A simulation environment for analyzing ancillary services from distribution grids

Marco Rossi (RSE)
A simulation environment for analyzing ancillary services from distribution grids

Development of realistic 2030 scenarios for the three reference countries

Italian case presented as example

Development of a simulation platform for the comparison of TSO-DSO coordination schemes

Presentation of the simulator working principles

Simulation of the potential distribution system contribution to ancillary services

Simulation of real-time balancing market and congestion management
How the simulator works

Simulation based on three layers

1. Market layer
2. Bidding and dispatching layer
3. Physical layer

The simulator works by iterating through time steps. At each time step, the state of the system is updated based on interactions across the three layers. The process is repeated for each subsequent time step, allowing for a dynamic simulation of the system's behavior over time.
How the simulator works

How the physical layer is simulated

- Physics simulation of controllable devices
- Network simulation
- Low-level operations on network asset
- Automatic Frequency Restoration (aFRR) Restoration

Time steps:
- Time
- Time step $k$
- Time step $k+1$
- Time step $k+2$
How the simulator works
How the physical layer is simulated

Thermostatically Controlled Load

- Environmental temperature
- Customers’ comfort and behavior
- Building thermal model
- Air conditioning system

Dynamic model

Aggregator

Temperature set-point

Active power consumption

Physics simulation of controllable devices

Network simulation

Low-level operations on network asset

Automatic Frequency Restoration

aFRR

Time

(time step k)

(time step k+1)

(time step k+2)
How the simulator works
How the physical layer is simulated

**Distribution Network Simulation**
- Collection of the power exchange of each device
- Power flow of the distribution network

**Transmission Network Simulation**
- Power exchange of large devices and distribution networks
- Power flow of the transmission network

**Physics simulation of controllable devices**

**Network simulation**

**Low-level operations on network asset**

**Automatic Frequency Restoration (aFRR)**

How the simulator works:
- At time step $k$:
  - Physics simulation of controllable devices
- At time step $k+1$:
  - Network simulation
- At time step $k+2$:
  - Low-level operations on network asset
  - Automatic Frequency Restoration (aFRR)

Distribution Network Simulation:
- Collection of the power exchange of each device
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Transmission Network Simulation:
- Power exchange of large devices and distribution networks
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How the simulator works
How the physical layer is simulated

Low-level network management operations
Network management in case of critical situations

- Automatic response of network asset
- Network topology reconfiguration
- Failure of a device and/or network component (trip of protections)
- Overvoltage and/or overloading of network buses and lines

Time

- Time step $k$
- Time step $k+1$
- Time step $k+2$
How the simulator works
How the physical layer is simulated

Automatic Frequency Restoration (aFRR)

In case of imbalance, automatic controllers promptly activate reserves in order to mitigate it. (the reserves will be restored later by balancing market)

- Instantaneous imbalance level calculation
- Activation of resources by means of a control signal
- Re-simulation of the network

Automatic Frequency Restoration (aFRR)
How the simulator works
How the bidding process is simulated

- Measurement of the devices status
- Evaluation of the available flexibility
- Construction of the flexibility bid
- Consideration of different markets

- Time step $k$
- Time step $k+1$
- Time step $k+2$

- How the bidding process is simulated
  - Time
  - Time step $k$
  - Time step $k+1$
  - Time step $k+2$
How the simulator works
How the bidding process is simulated

Measurement of the devices status

*(electric vehicle)*

- Current state of charge
- Driver necessities
- Mathematical model of EV

Optimization function

Total flexibility to sell

Evaluation of the available flexibility

Construction of the flexibility bid

Consideration of different markets

Measurement of the devices status

How the bidding process is simulated

Time step $k$

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How the simulator works
How the bidding process is simulated

Construction of the bid

- Optimization function
- Actual and forecasted cost of energy
- Eventual discomfort
- Bid reflecting the available flexibility and its cost

Evaluation of the available flexibility

Consideration of different markets

Measurement of the devices status

How the simulator works

Construction of the flexibility bid

Actual and forecasted cost of energy

Eventual discomfort

Bid reflecting the available flexibility and its cost

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Evaluation of the available flexibility

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Measurement of the devices status
How the simulator works
How the bidding process is simulated

Market arbitrage

- Market player
- Flexibility bid

Real-time balancing market
Intra-day market

Intra-day market is not simulated, but its interference on the balancing market bidding is considered.

