2017 Competition
Evaluating the Performance of Modern Heuristic Optimizers on Smart Grid Operation Problems

Test bed 1:
Stochastic OPF based active-reactive power dispatch

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2014 competition

• OPTIMAL ACTIVE-REACTIVE POWER DISPATCH PROBLEM

\[ C_{\text{total}} = \sum_{i=1}^{N_c} C_i(P_{s,i}) \]

The conventional generators are assumed to have a quadratic cost function with \( P_{s,i} \) as the scheduled power output of generator \( i \); and \( \alpha_i, \beta_i, \gamma_i \) as the cost coefficients of generator \( i \):

\[ C_i(P_{s,i}) = \alpha_i + \beta_i P_{s,i} + \gamma_i P_{s,i}^2 \]
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- OPTIMAL ACTIVE-REACTIVE POWER DISPATCH PROBLEM

Optimal Active-Reactive Power Dispatch (OARPD)

In the formulation proposed, the objective is set to minimize the expected value of the total generation cost ($C_{total}$):

$$\min E[C_{total}]$$

where $E[*]$ denotes the expectation operator, given by the probability-weighted average of all possible values of a random variable.
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• OPTIMAL ACTIVE-REACTIVE POWER DISPATCH PROBLEM

The total generation cost is given by:

\[ C_{\text{total}} = \sum_{i=1}^{N_c} C_i(P_{s,i}) \]

\[ + \sum_{i=1}^{N_w} C_{w,i}(W_{s,i}) + \sum_{i=1}^{N_w} C_{w,u,i}(W_{s,i}, W_i) + \sum_{i=1}^{N_w} C_{w,o,i}(W_{s,i}, W_i) \]
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• OPTIMAL ACTIVE-REACTIVE POWER DISPATCH PROBLEM

The cost of a wind power generator is divided into three components. The first component accounts for the direct cost paid by the system operator to the owner of the wind generator.

Factors for underestimation and overestimation of power availability are included in the formulation as the second and third components mentioned in the previous paragraph, due to the uncertainty of the wind power available at any given time.

\[ C_{w,i}(W_{s,i}) = c_{w,i} \cdot W_{s,i} \]

\[ C_{w,u,i}(W_{s,i}, W_i) = c_{w,u,i}(W_i - W_{s,i}) \]

\[ C_{w,o,i}(W_{s,i}, W_i) = c_{w,o,i}(W_{s,i} - W_i) \]
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- Underestimated condition

The scheduled power ($P_{si}$) in the renewable generator $i$ is lesser than the available real power ($P_{ai}$), and there will be a cost for underestimate given by: $C_u = c_u(P_{ai} - P_{si})$ due to the total available power that is not used in the system (only it is used $P_{si}$). It would be a kind of power wasted, but in the real life could be considered as a power directed to an energy storage system with a related cost for using the system ($c_u$).

- Overestimated condition

The scheduled power ($P_{si}$) in the renewable generator $i$ is bigger than the available real power ($P_{ai}$), and there will be a cost for overestimate given by: $C_o = c_o(P_{si} - P_{ai})$ due to the total available power is not enough to get the power to be scheduled in the system ($P_{si}$). In this case the network operator must turn on or request more power to another energy source with a related cost ($c_o$).
In order to solve the proposed formulation, several population based optimization algorithms are used; in this way the target function is subject to the following kind of constraints depending in how they are handled in the optimization algorithms:
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1) Equality constraints considered with a power flow inside of the optimization algorithm

