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R QUALITY IMPROVEMENT THROUGH GENERATION AND POWER EXCHANGE ON DISTRIBUTION LEVEL

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INTRODUCTION
The distribution networks will become more and more independent for reasons of dispersed generation, storage and power exchange between distribution systems. However, the dispersed generation comes mostly from sources which output depends on meteorological conditions and can not be continuously in accordance with the demand. The approach for inclusion the discontinuous character of renewable energy generation into the system planning and the decentralized energy management is considered. For a pilot network it is shown that the dispersed generation close to the customer and the power exchange on distribution level may be an economical and ecological favorable alternative to the network enhancement for providing a higher level of power quality.

DISPERSED GENERATION
The dispersed generation and its power infeed into the distribution systems is driven by economical effects of the deregulation process and meets the intention for environmental protection additionally. The rules for the distribution network connection are defined in [2]. Which are the reasons for the fast grow of dispersed generation in the last years?
First of all, the energy supply company has to pay for the use of the overlaying transmission and distribution networks in relation to the peak load. Consequently, the decrease of the load transfer through the networks by load management and own generation can lead to an economical benefit for the supply company.
Secondly, the move or/ and increase of loads in the distribution networks requires usually further investment for the network enhancement. But if the own generation moves closer to the customers and covers the load increase the investment for network extension can be saved.
Thirdly, the combination of economical and ecological advantages fits the policy for environmental protection and is co-financed by laws of the German government.

The economical and technical efficiency of this approach has to be investigated in a special pilot project named “Edison”. This project is supported by the German Federal Ministry of Economy and Technology.
Besides the application of renewable energy sources (wind and solar), of storage units and of units using cogeneration of electric power and heat for single households or district heating on the base of fuel cells and gas turbines the following additional goals are matter of the project:

1. Implementation and operation of the decentralized energy management system DEMS for
   - minimizing energy costs
   - maximizing the use of renewable energy
   - maximizing the network utilization and prevention of local network overloads.

The principle of DEMS is presented in figure 1. The DEMS control output is connected to all units participating in the energy management process via communication links. The target values for all generation units and controllable loads can be set in accordance with a previously calculated schedule in a 15 minutes interval and in emergency cases faster or manually. The goal is to achieve the behavior of a “virtual power station” with a
definite power output in relation to the demand in the environment of controllable loads, several generation and storage units.

2. The dispersed generation will change the hierarchical structure of the distribution networks so that, in the context of these modifications, a detailed new system planning process is also required with respect to the economical and technical application of the new technologies. A need for development of simulation models for the new technological components and their inclusion into existing network planning software occurs for precise calculation of

- the changing load flow conditions in accordance with the load course and the discontinuous character of the dispersed generation (static scenarios),
- the behavior in the case of faults and dynamic changes of load or topology (dynamic scenarios).

These simulation models were developed for wind generators, photovoltaic power sources, several kinds of batteries, fuel cells and gas turbines with cogeneration of heat and power. Their application was proven in a network study. It was shown that the growing share of dispersed generation in distribution systems needs such an enhanced approach to the network planning [1].

POWER EXCHANGE VIA MVDC-COUPLER

An additional opportunity for minimizing the energy costs is the energy purchase from other distribution or industrial systems in the neighborhood. However, the galvanic connection of distribution or industrial networks is mostly impossible for different reasons like:

- Differences of the voltage angles on the feeding busbars cause unacceptable circular currents;
- Limitation of residual currents in neutral compensated networks;
- Different neutral earthing concepts of both networks;
- Separation of the networks is needed for reason of different levels of voltage quality or reliability.

In this and other cases a galvanic separated connection of the networks is required to perform the desired power exchange.

In recent decades power electronics have evolved into efficient, reliable and flexible technology. Therefore, Medium Voltage Direct Current (MVDC) Couplers based on self commutating converters using IGBT elements (Insulated Gate Bipolar Thyristor) found an economical advantageous application in several projects for galvanic separated network coupling on distribution level [3]. The principle of a MVDC Coupler is demonstrated in figure 2. The active power flow P can be adjusted to the system requirements in both directions. Thanks to self commutating technology, the coupler can additionally control the reactive power Q and, consequently, the voltages in both interconnected networks independently.

![Figure 2. Principle of a MVDC Coupler](image)

The changes from operation with reactive power generation into operation with reactive power demand can be performed within some ten milliseconds as it is shown in figure 3.

![Figure 3. Change of operation mode of a MVDC Coupler and elimination of harmonics](image)

Further more, the MVDC Coupler uses filters to eliminate the harmonics resulting from the AC/DC converting. These filters can also help to avoid harmonics in both networks (see figure 3). The simulation models of the MVDC-coupler were developed for static and dynamic scenarios as well.

FEATURES OF THE REFERENCE SYSTEM AND ITS RESTRUCTURING

The new generation, storage and MVDC coupling technologies are used in an actual municipal network with fare rural network parts. The topology of this network is presented in Fig.4.

The network parts Net3 and Net4 are separated for reason of residual current limitation. Net3 is supplied via the overhead line 2 only and during an outage of this line the supply of the network Net3 will be interrupted. The (n-1)-reliability criterion could not be fulfilled. Further more, the outage of line 1 causes a limit exceeding of the power transfer through the network part Net1 and requires a load limitation. The outage of line 3 causes a supply interruption...
for the customers of the two last ring main units C and D of the network part Net4.