- Measurement of the devices status
- Evaluation of the available flexibility
- Construction of the flexibility bid
- Consideration of different markets

time step \( k \)
time step \( k+1 \)

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How the simulator works
How the bidding process is simulated

Large power units (transmission system)
How the simulator works
How the bidding process is simulated

Industrial complexes

Aggregator of thermally controlled loads
Bid €

Aggregator of shiftable loads
Bid €

Aggregator of dimmable loads
Bid €

Aggregator of storage-based devices
Bid €
How the simulator works
How the bidding process is simulated

Aggregator of curtailable generators

Distribution networks

Bid €
How the simulator works

How the bidding process is simulated

Aggregator of curtailable generators

Aggregator of storage-based devices

Distribution networks
How the simulator works

How the bidding process is simulated

Distribution networks

Aggregator of curtailable generators

Aggregator of storage-based devices

Aggregator of thermally controlled loads

Aggregator of shiftable loads

Aggregator of dimmable loads
How the simulator works

How the market process is simulated

1. Market layer
   - Physical layer
   - Bidding and dispatching layer
   - Collection of the bids from market players
   - Market clearing process
   - Communication of the accepted bids

2. Estimation of the network state at \( k+1 \)

3. Time steps:
   - Time step \( k \)
   - Time step \( k+1 \)
   - Time step \( k+2 \)
How the simulator works
How the market process is simulated

Estimation of the network state at $k+1$

- The most updated status of the network is communicated from the physical layer.
- Forecasting error is simulated assuming that it is decreasing exponentially.
- Estimation of network imbalance and congestion status at $k+1$.

Collection of the bids from market players

Market clearing process

Communication of the accepted bids

<table>
<thead>
<tr>
<th>time</th>
<th>time step $k$</th>
<th>time step $k+1$</th>
<th>time step $k+2$</th>
<th>19</th>
</tr>
</thead>
</table>
How the simulator works
How the market process is simulated

Collection of the bids and market clearing

- Bids from transmission system devices
- Bids from distribution system devices

Market clearing algorithm

Model of the transmission system
Model of the distribution system

Estimation of the network state at $k+1$

Collection of the bids from market players

Market clearing process

Communication of the accepted bids

Time

- Time step $k$
- Time step $k+1$
- Time step $k+2$
How the simulator works
How the market process is simulated

Collection of the bids and market clearing

Collection of the bids from market players
Market clearing process
Communication of the accepted bids

Estimation of the network state at $k+1$

Model of the transmission system
Model of the distribution system

Market clearing algorithm

Bids from transmission system devices
Bids from distribution system devices

How the simulator works
How the market process is simulated
Estimation of the network state at $k+1$

Collection of the bids from market players

Market clearing process

Communication of the accepted bids

Collection of the bids and market clearing

Bids from transmission system devices

Bids from distribution system devices

TSO

DSO

Market clearing algorithm

Model of the transmission system

Model of the distribution system

How the simulator works
How the market process is simulated
How the simulator works
How the market process is simulated

Communication of the market directives
Network operations aimed at accommodating the activations

Bids acceptance

Estimation of the network state at k+1
Collection of the bids from market players
Market clearing process
Communication of the accepted bids

How the market process is simulated

Bids acceptance

(time step k)
(time step k+1)
(time step k+2)
How the simulator works
How the dispatching process is simulated

**Market layer**

**Physical layer**

Bidding and dispatching layer

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**How the dispatching process is simulated**

- Time step $k$:
  - Measurement of the devices status
- Time step $k+1$:
  - Evaluation of the available flexibility
  - Optimal repartition of the activation signal

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**Physical layer**

- Time: $k$, $k+1$, $k+2$
Optimal repartition of the activation signal

Measurement of the devices status

( Hydro power plant)

Current water flow

Generator status

Math. Model of the power plant

Optimization function

Available flexibility of each device

How the simulator works

How the dispatching process is simulated

Measurement of the devices status

(time step k+1)

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<td>Math. Model of the power plant</td>
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<tr>
<td>Optimization function</td>
</tr>
<tr>
<td>Available flexibility of each device</td>
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</table>

