

ADVANCED PLANNING AND OPERATION OF DISPERSED GENERATION ENSURING POWER QUALITY, SECURITY AND EFFICIENCY IN DISTRIBUTION SYSTEMS

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1 MOTIVATION

In Europe the dependency on imported primary energy increases from year to year and will achieve 70 % in 2003 [1]. As a countermeasure against this growing dependency national programs inside the European Community are directed to increase the share of renewable energy sources and the efficiency of power generation by cogeneration of heat and power (CHP). Targets are set from the European Commission for each country.

Generally, the share of renewable energy sources has to be increased until 2010 from 14 % to 22% [1] and the share of CHP has to be doubled from 9 to 18% [2].

Assuming that the wind power will grow preliminary by the way of large wind farms feeding into the transmission grids with additional 40 GW installed power until 2010 (today approximately 30 GW are operated in Europe and over 50 % of them are located in Germany), the dispersed generation shall achieve an additional growth of 300 TWh/a to meet the mentioned goals.

The output of most of the renewable energy sources depends on meteorological conditions and the CHP output is driven by the demand of heat. The rated installed wind power, for example, is used in Germany for approximately 1600 h per year only. Thus, if the contribution of renewables and CHP in the electric energy generation shall achieve 40 %, their share of the installed power generation capacity must exceed 60 %.

The question arises, how a network can be operated with such a large share of today mostly undispatchable power sources? How can the reserve power be limited which is required for compensation of power fluctuations and ensuring a safe network operation?

Thus, it becomes clear that advanced planning and energy management approaches have to be introduced to ensure the today existing high level of power quality in the future as well.

In this context, a vision sees the power system of the future consisting of a number of microgrids. In each of these microgrids a significant share of the power demand will be covered by dispersed generation. However, the power balance of the microgrids shall be planable and dispatchable in such a way that the import or export of power from or into the higher level network has to follow a schedule which can be predicted with a high level of accuracy in advance.

2 GOALS OF A GERMAN PILOT PROJECT

A pilot project called EDISON (Electricity Distribution Integrating Systems Of New generation, storage and coupling technologies and using advanced information and communication systems for the dispatch) was founded by the Federal Ministry for Economy and Technology in Germany to

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investigate the operational behavior of a distribution microgrid with a large share of renewable sources and CHP units.

The targets were defined as the development of:

- methods analyzing the conformity and reliability of large scale dispersed generation in existing networks;
- the dispatchability of microgrids with a significant share of dispersed generation and storage by means of decentralized power generation and load management (further called as Decentralized Energy Management Systems DEMS) and the use of the related communication channels in practice;
- experience in practice and definition of the future requirements for the operation of such new technologies like Fuel Cell CHP, innovative battery storage units or MVDC couplers [3].

A part of a 20 kV distribution network in a rural area was selected as microgrid. This microgrid can be characterized as follows:

- The microgrid serves a village with 3200 inhabitants, the peak load is 3,5 MW.
- The microgrid is connected to the main network parts by one overhead line with a length of 4 km only. However, about 200 m from the village border the dead end feeder of a neighbor network supplies a farm. A direct connection of both networks for getting a second infeed is not possible because of threshold exceeding of the residual currents in both neutral compensated networks.
- As a result of the remote location of the microgrid from the feeding substation the voltage level drops down to 95% in the worst case.
- The reliability assessment targets are unacceptable with 1,14 h outage time per year and 3,1 MWh/a energy not served in time.
- Three 20/ 0,4 kV transformers are overloaded for 2 hours in winter nights up to 126% because of a high concentration of night heating units in the related 0,4 kV networks.

The potential for establishment of dispersed generation was analyzed and in the result the connection of innovative components was foreseen in accordance with figure 1.

