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

M. Nick, R. Cherkaoui, M. Paolone

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Contents

Introduction and Motivations

Smart Grids

- Progressive installation of distributed energy resources (DERs)
- Evolution of distribution networks **passive** → **active**

Challenges

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

Promising near-term solutions to postpone infrastructure investments:

→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

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Objective function

cost of changing the transformer tap-changer position

Energy cost

Day-ahead deviation cost

$$\textbf{minimize}\ \rho_{Sc}\sum_{Sc}\sum_{t}\{W_{Tap}TC_{Sc}(t)+W_{E}(E_{Sc}(t)\,\pi_{Sc}(t)+\gamma_{Sc,t}\left|E^{DA}(t)-E_{Sc}(t)\right|)$$

$$+W_{L}[\left(\sum_{ij\epsilon G}r_{ij}f_{ij,Sc}(t)\right)+\sum_{s}L_{s,Sc}(t)]+W_{LC}\sum_{i}LC_{i,Sc}\}$$

Network and BESS loses

Load curtailment

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Problem Formulation

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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

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Solution approach

The problem is ***Stochastic Non-Convex Mixed integer***

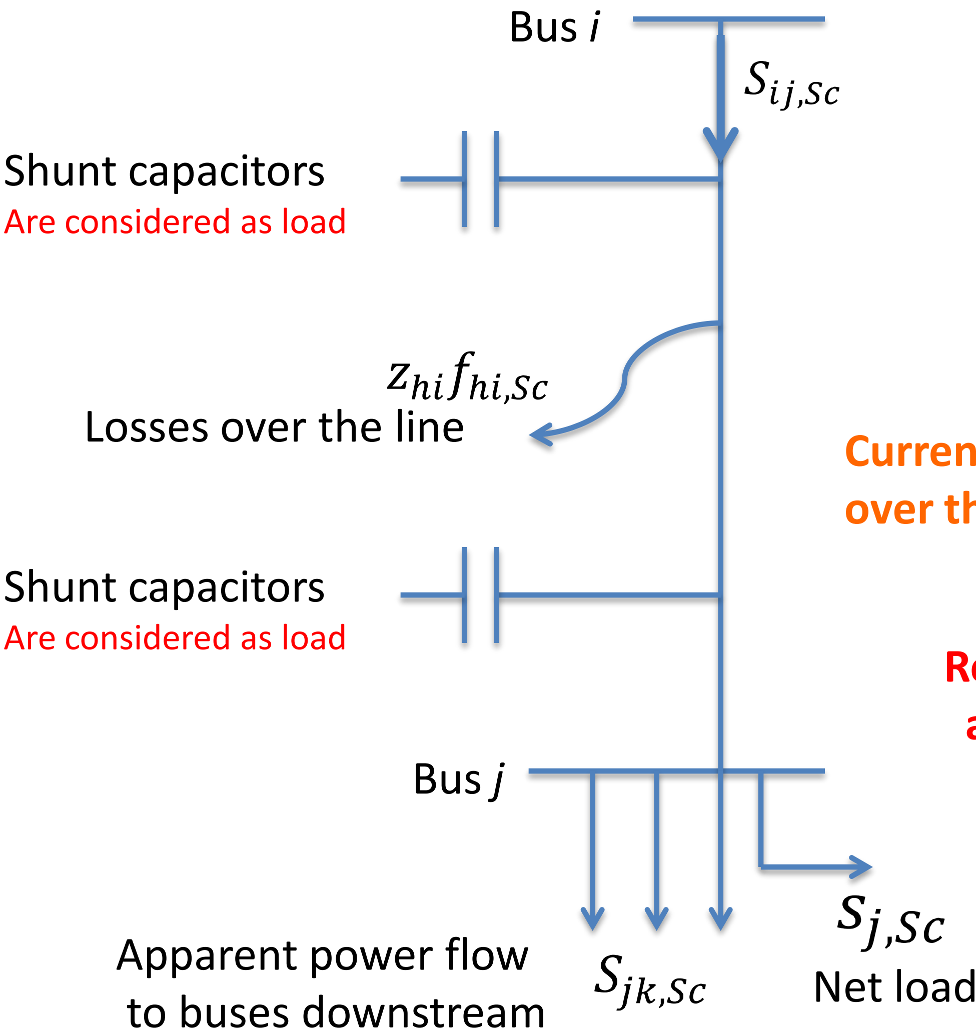
- ✓ *Integer variables* related to the *position* of the substation transformer *tap-changer*

- ✓ 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*

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

$$v_i = v_j + 2Re\left(\bar{z}_{ij} S_{ij}\right) - \left|z_{ij}\right|^2 f_{ij}$$

