Stochastic Day-ahead Optimal Scheduling of Active Distribution Networks with Dispersed Energy Storage and Renewable Resources

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Introduction and Motivations

Smart Grids

- Progressive installation of distributed energy resources (DERs)
- Evolution of distribution networks: passive $\rightarrow$ active

Challenges

- Lack of direct controllability of distributed generations (DGs) by distribution networks operators (DNOs)

Promising near-term solutions to postpone infrastructure investments:

$\rightarrow$ Indirect DG and grid control by means of distributed storage systems (DSSs) owned by the DNOs.
Possible approach for the ADNs control proposed in the literature:

→ optimal day-ahead scheduling of embedded energy resources

This is an Optimal Power Flow (OPF) problems that can be solved according to various objective functions:

✓ voltage deviations minimization,
✓ line congestions minimization,
✓ network losses minimization,
✓ energy-cost minimization,
✓ etc.

we focus on stochastic optimal scheduling of ADNs considering economical and technical aspects in a multi-objective function
Problem Formulation

Stochastic optimal scheduling of ADN considering the presence of battery energy storage systems (BESSs) and uncontrolled PV

Multi-objective function:
minimization of:

1. energy cost from the external grid,
2. penalty deviations from the day-ahead schedule of the energy import/export from/to external grid,
3. cost of changing the transformer tap-changer position and
4. total network and BESSs losses
Problem Formulation

**Uncertainties of the model**
- Load and PV forecast
- Price forecast

**Two stage stochastic programming using scenario tree**

1. **First stage decisions:**
   - declares the amount of import/export energy from the external grid at each hour in the day-ahead market.

2. **Second stage decisions:**
   - The operation and control of the grid for various scenarios
Problem Formulation

Objective function

\[
\text{minimize } \rho_{Sc} \sum_{Sc} \sum_{t} \{W_{Tap} TC_{Sc}(t) + W_{E}(E_{Sc}(t) \pi_{Sc}(t) + \gamma_{Sc,t} |E^{DA}(t) - E_{Sc}(t)|) + W_{L}[\left( \sum_{ij \in G} r_{ij} f_{ij,Sc}(t) \right) + \sum_{s} L_{s,Sc}(t)] + W_{LC} \sum_{i} L_{C,i,Sc}\}
\]

- cost of changing the transformer tap-changer position
- Energy cost
- Day-ahead deviation cost
- Network and BESS loses
- Load curtailment
Constraints of the problem

1. The network operational and security constraints:
   ✓ Load balance
   ✓ Voltage limits
   ✓ Maximum feeder and transformers flow limits

1. The BESSs operational constraints
   ✓ State of Charge (SoC)
   ✓ Maximum and minimum power rating and reservoir capacity limits
Solution approach

The problem is *Stochastic Non-Convex Mixed integer*

- **Integer variables** related to the *position* of the substation transformer *tap-changer*

- The *load balance* constraints are *non-convex*

- **Stochasticity** is due to the uncertainty of *PV profile, load profile and energy price*

→ Use of the exact relaxation of the Optimal Power Flow (OPF) for radial distribution networks
Solution approach

Complex power flow over the feeder between buses $i$ and $j$

$$S_{ij} = s_j + \sum_{k:j\rightarrow k} (S_{jk} - z_{ij} f_{ij})$$

$$v_i = v_j + 2 \text{Re}(z_{ij} S_{ij}) - |z_{ij}|^2 f_{ij}$$

Relaxing the current flow equation and obtain a Second Order Cone optimization problem:

$$f_{ij} \geq \frac{|S_{ij}|^2}{v_i}$$
Case studies

Modified IEEE 34 buses test system
Total net daily active load scenarios (aggregated of the load and PV generation). The base power is 2.5 MW.

- The K-means is used to cluster and reduce the number of scenarios
- The MISOCOCP solver of Gurobi optimization software via YALMIP-MATLAB interface is used.
Case studies

Comparison of each term of the objective function in two cases i) with BESSs and ii) without BESSs

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</thead>
<tbody>
<tr>
<td>With BESSs</td>
<td>0.2138</td>
<td>No</td>
<td>0</td>
<td>2</td>
<td>1.23</td>
<td>201.22</td>
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<tr>
<td>Without BESSs</td>
<td>0.299</td>
<td>YES</td>
<td>0.85</td>
<td>3.17</td>
<td>1.8</td>
<td>246.34</td>
</tr>
</tbody>
</table>

- The network losses (28%), energy cost (18%), and total day-ahead deviations (32% downward deviation, 37% upward deviation) are decreased with BESSs
- The transformer tap-changer is not used with presence of BESSs
- The load curtailment is prevented with the use of BESSs
Case studies

The boxplot of the IEEE 34 test feeder nodal voltages.

- The voltage profile is improved with the use of BESSs
- The variation of the voltage across the network is decreased with the use of BESSs

With BESSs

without BESSs
Case studies

BESSs daily active power schedule together with their maximum and minimum variations (base power equal to 2.5 MW).

- The variations are the capacities that for compensating the day-ahead forecast errors.

- The reserve capacity is high in middle of the day order to compensate the PV production forecast errors.
CONCLUSIONS

✓ The paper has proposed a stochastic methodology to solve the problem of the probabilistic day-ahead scheduling of energy resources connected to ADNs.

✓ A mixed Integer Second Order Cone Programming formulation is used to model the optimization problem with a multi-objective function.

✓ The results show that the optimally controlled BESSs not only improve the quality of the service (i.e., decrease of voltage deviation) but also reduce the total losses and the day-ahead scheduling mismatch with respect to real-time scenarios.

✓ the proposed optimal control of these resources enables the load shifting and decreases the cost of energy supplied by the external sub-transmission network.
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