Secure, decentralised Architecture for Power System Operation

Verlässliche, dezentrale Architektur zum Betrieb des elektrischen Energiesystems

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SMART GRIDS WEEK I VIENNA 2015
Smart Grid challenges

- Load – generation balance in high voltage grid
- Voltage violations in distribution grid

Centralised architecture

Decentralised architecture

Paradigm

VPP

ICT challenge
Big data exchange

extremely ramified and complex central coordination

Microgrids
“Although a detailed definition of microgrids is still under discussion in technical forums, a microgrid can be described as a cluster of loads, Distributed Generation (DG) units and ESSs operated in coordination to reliably supply electricity, connected to the host power system at the distribution level at a single point of connection, the Point of Common Coupling (PCC).

The adoption of microgrids as the paradigm for the massive integration of distributed generation will allow technical problems to be solved in a decentralized fashion, reducing the need for an extremely ramified and complex central coordination and facilitating the realization of the Smart Grid.”

Per definition the “Energy Supply Chain Net” is a set of automated power grids, intended for “Chain Links” or “Links”, which fit into one another to establish a flexible and reliable electrical connection. Each individual “Link” or a “Link”-bundle operates independently and have contractual arrangements with other relevant boundary “Links”, “Link”-bundles, and suppliers which inject directly to their own grid. Each “Link” or “Link”-bundle is communicatively coupled with the other relevant “Links” or “Link”-bundle’s via the usual communication instruments.

Power system overview based on the “Energy Supply Chain Net” model: horizontal und vertical axis

1. The **Link** is defined as a composition of a grid part, called Link_Grid, with the corresponding Secondary-Control and the Link_Interfaces.

- The **Link/Grid** refers to electrical equipment like lines/cables, transformers and reactive power devices, which are connected directly to each other by forming an electrical unity.

- The **Link/Grid size** is variable and is defined from the area, where the Link/Secondary-Control is set up.

*Source: “Secure Decentralized Architecture for Smart Grid Operation”, accepted to be published in Electric Power Systems Research - Journal - Elsevier*
2. The **Producer_Complex** is defined as a composition of an electricity production facility be a generator, photovoltaic, etc., its Primary-Control and the Producer_Interface.

3. The **Storage_Complex** is defined as a composition of a storage facility be the generator of a pump power plant, batteries, etc., its Primary-Control and the Storage_Interface.

**Source:** “Secure Decentralized Architecture for Smart Grid Operation”, accepted to be published in Electric Power Systems Research - Journal - Elsevier
The distributed Link-based architecture is defined

Different Link types:

a) HV-Link; b) MV-Link; c) LV-Link and d) CP-Link

High voltage

Customer plant

Medium voltage

Low voltage


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Power system operation processes

- Monitoring process

- Power system scenario analyses process

- Power system posturing processes (static security, angular stability, voltage stability)

- Load-generation balance process

- Operation optimization process
## Interface definition

### TABLE 1

<table>
<thead>
<tr>
<th>Electrical entities to be exchanged (*)</th>
<th>Link-Link</th>
<th>Link-Producer_Complex (**)</th>
<th>Link-Storage_Complex</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{\text{meas}}, \delta_{\text{meas}} )</td>
<td>( \checkmark )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( P_{\text{meas}}, Q_{\text{meas}} )</td>
<td>( \checkmark )</td>
<td>( \checkmark )</td>
<td>( \checkmark )</td>
</tr>
<tr>
<td>( P_{\text{set_point}}, Q_{\text{set_point}} )</td>
<td>( \checkmark )</td>
<td>( \checkmark )</td>
<td>( \checkmark )</td>
</tr>
</tbody>
</table>

- **Fast**
  - \( P_{\text{des}} \pm \Delta P \), \( Q_{\text{des}} \pm \Delta Q \)
  - Delivered time
  - Time interval

- **Very Fast**
  - \( V_{\text{meas}}, \delta_{\text{meas}} \)
  - \( P_{\text{meas}}, Q_{\text{meas}} \)

\* data related to the boundary node
\** P and Q can have only one sign. Producers only inject power on the grid
\*** static data should not be exchanged via interface

### TABLE 2

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>( P_{\text{dayahead Schedule}} \pm \Delta P )</td>
<td></td>
<td>( \checkmark )</td>
<td></td>
</tr>
<tr>
<td>( Q_{\text{dayahead Schedule}} \pm \Delta Q )</td>
<td></td>
<td>( \checkmark )</td>
<td></td>
</tr>
</tbody>
</table>

- **Static**
  - Static and dynamic (lumped) load characteristic \( k_{PV}, k_{QV}, k_{PF}, k_{QF} \)...
  - \( I_{\text{equiv}}, Z_{\text{equiv}} \)

