VIRTUAL POWER PLANT FUNCTIONALITIES
DEMONSTRATIONS IN A LARGE LABORATORY FOR DISTRIBUTED ENERGY RESOURCES

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ABSTRACT

Future scenarios of having a large share of renewable energies and distributed generators in electric power supply require an active participation of these units in system operation in order to guarantee secure power supply. This paper considers the aggregation concept of a virtual power plant to directly control distributed energy units with regard to active and reactive power. The large DeMoTec laboratory at ISET is used for demonstrating the capabilities of providing ancillary services by Distributed Energy Resources (DER). One experiment is presented demonstrating optimized reactive power supply by distributed generators with the objective to minimize network congestions and operational costs.

INTRODUCTION

According to related political aims, incentives are offered in some countries that boost distributed generators and renewable energies. In the past, the main objective was to feed-in maximum active power, but in future, the need for active participation by supporting network operation increases. With high shares of distributed generators they principally should cover similar control tasks as conventional power plants, including active and reactive power control.

A consortium of 20 partners works on a 4-year project codenamed FENIX (see http://www.fenix-project.org) whose overall aim is to conceptualise, design and demonstrate a technical architecture and commercial framework that would enable distributed generation to constitute the cost efficient, secure and sustainable European electricity supply system of the future. The objective of FENIX is to boost the contribution of distributed generators to the electric power system, through aggregation into Virtual Power Plants (VPP) [1]. One key task to reach this objective is the demonstration of various capabilities of Controllable Distributed Energy (CDE) units (incl. generators, loads and storage) [2] that are aggregated in a VPP [3] in laboratory environment. ISET provides with the Design Centre of Modular Supply Technologies (DeMoTec) a well-equipped laboratory for such demonstrations. The Information, Communication, and Control Technology (ICCT) infrastructure for controlling distributed energy units with regard to active and reactive power is available and allows a variety of scenarios and demonstrations on how CDE units can contribute to network operation by providing ancillary services [4].

This paper presents the laboratory infrastructure and first experiments with regard to optimized reactive power supply.

DEMONSTRATION OF THE FENIX CONCEPT

VPPs according to the FENIX concept [1] can have many functionalities including

- Participation on electricity markets,
- Participation in balancing mechanisms,
- Contribution to voltage control,
- Contribution to keeping active and reactive power schedules, and
- Contribution to congestion management.

These functionalities are demonstrated in real networks of IBERDROLA in Spain and EDF Energy in the UK. But also demonstrations in laboratory and by simulation are performed.

Many of the listed functionalities of the FENIX VPP concept can be effectively demonstrated in DeMoTec. In addition, simulations with the professional network simulation software PowerFactory from DIgSILENT are used at ISET for further validation.

LABORATORY INFRASTRUCTURE

The laboratory infrastructure of the DeMoTec is explained in this section: (1) the controllable distributed energy units, (2) the network topology, and (3) the ICCT infrastructure. Here, the focus is on the used infrastructure for the FENIX demonstrations.

Controllable Distributed Energy Units

Six different distributed energy units in DeMoTec are extended to be controllable with regard to active and reactive power in grid-tied operation. These units are

- 200 kVA Biodiesel Generator Set,
- 100 kVA Multifunctional Inverter
- 80 kVA Synchronous Generator (SG) Set in Figure 1,
- 20 kVA Speed-Variable Inverter-Coupled Diesel Generator Set,
- 15 kVA Synchronous Generator Set, and
- 12 kVA load cabinets.

The first four units can also be operated in grid-forming mode where they are controlled with regard to voltage and frequency. This allows operating the experimental setup in island mode, independent from the mains.
**Network Topology**

The DeMoTec power network allows connecting the available distributed energy units at four different busbars in the 400 V network and interconnecting them over a 10 kV hardware network simulator as given in Figure 2.

**ICCT Infrastructure**

The ICCT infrastructure is designed for controlling distributed energy units with regard to active and reactive power. Figure 3 depicts the ICCT infrastructure that consists of a central Supervisory Control and Data Acquisition (SCADA) unit as well as six local Remote Terminal Units (RTUs) for the different CDE units. These units are programmed using LabVIEW and installed on standard Windows Personal Computers (PCs). In addition, a central measurement server on a Windows PC provides data from the measurement devices A2000 from GMC that are installed at different nodes in the DeMoTec grid.

The communication is based on standard open protocols with interfaces to proprietary protocols. OLE for Process Control (OPC™) via Ethernet is used as the standard protocol for communication between the SCADA OPC server and the RTUs (OPC clients). Each CDE unit has its proprietary protocol for local control that is interfaced by LabVIEW. The RTUs can be controlled by the SCADA in a centralized approach or they can be controlled locally in a decentralized approach independent from the SCADA. This allows analyzing different ways of integrating CDE units in network operation. Moreover, it is possible to connect professional SCADA systems using the standard OPC interface. Also synchronization with PowerFactory simulations is feasible.
EXPERIMENT: REACTIVE POWER SUPPLY

The experiment demonstrates the approach of centrally optimizing the reactive power dispatch taking into account network elements, network losses, reactive power supply costs, and the capabilities of each of the connected CDE units. First the experimental setup is described, then the approach of optimized reactive power supply and finally the measurement results.

Objective

Congestions in the external grid are assumed in this case study. The (DeMoTec) network operator aims at compensating the full reactive power flow at the grid connection point in order to reduce these congestions. The objective is to compensate at minimum operational costs.