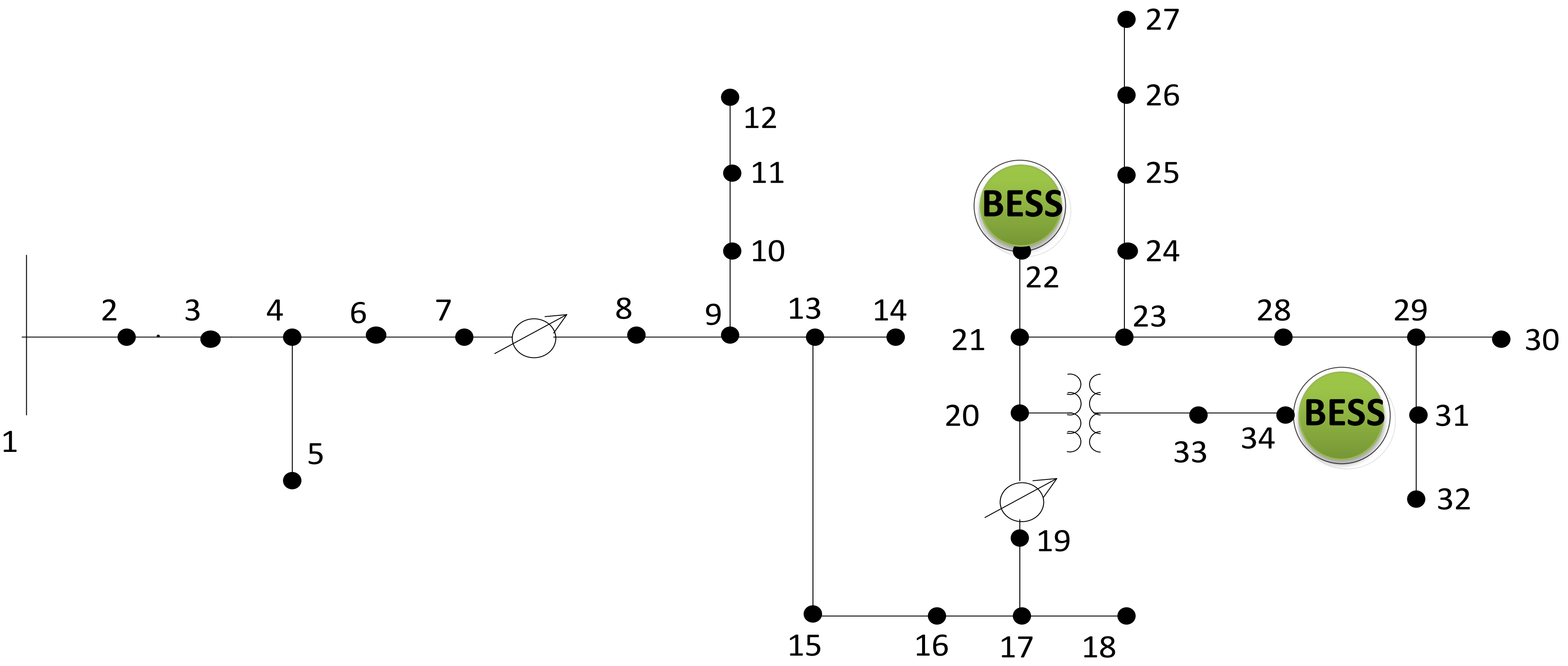
Current flow over the line

$$f_{ij} = \frac{\left|S_{ij}\right|^2}{v_i}$$

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

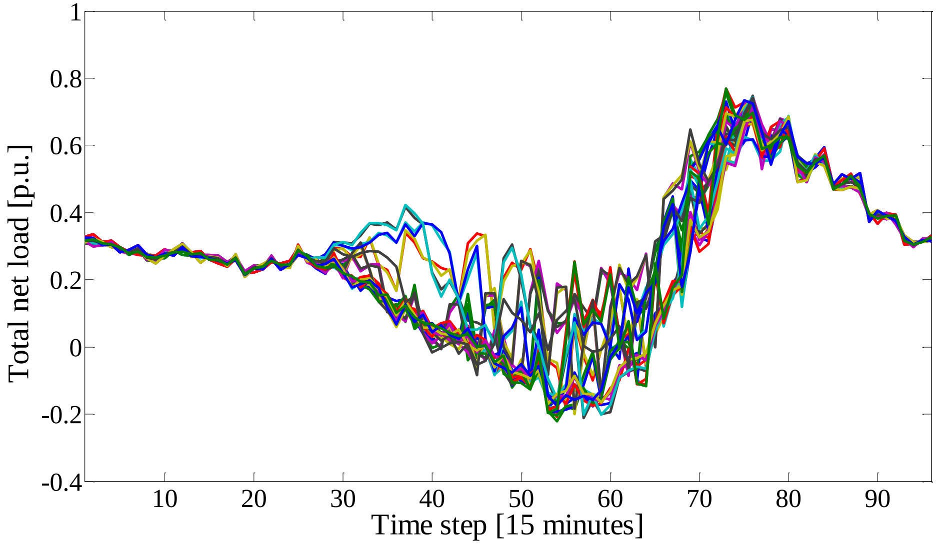
$$f_{ij} \geq \frac{\left|S_{ij}\right|^2}{v_i}$$