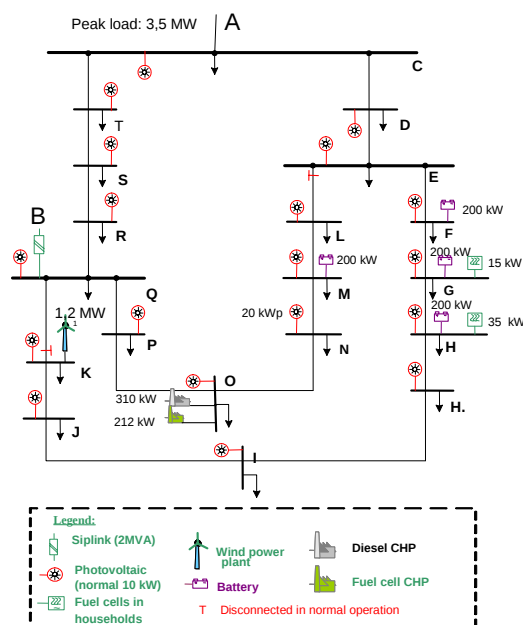


Fig. 1 Scheme of the 20 kV microgrid with dispersed units for generation, storage and MVDC network coupling

The microgrid was equipped with the following dispersed components:

- MVDC network coupler for 2 MVA transfer power between the microgrid and the neighbor network performing a second supply infeed,
- wind power plant of 1,2 MW on a hill,
- batteries of 800 kW connected in 4 low voltage networks with partial transformer overload,
- fuel cells for household CHP of 50 kW el, (10 units with 5 kW each),
- photovoltaic units of 200 kW, distributed in the whole microgrid with ratings of 10 kW.

For the supply of a new thermal spa the following units are foreseen:

- fuel cell CHP of 212 kW el and 230 kW th,
- diesel CHP of 310 kW el and 520 kW th,
- heating station for 2,3 MW th.

Consequently, a maximum power of 2,77 MW can be generated by the dispersed generation and storage units. Additionally, 2 MVA power can be supplied via the MV DC coupler. In the result, the village can be

fully served during the outage of the feeding line (branch A-C). In the first task it was necessary to develop and use the advanced network planning tools for investigations of conformity and reliability of the network restructuring with dispersed generation, storage and coupling (DGSC).

3 ADVANCED NETWORK PLANNING TOOLS

3.1 Criteria for network connection of DGSC

For the network connection of DGSC special rules [4] were established in Germany regarding:

- load flow conditions, overload situations are restricted,
- keeping the short circuit withstandability,
- voltage level in the connection point (limit 2 % difference),
- limitation of influences accordingly to flicker, harmonics and ripple control signals.

The network planning tools shall be able to assess the conformity with the connection criteria.

However, the detailed network analysis in this context requires simulation models for the new technologies reflecting their steady state and dynamic behaviour.

3.2 DGSC modelling for long and short time simulations

The long time models for steady state scenarios shall reflect the functional behavior of the new DGSC technologies on the one hand. On the other hand, for the introduction of dispatchability an interface to the DEMS has been developed.

To fulfill all these requirements the structure of the long time models has three surfaces (figure 2). The first and the main surface consists of the physical model description which is based mainly on mathematical equations or measurements describing the functional behavior. It builds the central structure of each model. This physical surface (PhS) of the model is then merged into its particular

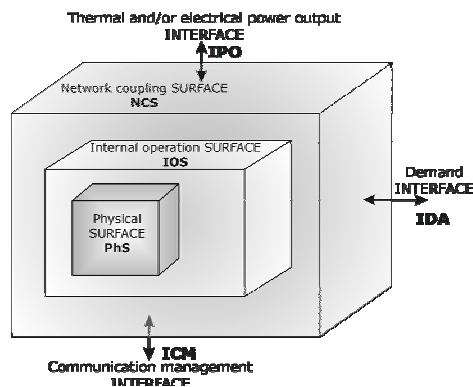


Fig. 2 Surface-Interface-Structure of DGSC models

surrounding conditions, like, for example the relation between thermal and electrical demand for a fuel cell CHP. The PhS together with the emulated surrounding systems create the second platform – the internal operation surface (IOS) of the DGSC unit. The third model surface – the network coupling surface (NCS) of the unit describes the technical connection to the network.