Evaluation of the available flexibility

Optimal repartition of the activation signal
How the simulator works
How the dispatching process is simulated

Optimal repartition of the activation signal
(disaggregation)

Optimization function
Accepted bid

Measurement of the devices status
Evaluation of the available flexibility
Optimal repartition of the activation signal

time

time step $k$

time step $k+1$

time step $k+2$
How the simulator works

How the physical layer is simulated

- **Physics simulation of controllable devices**
- **Network simulation**
- **Low-level operations on network asset**
- **Automatic Frequency Restoration (aFRR)**

Diagram:
- **Time step k**
- **Time step k+1**
- **Time step k+2**

- Network simulation:
- Automatic Frequency Restoration (aFRR)
- Low-level operations on network asset
- Physics simulation of controllable devices
How the simulator works

How the physical layer is simulated

Thermostatically Controlled Load

- Environmental temperature
- Customers’ comfort and behavior
- Building thermal model
- Air conditioning system

Dynamic model

Aggregator

Temperature set-point

Active power consumption

Physics simulation of controllable devices

Network simulation

Low-level operations on network asset

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How the simulator works

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Physics simulation of controllable devices

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Low-level operations on network asset

Automatic Frequency Restoration (aFRR)
Coordination schemes with **common market** in which transmission and distribution resources participate

Details on the exchanged information: used for the design of the **ICT network** and calculation of ICT costs (processed later by CBA)
Key products

Validated simulation environment (software modules + scenarios)

Dedicated Cost Benefit Analysis approach

Best TSO-DSO interaction patterns for each considered national case

Guidelines on hardware utilization within the considered TSO-DSO schemes
Thank You

Marco Rossi

Contact Information
Affiliation: RSE S.p.A.
Phone: +39 02 3992 5687
Email: marco.rossi@rse-web.it
How the simulator works
How imbalance and congestions are simulated

A **forecasting error** is introduced in order to model:
- deviations in electricity production from RES
- load stochastic behavior
- power plants/network failures
- non-accepted bids in previous markets

Consequences of these deviations:
- **Transmission system imbalance**
- *(Distribution system imbalance)*
- **Congestions on transmission network**
- **Congestions on distribution network**
European reference scenarios are processed in order to generate the system configurations and data to be used in simulation and laboratory studies.
2030 Scenario Data

Geographical allocation of the energy resources expected for 2030

- Population growth
- Renewables expansion
- Exploitation of new electrical devices
- Industrial development
2030 Scenario Data

Mapping of the geographical information on the electricity network
Coordination schemes with **separated markets**: one for transmission and one for distribution resources

### C. Transmission

**Market**
- Tx Market Operator
  - Bids and information on the Tx devices' capabilities
  - Market clearing
- Tx Retailer
  - Bids generation for non-aggregated resources at Tx
- Network operator
  - Forecasting of Tx network situation at \( k, k+1, k+2, \ldots \)
  - Tx devices status at \( k, k+1, k+2, \ldots \)
- Devices
  - Communication of the Tx network operations to be performed to allow the activation of flexibility
- Network
  - Tx network situation at \( k, k+1, k+2, \ldots \)
  - Power exchange in correspondence of the primary subsstation
- Physical (Tx)
  - Transmission and distribution networks and operation
  - ICT specifications and planning
  - Country-specific aspects and peculiarities

### C. Distribution

**Market**
- Dx Market Operator
  - Bids and information on the Dx devices' capabilities
  - Market clearing
- Aggregator
  - Bids generation for aggregated resources at Dx
- Dx Retailer
  - Bids generation for non-aggregated resources at Dx
- Network operator
  - Forecasting of Dx network situation at \( k, k+1, k+2, \ldots \)
  - Dx devices status at \( k, k+1, k+2, \ldots \)
- Devices
  - Communication of the Dx network operations to be performed to allow the activation of flexibility
- Network
  - Dx network situation at \( k, k+1, k+2, \ldots \)
  - Power exchange in correspondence of the primary subsstation
- Physical (Dx)
  - Transmission and distribution networks and operation
  - ICT specifications and planning
  - Country-specific aspects and peculiarities