Experimental Setup

Three distributed generators are controlled in this experiment:
- a 20 kW Biogas plant (Biogas) represented by the 80 kVA SG,
- a 8 kW Wind turbine (WT) represented by the 15 kVA SG, and
- a 16 kWp photovoltaic generator (PV) represented by the 20 kVA inverter-coupled generator.

The active power generation of these three units is given in Figure 4 with the measured values in DeMoTec. Basic parameters to calculate the operational costs of reactive power supply can be reduced by 10% if the biogas plant is used instead of a STATCOM at the connection point to the external grid. The (DeMoTec) network operator aims at optimizing the reactive power dispatch taking into account the network but also in the grid-coupling converters of the connected CDE network elements, network losses, reactive power supply costs, and the capabilities of each of the connected CDE units. First the experimental setup is described, then the approach of optimized reactive power supply and finally the measurement results.

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The reactive power demand of this LV feeder as well as the reactive power supply can be reduced by 10% if the biogas plant is used instead of a STATCOM at the connection point to the external grid. The reactive power demand of this LV feeder as well as the reactive power supply of the DeMoTec network is compensated by the three generators according to the calculated reactive power profile.

Table 1. Parameters of represented generators

<table>
<thead>
<tr>
<th></th>
<th>PV</th>
<th>WT</th>
<th>Biogas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of grid-coupling converter</td>
<td>Inverter</td>
<td>SG</td>
<td>SG</td>
</tr>
<tr>
<td>Maximum efficiency $\eta_{\text{max}}$ of grid-coupling converter</td>
<td>97%</td>
<td>96%</td>
<td>95%</td>
</tr>
<tr>
<td>Maximum active power $P_{\text{max}}$</td>
<td>16 kW</td>
<td>8 kW</td>
<td>20 kW</td>
</tr>
<tr>
<td>Sizing ($S_{\text{max}}/P_{\text{max}}$)</td>
<td>1</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td>Guaranteed $Q_{\text{max}}$</td>
<td>0 kvar</td>
<td>0 kvar</td>
<td>15 kvar</td>
</tr>
<tr>
<td>Deactivation</td>
<td>At night</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Feed-in Tariff (generation)</td>
<td>40 c€/kWh</td>
<td>10 c€/kWh</td>
<td>20 c€/kWh</td>
</tr>
<tr>
<td>Power purchase costs (consumption)</td>
<td>10 c€/kWh</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Measured values of active power generation $P$ from PV (red), WT (blue) and Biogas (green)

The reactive power that needs to be compensated is simulated software-based as an additional 30 kVA load. It represents a LV feeder with consumer loads that is connected at the same connection point to the external grid.

The reactive power generation of this LV feeder as well as the reactive power demand of the DeMoTec network is compensated by the three generators according to the calculated reactive power profile.

Optimized Reactive Power Supply

Reactive power supply causes additional losses not only in the network but also in the grid-coupling converters of supplying generators. These additional losses cause operational costs. An assessment approach is presented in [5]. The operational costs of reactive power depend on the actual operational point of the considered generator and its specific characteristics as given in Table 1. These variable costs give potentials for economic optimization. The distribution of reactive power supply to all three units is optimized with the objective to minimize the operational costs of reactive power supply. In the given example, the operational costs of reactive power supply can be reduced by 10% if the biogas plant is used instead of a STATCOM at the connection point to the external grid with a maximum efficiency of 98% that is connected with the same 100 kVA transformer.
If the network operator takes into account the PV plant and the WT in addition to the biogas plant the operational costs are reduced further by approx. 46%.

The optimized reactive power supply is simulated with PowerFactory and depicted in Figure 6 where the reactive power flow at the external grid is near to zero. As the WT has the lowest operational costs it is used at the highest rate (in per unit values). The PV generator stays deactivated at night without irradiation because the costs are higher than during the day (see explanation in [5]). During the day, it is used as well but at the lowest rate because of the highest costs by lost feed-in payments. At around 18 h, the share of the WT is reduced because it operates near rated active power and no additional reactive power capacity is available. In this case, the other generators have to supply a higher share of the reactive power.

**Comparison with Measurements in DeMoTec**

The expected behaviour according to the target values is compared to measurements in the DeMoTec with the described experimental setup. One test run representing 24 h is performed within 48 min with 30 s for each 15 min step and with a resolution of approx 0.5 s between each measurement point.

![Figure 6](image)

*Figure 6. Reactive power supply from PV (red), WT (blue), Biogas (green), reactive power demand of the Load (black) and total flow to External Grid (grey)*

![Figure 7](image)

*Figure 7. Reactive power supply [kvar] measured in DeMoTec at the external grid connection Q\text\_meas (grey) and reactive power of the assumed load Q\_load (black)*

The objective of this central control approach is to compensate the reactive power demand of the load at the external grid connection. To verify the achieved result, the reactive power flow in the DeMoTec experiment is measured at the connection point to the external grid and compared with the sum of all reactive power profiles of the generators as given in Figure 7. Small differences are mainly caused by oscillations of reactive power supply by some laboratory units.

**CONCLUSIONS**

A virtual power plant concept allows directly controlling distributed energy units with regard to active and reactive power in order to support system operation. The DeMoTec laboratory at ISET is used for demonstrating the capabilities of providing ancillary services by distributed energy units. One experiment is presented demonstrating optimized reactive power supply with the objective to minimize network congestions and operational costs. The determined optimal reactive power schedules for the generators are kept well with little deviations that will be improved further.

The infrastructure allows many more scenarios being demonstrated with modified configurations and control functions. In addition, these experiments are simulated with PowerFactory in order to prepare, extend and complement the demonstration activities.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