Figure 4. Topology of the reference network and critical situations

In the network part Net3 two low voltage networks have a big number of heating units consuming the energy at night. An overload of the feeding 20/0.4 kV transformers occurs up to 26% for appr. 2 hours in winter nights (case 4). All these circumstances cause an unacceptable low level of supply reliability for the customers.

Figure 5. Restructuring of the reference network by means of dispersed generation/ storage (DG/S) and MVDC-Coupler

The restructuring of the distribution system was analysed using dispersed generation, storage and HVDC coupling as presented in figure 5. The following measures are foreseen in accordance with the existing opportunities:

1. Splitting of Net3 in two parts Net3-1 and Net3-2;
2. Cable connection between D and Net3-2 (600 m);
3. Connection of Net3-1/2 by a MVDC Coupler;
4. Dispersed generation in NET2:
   - Gas turbine cogeneration unit 1.5 MW,
   - Fuel Cell cogeneration unit 250 kW;
5. Dispersed generation in NET3-1 (low voltage):
   - Household fuel cells 50 kW,
   - Photovoltaic units 100 kW,
   - 3x100 kW batteries (600 kWh);
6. Dispersed generation in Net3-2 (medium voltage):
   - Wind power generation 1.2 MW,
   - 1 MW (2MWh) battery.

An example of the use of the simulation models in the environment of dynamic changing load flow conditions in the reference network is shown in figure 6.

Figure 6. Load profiles (P) of the infeed, via MVDC Coupler and of the dispersed generation/ storage units

The results of the investigations for the restructured network may be summarised as follows:

- In all critical outage situations acc. Figure 4 the (n-1)- criterion for reliability is fulfilled;
- The load flow and short circuit calculations in the dynamic changing generation conditions (using the above mentioned simulation models) demonstrate the feasibility of the restructuring approach;
- The batteries in NET3-1 support the supply of the heating units during the night peak and bring down the overload of the transformers;
- All the simulation models for the new network components were successful tested and can be used future projects.

Additionally, an fundamental improvement of power quality regarding both its components:

- Voltage quality
- Reliability of supply

was achieved, what is demonstrated in the next chapter.
IMPROVEMENT OF POWER QUALITY

Reliability

Today, probabilistic methods to provide concrete reliability indicators are included in advanced software tools for power system planning. The reliability investigations provide a detailed description of supply reliability using appropriate indices, see Table 1. These indices then provide a quantitative quality statement for the whole power system or for individual customers.

Table I  Probabilistic reliability indices

<table>
<thead>
<tr>
<th>Index</th>
<th>Sym.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of supply interruptions</td>
<td>$F_i$</td>
<td>1/a</td>
</tr>
<tr>
<td>Average duration of supply interrupt.</td>
<td>$T_i$</td>
<td>h</td>
</tr>
<tr>
<td>Probability of supply interruption (also: non-availability)</td>
<td>$Q_i$</td>
<td>1, or min/a</td>
</tr>
<tr>
<td>Interrupted power (cumulative)</td>
<td>$P_i$</td>
<td>MVA/a</td>
</tr>
<tr>
<td>Energy not delivered in time (cum.)</td>
<td>$E_i$</td>
<td>MVAh/a</td>
</tr>
<tr>
<td>Monetary evaluation</td>
<td>$C_i$, $R_i$</td>
<td>€/a</td>
</tr>
</tbody>
</table>

In this way, an differentiated assessment is possible and should be used complementary to the (n-1) criterion. For the considered network the following improvement of the assessment indices could be achieved:

- Expected energy not delivered in time:
  - 3.1 MWh/a $\rightarrow$ 0.12 MWh/a;
- Expected duration of supply interruptions in Net3:
  - 1.15 h/a $\rightarrow$ 2 minutes/a.

Consequently, an expensive network enhancement with a doubling of branches could be avoided through the described restructuring.

Voltage quality

During a day, as the result of the changing load flow the highest voltage drops occur in the remotest network part Net3. The voltage controller in the feeding substation has to keep the voltage tolerances within the bandwidth. However, for the original network topology the voltage in Net3 decreases until 97% in the case of normal network operation (figure 7).

After restructuring the voltage drop does not exceed 1% and this is achieved without any operation of the tap changer.

In figure 8 the similar relations are shown for the case of an outage of line 1. Here the voltage drop achieves 5% for the original network and can be limited to 3% in the restructured network.

CONCLUSIONS

The use of dispersed generation and power exchange on the distribution level can help to improve the power quality in existing networks. In this context, the application of the new technologies for dispersed generation, storage and MVDC coupling can be an economical advantageous alternative to the traditional network extension. However, this is not a general statement and the approach of restructuring needs a detailed network analysis for finding out the feasibility limits and the optimum operation conditions. For this purpose simulation models of the new technologies were developed and implemented in existing planning tools. Furthermore, the network operation shall be supported by an decentralized energy management. Such a system prepares and manages the optimized schedule for the dispersed generation, storage and power exchange units in accordance with the weather and the load forecast. The DEMS ensures the behavior of a “virtual power plant” providing a definite and dispatchable power output.

REFERENCES