Case studies

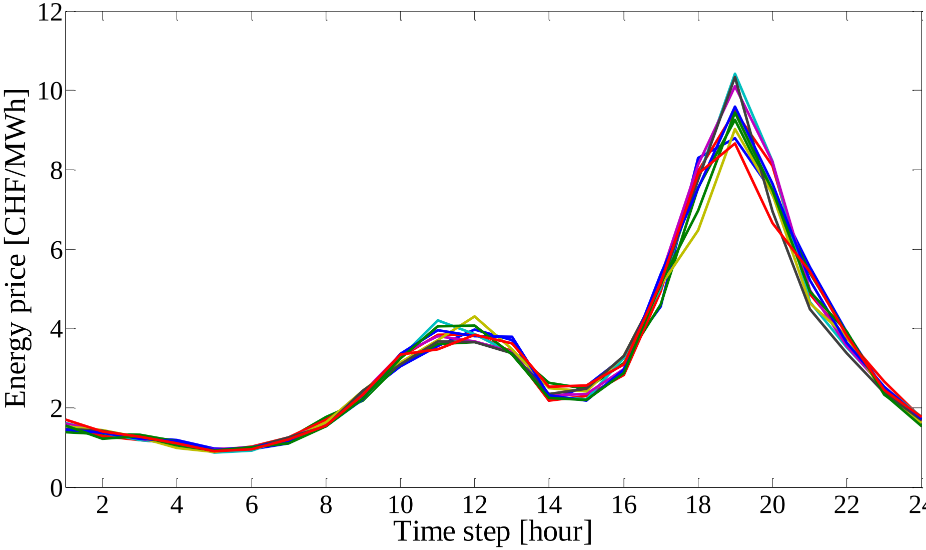


Modified IEEE 34 buses test system

Case studies



Total net daily active load scenarios (aggregated of the load and PV generation). The base power is 2.5 MW.



Energy price scenarios.

- ✓ **The K-means is used to cluster and reduce the number of scenarios**
- ✓ **The MISOCP solver of Gurobi optimization software via YALMIP-MATLAB interface is used**.

Case studies

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

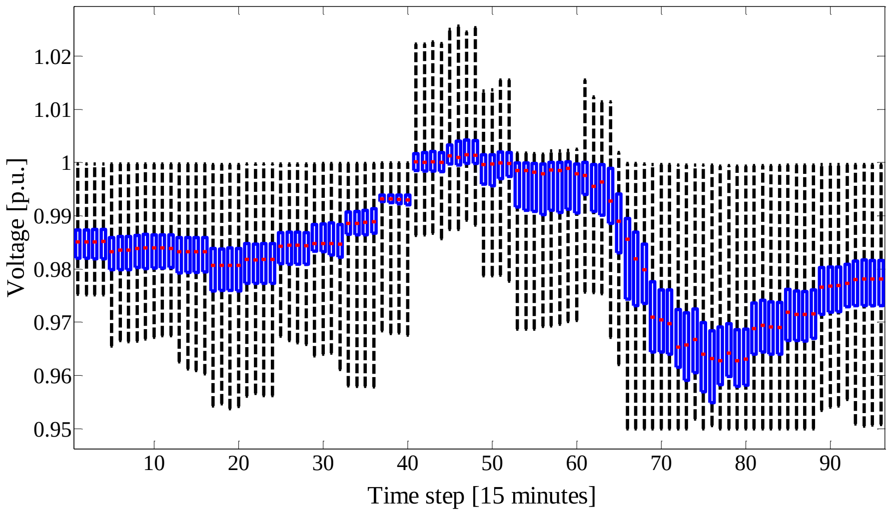
	Total average loss in whole scenarios [p.u.]	Use of Tap-changer	Load curtailment [p.u.]	Total Upward deviation [p.u.]	Total Downward deviation [p.u.]	Energy cost from the external grid [CHF]
With BESSs	**0.2138**	**No**	**0**	**2**	**1.23**	**201.22**
Without BESSs	**0.299**	**YES**	**0.85**	**3.17**	**1.8**	**246.34**