- **Dynamic**
  - Dynamic equivalent Generator parameters like \( x_d, x_d', \ldots, T_{d0}, \ldots \)
  - Equivalent voltage regulator, static exciter parameters like \( K_A, T_A, \ldots \)
  - Equivalent governors, turbine parameters like \( K_1, T_{G1}, \ldots \)
  - Schedule for demand response capability
  - Reserves schedule (secondary, tertiary)

\* data related to the boundary node
\** P and Q can have only one sign. Producers only inject power on the grid
\*** static data should not be exchanged via interface

System operators for different Link types

Proposed structure

European type

System operators for different Link types

Each Link or Link-bundle operator be HVSO, MVSO, and LVSO including even the House-Lord (more exactly the HMU) should:

- balance the load and the injection in real-time, where the load represent the summation of the system native load and the scheduled exchange to other Links, while the injection represent the summation of the generation, injection from storage devices and the scheduled exchange to other Links.

- actively manage its Link or the Link-bundle

- monitor its Link-grid or the bundle of Link-grid

- access all the data of the Link

- exchange the data with the neighbour Links and all devices connected directly to the own Link-grid or to the bundle of Link-grid

- have the right to use and offer services to the neighbours

- have the right to dispute with the neighbours to guarantee a reliable and stable operation of his own Link_Grid

- decide the actions should be taken for a secure and optimal operation of the own Link or Link-bundle

- be incentivized to invest in adequate solutions, beyond physical reinforcements, to increase the flexibility of the Link or Link-bundle

- to facilitate effective and well-functioning retail markets

Demand response process: line overload on high voltage grid

One line is overloaded. It is required 2% and 6% demand reduction in points \( A^H \) and \( B^H \) respectively.

**MV_Link_1**
2% demand reduction can be reached by using CVR. No other actions are necessary.

**MV_Link_2**
Only 5.4% demand reduction can be reached by using CVR. Other actions are necessary.

**LV_Link_1**
0.4% demand reduction can not be realised within the link. Other actions are necessary.

**LV_Link_2**
0.2% demand reduction can not be realised within the link. Other actions are necessary.

Customer-Link
0.4% demand reduction by switching off cooling system. No other actions are necessary.

Dynamic security process for the HV_Link:
a) Interlink information exchange; b) Calculation model

The dynamic behavior of a neighbor Link has changed. Recalculate the dynamic (angular and voltage) stability.

One DG is switched on. \( \text{DEG}^{\text{new}} \) and \( \text{EI}^{\text{new}} \) are calculated on line. They are different from the previous one.

The scheduled data exchange on:

a) centralized and    b) decentralized architectures

Number of exchanged schedules

3 \cdot N

N – Number of Significant Grid Users (Power Generating Facility Owner)


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The scheduled data exchange on:

a) centralized and b) decentralized architectures

Article 25

Scheduled data exchange between TSOs, DSOs and Significant Grid Users according to Article 1(5)(a) and Article 1(5)(d) connected to the Distribution Network

1. Each Significant Grid User which is a Power Generating Facility Owner according to the Article 1(5)(a) and Article 1(5)(d) and with Connection Point to the Distribution Network, shall provide its TSO and/or its DSO with its scheduled unavailability, Active Power restriction and its forecast scheduled Active Power output at the Connection Point. Organization of the data exchange shall be defined according to the key organisational requirements, roles and responsibilities established in Article 16(6) to Article 16(8).

2. Each Significant Grid User which is a Power Generating Facility Owner according to Article 1(5)(a) and Article 1(5)(d) shall provide to its TSO and/or its DSO any forecasted restriction in the Reactive Power control capability. Organization of the data exchange shall be defined according to the key organisational requirements, roles and responsibilities established in Article 16(6) to Article 16(8).

Source: Network Code on Operational Security, 24 September 2013, ENTSO-e homepage
Power system global component base IT architecture

The accommodation of the different link_operators as market actors

MV-Link, realized and operated in the framework of ZUQDE project

Reactive power and voltage control
MV-Link, realized and operated in the framework of ZUQDE project

Reactive power and voltage control
Conclusions

The new decentralised architecture for the power system operation:

- is kept simple and distinct

- has one major, standardised component, the “Link”, which presents the entire power grid and the customer plants. The “Link” upgrades the “microgrid” paradigm.

- provides cyber security and data privacy by minimizing the number of the exchanged data

- facilitates all actual power system operation processes like load-generation balance, voltage assessment, outage managements, etc.

- facilitates the involvement of demand response in the grid operation

- fulfils the electricity market rules
Thank you for the attention

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