These constraints are given by the active power flow balance equations and the reactive power flow balance equations at all buses:

\[ P_{gi} - P_{di} - \nu_i \sum_{j \in NB} \nu_j (g_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) = 0 \]

\[ Q_{gi} - Q_{di} - \nu_i \sum_{j \in NB} \nu_j (g_{ij} \sin \theta_{ij} + B_{ij} \cos \theta_{ij}) = 0 \]
2) Inequality constraints related with the decision variables

\[ P_{s,i}^{\text{min}} \leq P_{s,i} \leq P_{s,i}^{\text{max}}, \ i \in N_g - 1 \]

\[ v_{gi}^{\text{min}} \leq v_{gi} \leq v_{gi}^{\text{max}}, \ i \in N_g \]

\[ T_k^{\text{min}} \leq T_k \leq T_k^{\text{max}}, \ k \in N_T \]

\[ Shunt_i = \begin{cases} 
0 & \text{or} \\
\text{defaultShunt}_i & \end{cases}, \ i \in N_{CD} \]

where \( N_g \) is the number of buses with conventional generators; \( N_T \) is the number of branches with transformers with on line tap changers. \( \text{defaultShunt}_i \) is the reactive power injected at nominal tension by the compensation device in bus \( i \), and \( N_{CD} \) is the number of compensation devices.
3) Inequality constraints related with the fitness function inside of the optimization algorithm

These constraints are given by the reactive power generation limit at each generator bus, the voltage magnitude limit at each load bus, and the power flow limit constraint of each transmission line:

\[ Q_{gi}^{\text{min}} \leq Q_{gi} \leq Q_{gi}^{\text{max}}, \ i \in N_g \]

\[ v_{\text{loadi}}^{\text{min}} \leq v_{\text{loadi}} \leq v_{\text{loadi}}^{\text{max}}, \ i \in N_{LB} \]

\[ s_l \leq s_l^{\text{max}}, \ l \in N_E \]

where \( N_g \) is the number of buses with conventional generators, \( N_{LB} \) represents the number of load buses, that is to say, buses where \( P_{di} \) is different to zero, and \( N_E \) represents the number of branches in the network.
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Generic flow chart.

- Heuristic Search Parameters
  - Initialization (Random Population)
    - Power Flow
      - Objective Evaluation: Generation Cost
        - Fitness Function Value: Objective + Penalty Functions
          - Number of expected value evaluations < Maximum number of iterations
            - Choose the best Fitness Function Value
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Fitness Function Value: Objective + Penalty Functions

\[
PF = \rho \left\{ \sum_{i=1}^{N_g} \left[ (Q_{gi} - Q_{gi}^{\min})^2 + (Q_{gi}^{\max} - Q_{gi})^2 \right] + \right. \\
\sum_{i=1}^{N_B} \left[ (v_{loadi} - v_{loadi}^{\min})^2 + (v_{loadi}^{\max} - v_{loadi})^2 \right] + \\
\left. \sum_{l=1}^{N_I} (s_{l}^{\max} - s_{l})^2 \right\} 
\]

The penalty function is calculated for non-contingency and contingency (N-1) conditions.
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Table 1: Composition of test system

<table>
<thead>
<tr>
<th></th>
<th>IEEE 57 bus system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generators</td>
<td>7</td>
</tr>
<tr>
<td>Loads</td>
<td>42</td>
</tr>
<tr>
<td>Lines/cables</td>
<td>63</td>
</tr>
<tr>
<td>Transformers Stepwise</td>
<td>15</td>
</tr>
<tr>
<td>Transformers Fixed tap</td>
<td>2</td>
</tr>
<tr>
<td>Shunt compensation Binary On/Off</td>
<td>3</td>
</tr>
</tbody>
</table>
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Stochastic OPF for IEEE 57 bus system considering Wind generators

![Graph showing available power (MW) vs. Montecarlo Scenarios of Wind Generator at Bus 2](image)

(Cases 1 and 4)

![Histogram showing frequency vs. wind speed (m/s) for wind generator at bus 2](image)

![Histogram showing frequency vs. available real power (MW) for wind generator at bus 2](image)

Figure 1. Wind Generator at bus 2.
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Stochastic OPF for IEEE 57 bus system considering Wind and Solar

(Cases 2 and 5)

Figure 6. Solar Generator at bus 6.
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Stochastic OPF for IEEE 57 bus system considering Wind, Solar and Small-Hydro generators

Monte Carlo Scenarios of Generation at Bus 9

(Cases 3 and 6)