The model includes three interfaces describing:

- the electrical and thermal demand,
- the electrical and thermal power output,
- the communication interface with the DEMS.

The typical basics of the DGSC models for long and short term simulation are characterized in Table I.

Table I Characteristics of the DER models.

DER	Short-time	Long-time
Wind unit	Control models including pitch control, speed governor, f, V, P;Q control for following generator types • squirrel cage induction • doubly fed induction • converter connected synchronous	Wind forecast with power conversion model
PV system	Converter control model	Solar radiation forecast and P/Q source
FC CHP	Converter control model	P/Q source with energy storage and thermal demand model
CHP based on rotating machines	Generator with control system model	P/Q source with energy storage and thermal demand model
Battery storage	Converter control model	P/Q source with integrated model of the battery
MCDC Coupler	Converter control model	P/Q source with control model

The short time models (dynamic scenarios) are mainly used for the analysis of the “fault ride through” behavior. They are based on the modeling of the internal control and protection systems.

3.3 Example for a long time model

The building process of a long-time model is shortly explained on the example of the Lead-Acid Battery unit (figure 3).

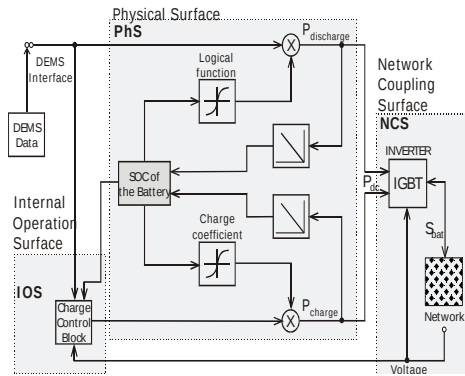


Fig. 3 Simplified long time model of a battery unit

The internal behavior of the battery is based on the dependency between charge and discharge power and the state of charge SOC. It is supervised by the control unit.

If DEMS demands active power, which should be delivered from the battery to the network than this demand is transferred by the interface to the inner battery model which examines the SOC and provides, depending on it, the requested or the possible energy quantity. The power during discharging is nearly constant up to the adjustable threshold value of, e.g., 30 % SOC.

The battery model disposes of the charge control unit, building its IOS surface. During the process the charge coefficient is considered reflecting the behavior of the

inner battery resistance.

The bi-directional flow of the energy is ensured through the converter, which together with the transformer unit builds the network coupling for the battery storage unit.

The inverter disposes of the voltage control unit, which allows reactive power injections.

4 CONFORMITY AND RELIABILITY

The models for the new DGSC technologies were implemented in the existing tool for dynamic network investigations NETOMAC. For the assessment of the connection criteria it is necessary to provide load flow calculations for the load and the generation profiles. Due to intermittency of renewable power generation not only the peak load situations may cause congestions. For example, in a microgrid with large scale wind power congestions can appear in situations with strong wind and minimum load.

Thus, the microgrid was analyzed regarding all the connection criteria. The results of the load flow calculations are demonstrated in figure 4.