- ✓ 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

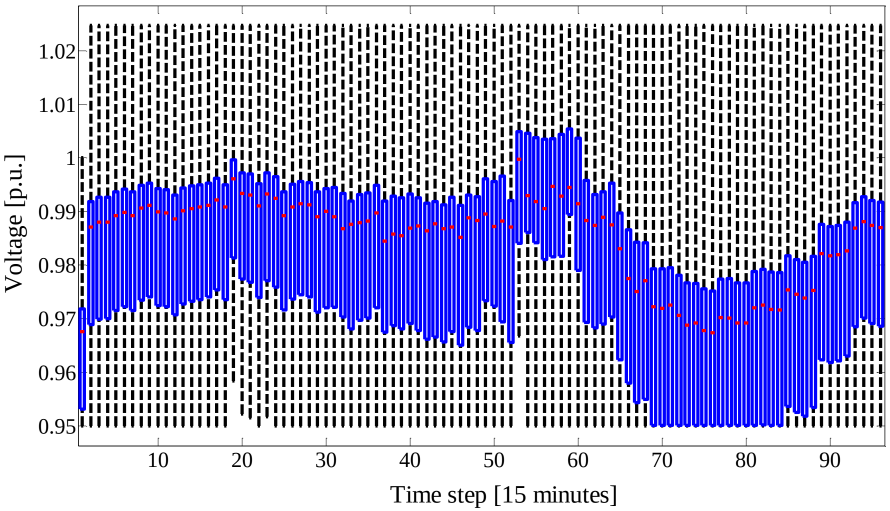
Case studies

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

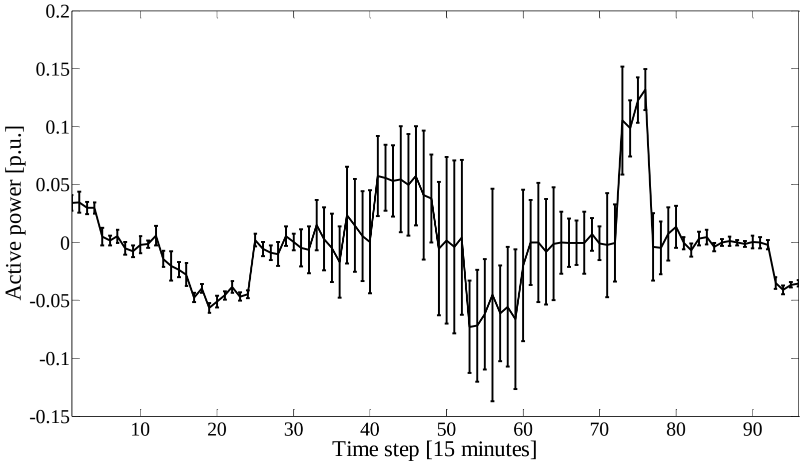


without BESSs

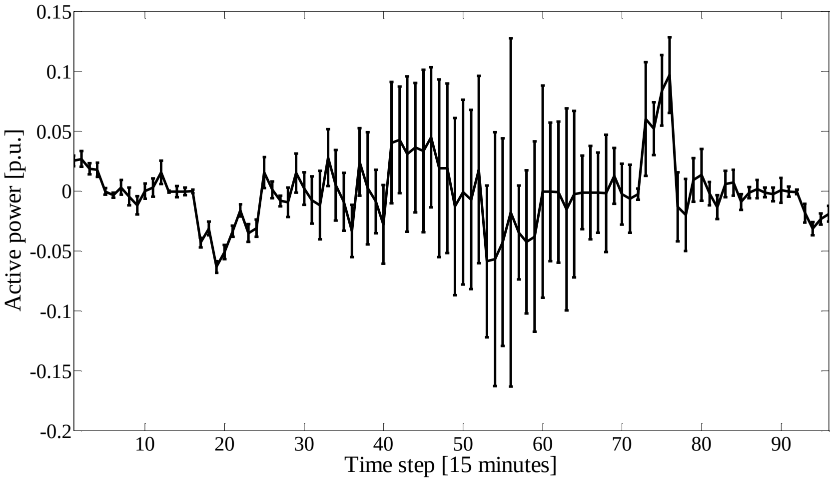
Case studies

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



BESS 2



BESS 1

CONCLUSIONS

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- ✓ 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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