for the function of membership, $\mu F_k$ subjectively and is defined as strictly monotonically with decrease and continuity function has the following expression:

$$\mu F_k (i) = \begin{cases} 0, & \text{Otherwise} \\ \frac{F_k^{Max} - F_k(i)}{F_k^{Max} - F_k^{Min}}, & F_k^{Max} \leq F_k(i) \leq F_k^{Min} \end{cases}$$

(21)

The procedure is as follows:

$$F^2 = Min E\mu_{ig,t} (P_{ig,t}) \leq \varepsilon$$

(22)

The $\varepsilon$ value will be varied from $F^2_{Max}$ to $F^2_{min}$ and then $F^1$ (cost function) is minimized.

The final solution using (DM) can then be found as:

$$Max_{1:nS} \left( \min_{1:nF} (\mu F_k) \right)$$

(23)

Where $nS$ number of total solution and $nF$ number of objective functions.
5. ANALYSIS AND DISCUSSION OF RESULTS

In this paper, four cases are considered to demonstrate the performance of the proposed method such as:

Case 1: Economic dispatch.

Case 2: NOx emission dispatch.

Case 3: SOx emission dispatch.

Case 4: Combined economic emission dispatch.

All results of simulations are obtained in MATLAB-simulink R2013a using i3-2310M CPU @ 2.10 GHz. This proposed method is applied with size of population as 200. 600 is the number maximum of iteration. The system power data for all cases are given from [36]. Four reservoir hydroelectric power plants are considered in this system, three thermal plants, equivalent power of wind generation unit, an equivalent PV solar power plant and an equivalent battery energy storage. A 24 intervals by day is the planning period. The valve point effect loading (VPEL) is considered into count. Hydrothermal parameters are more detailed in reference [37].

Sox and NOx coefficients are given in [38]. The rating of wind power generator is $pr = 150$ MW. The cut-in, cut-out and rated wind speeds are $vin = 4$ m/s, $vo = 25$ m/s and $vr = 15$ m/s respectively. The direct cost coefficient $Kwin$ for the wind power generator is taken 3.25. The rating of solar PV generator is $PS = 150$ MW. The direct cost coefficient $Kpv$ for the solar PV generator is taken 3.5. The solar radiation in the standard environment $Gstd$ and a certain radiation point $Rc$ are taken as 1000 W/m$^2$ and 150 W/m$^2$. The forecasted wind velocity and solar radiation are taken from [39].

(a) (b) (c) (d)

Figure.1. Evolution convergence case 1 (a), case 2 (b), case 3 (c) and case 4 (d)
The convergence of objective functions of all cases with iterations using MOPSO algorithm is depicted by Figure 1. It shows that MOPSO converges faster and has a superior performance. The curve has almost stopped declining since about the 550th iterations, it’s declines gradually, and it finally achieves the lowest level.

Figure 2. Pareto front and best solution case 1 (a), case 2 (b), case 3 (c) and case 4 (d)
Figure 2 (a)–(d) illustrated pareto front and best solution for all case, respectively. It is able to obtain the optimal pareto-front of the all solution, that are well distributed in the search space. The cost and emission objectives are actually contradictory and non-commensurate in nature. In such problems there is no single optimal solution to a problem. The best solution out of the Pareto-optimal solutions is a tedious task. In this paper, a fuzzy ranking method is used for finding the best compromise solution.

Figure 3. Hydro plant discharges (10^4m^3) case 1 (a), case 2 (b), case 3 (c) and case 4 (d)
Economic, NOx emission, SOx emission dispatch and combined problem objectives are minimized using MOPSO. Hydro, wind, PV solar and thermal production from economic optimization, NOx emission optimization, SOx emission optimization and combined problem are given in tables 1-4, respectively. The optimal hourly plant discharges of four hydro power plants from economic optimization, NOx emission optimization, SOx emission optimization and combined problem are listed in Figure 3 (a)-(d) respectively. Figure 4 (a)-(d) give the reservoir storage volumes of four hydro plants from economic minimization, NOx emission minimization, SOx emission minimization and combined problem respectively. PV solar and wind power production of total fuel cost for the scheduled day is same for cost optimization, NOx emission optimization, SOx emission optimization and combined problem.

Figure 4 Hydro reservoir storage volumes (104m3) from case 1 (a), case 2 (b), case 3 (c) and case 4 (d)
Respect the ramp rate constraint equation (5) to solve DEED with the all cases test systems. Figure 5 (a)–(d) show the results for the test system. Its show that the proposed method has the best results.

Table 1. Best scheduling and dispatching of generation (MW) for case 1 of test system

<table>
<thead>
<tr>
<th>H</th>
<th>PD</th>
<th>Thermal unit power generation</th>
<th>Hydro power generation</th>
<th>PV Solar</th>
<th>Wind</th>
<th>Pbat</th>
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<td></td>
<td></td>
<td>g1 g2 g3 g4 g5 g6 g7 g8</td>
<td>h1 h2 h3 h4</td>
<td></td>
<td></td>
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<td>t1</td>
<td>1750</td>
<td>455 450 130 20</td>
<td>50.3259 40 45 35</td>
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<td>t2</td>
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<td>455 450 130 20</td>
<td>50.3259 40 45 35</td>
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<td>t3</td>
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<td>69.2867 51.8500 48.7598 326.7162</td>
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<td>t4</td>
<td>1650</td>
<td>455 450 130 20</td>
<td>50.3259 40 45 35</td>
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<td>t5</td>
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<td>77.3516 40 45 35</td>
<td>71.9591 54.5000 38.2778 323.3603</td>
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<tr>
<td>t6</td>
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<td>455 450 130 20</td>
<td>127.3516 40 45 35</td>
<td>73.2429 55.0060 65.2563 304.1431</td>
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<td>227.3516 40 45 35</td>
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<td>80.9089 65.1696 64.3405 298.8537</td>
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Table 2. Best scheduling and dispatching of generation (MW) for case 2 of test system

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<th>Hydro power generation</th>
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Cost($/day) NOx Emission (Ton/day) SOx Emission (Ton/day)

498290 27.6394 187.2579

Table 3. Best scheduling and dispatching of generation (MW) for case 3 of test system

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<th>Wind</th>
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Cost($/day) NOx Emission (Ton/day) SOx Emission (Ton/day)

537240 25.8175 195.4521
Table 4. Best scheduling and dispatching of generation (MW) for case 4 of test system

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<th>SOx Emission (Ton/day)</th>
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Table 5 Summary results for the test system.

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<th>SOx Emission (Ton/day)</th>
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Total cost: 7140400 (Ton/day)

6. CONCLUSIONS AND PERSPECTIVES

In this paper, MOPSO applied for CDEEP the combined problem of economical distribution of dynamic emissions with transmission power loss and VPE. To cope with this non-convex problem, linear approximation is employed to transmission power loss and the non-smooth total fuel cost function, and therefore the classical CEED problem is converted to the MOPSO problem.

The property of convergence, the computation efficiency and the economic effect of emission are well demonstrated in our present paper. This allows us to say that this MOPSO optimization algorithm is an efficient and robust method which is capable of solving these examples of non-linear multi-objective optimization linked to electrical networks incorporating renewable energy, hydro and ESS operation and multi area are a future work.

ACKNOWLEDGEMENT

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REFERENCES