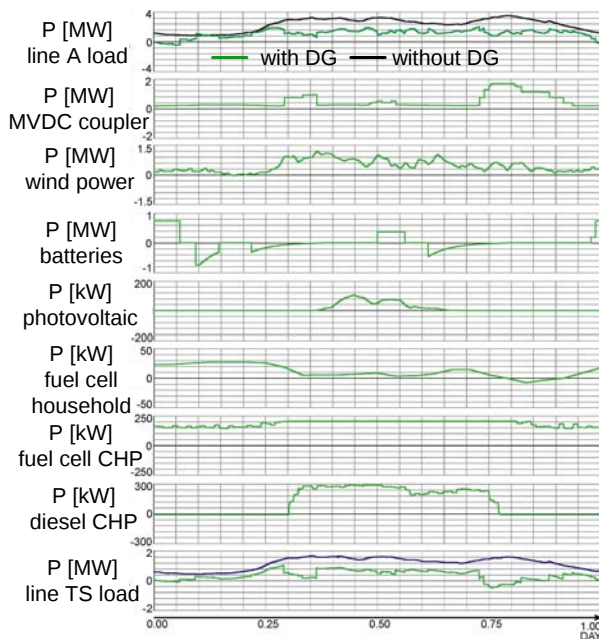


Fig. 4 Power supply of the microgrid with and without contribution of the DGSC units

In the first diagram the load flow through the overhead line from “A” is shown before and after network restructuring. The maximum flow over the line was reduced sufficiently in the result of the contribution of the DGSC units which is presented in the next diagrams.

In the last diagram the load flow through the branch T-S is demonstrated. The line load is reduced up to 40 % with a maximum of 1 MW at 6.40 a.m. Further more, in the evening hours a load flow of opposite direction is observed. The presence of the DGSC units reduces line load and therefore the power losses in the microgrid.

A positive effect was achieved in the voltage quality: the voltage in the microgrid could be improved and achieves only 98% in the worst case if the DGSCs generate only active power. But, if the capability of the MVDC coupler for voltage control is used, the voltage can be kept on the chosen target value of 101 % continuously.

Considering the changes in the short circuit power it can be stated that the network with a short circuit contribution of 8.4 kA keeps the dominance. The highest contribution in the short circuit power comes from the wind plant with a doubly fed induction generator. The maximum amplitude of the short circuit current is 320 A. That is far away from the short circuit limits of the microgrid.

The NETOMAC analysis of a doubly fed induction generator is shown in figure 5 for a three pole short circuit on the feeding line (A-C) of the microgrid (see figure 1). The first diagram shows the active and reactive power, the second the voltages and the third the currents. After the fault clearing the wind generator demands a high quantity of reactive power. For this reason the voltage comes up slowly. The converter connected DGSC units normally switch off within the first 10 ms because of the

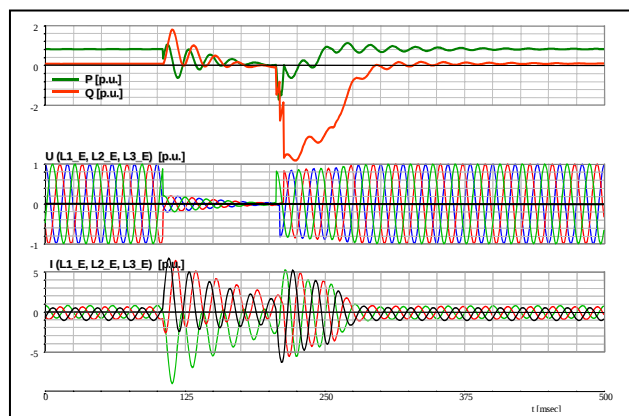


Fig.5 "Fault ride through" behavior of the wind plant

impulse blocking caused by the integrated protection. However, this behavior does not support the fast voltage recovery in the microgrid after the fault clearing. For this reason the control system of the MVDC coupler was adapted in such a way, that the MVDC coupler rides through the fault without trip and contributes with the rated (reactive) current in the short circuit. After the fault clearing the MVDC coupler can immediately start to serve the microgrid as an island.

The reliability in the microgrid could be fundamentally improved because of the second infeed via the MVDC coupler and the own generation.

The new reliability assessment indices are:

- 2 minutes/a interruption of supply,
- 0,12 MWh/a energy not served in time

However, this analysis was made under the assumption that the availability of the DGSC units is higher than 99%. That assumption is fulfilled for all implemented DGSC units excluding the used PEM (Proton Exchange Membrane) fuel cell only. Figure 6 shows the daily energy output of the fuel cell for a three month period.

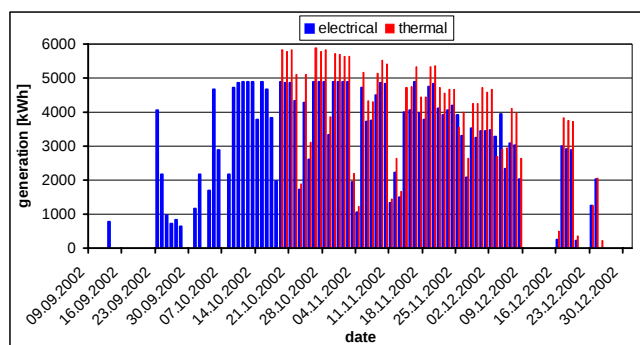


Fig. 6 Thermal and electrical energy output of the PEM fuel cell during 3 month operation

The availability of the PEM Fuel Cell was below 60 % what is not acceptable for a continuous operation. The main reasons of outages were caused by reformer problems and the reduced flame intensity of the aux-burner. During one year trial operation a lot of practical experience was gained. However, the PEM Fuel Cell will be decommissioned.

In the same time there have been better experiences with a MC (Molten Carbonate) Fuel Cell. This fuel cell achieved an availability of 98,9 % over a period of 10 month and an efficiency of 82 % in

practice. In the conclusion it can be expected that the high temperature fuel cells like MC or SO (Solid Oxide) will better meet the requirements of a continuous CHP.

At this point the strong requirement of availability for the future DGSC units shall be underlined. When the share of dispersed generation grows more and more and achieves significant contribution in the power balance, reliability and stable operation of the power system can be ensured only if the DGSC units fulfill the same requirements as the central power stations do. Consequently, new rules are requested which define the future responsibilities of the DGSC operators in keeping a high availability (e.g. in a Distribution Code).

5 DISPATCHING

The dispatching of the DGSC within the microgrids is the third major requirement for future stable and cost effective operation of the power system when the market share of DGSC increases significantly. A decentralized energy management system (DEMS) is required to enable the planning and dispatching of the power balance in the microgrids and thus to ensure a widespread integration of dispersed generation into the system operation. The functionality of a DEMS is presented in figure 7.

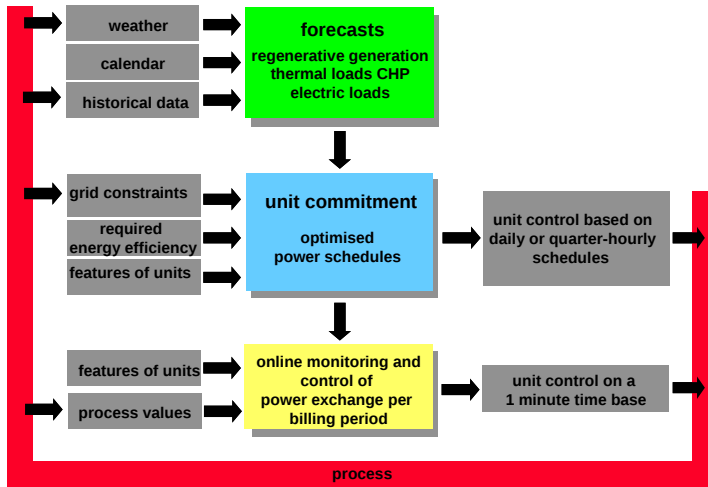


Fig. 7 Functions and features of DEMS

Using imported weather forecasts generation and demand are predicted and balanced. Compared to the forecasting accuracy of thermal and electrical demand, predictions of renewable generation are very poor. Average errors of 1 day ahead forecasts of 15 % occur and require decentralized reserve strategies.

Based on the forecasts controllable units and if available controllable loads are scheduled in a quarterly-hour billing period in a time horizon of 1 -3 days ahead. Optimization criteria for the unit commitment of all DGSC plants can be minimum costs, management of export contracts, maximum renewable power generation or minimum CO₂-emissions. Operation strategies like minimum power exchange or adherence to power profiles committed to utilities superimposed become possible. Also the energy efficiency of combined heat and power generation can be raised using DEMS. Power exchange is exactly defined; DGSC becomes planable.

Due to fluctuations within a billing period a fast adjustment of the energy exchange is required to meet the planning results. Therefore DEMS supervises automatically in a one minute time base the compliance with the power schedules. To cope with the unavoidable prediction errors of generation and demand the system performs already for unit commitment sufficient reserve strategies. Power reserves are provided by generation and storage units as well as by loads that are controlled by DEMS. Power reserves centrally required can be reduced. Further more, the balancing of the power is done cost optimized based on the power schedules considering all technical constraints.

The application of DEMS for the planning and unit commitment in the heat and power station of the thermal spa is demonstrated in figure 8.

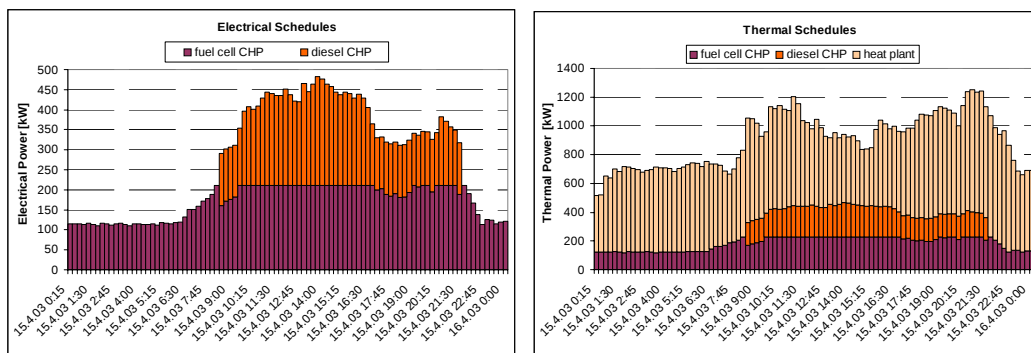


Fig. 8 DEMS schedule for power and heat generation in the power and heating station of the thermal Spa

In the EDISON project the diesel generator, the fuel cell, the batteries and the controllable load can be managed to compensated prediction errors and other unforeseen fluctuations of the wind and photovoltaic power generation in the microgrid acc. figure 1. Further more, the wind power plant

output can be restricted if there is a need. With this the cluster of DGSC units provides features of central power stations.

However, for ensuring these features in the normal practice legal and communication problems have to be solved. First of all, the law today supports the unlimited infeed of renewable power into the power system independent of the demand. Dispatching is not foreseen. This law shall be adapted in such a way that the dispatching will be mandatory, of course, targeting the maximum generation of renewable energy.

The communication problem is a technical one and can be solved by engineering.

6 COMMUNICATION

In contrary to the existing practice, where power generation is concentrated on a rather compacted area and therefore information and data is transferred on local networks or field busses, the DGSC dispatching will be spread over a wide area. For economical reasons the existing infrastructure has to be used for communication purposes. Experience to use dialup and dedicated telecommunication channels, radio communication and power line (e.g. ripple control for load management) was achieved in some application projects for DEMS.

The following DGSC units are involved in the DEMS dispatching: MVDC coupler, wind power plant, controllable load, batteries, heat and power station of the spa with fuel cell CHP, diesel CHP and the heating station.

Aggregation of dispersed photovoltaic units and household fuel cells and with this integration in DEMS is foreseen in principle but not realized in the project as the involvement into the dispatching requires additional expenses. The experience of the project shows that an economical efficiency of the dispatching can be achieved with units which contribute more than 3% in the power balance of a microgrid. For the actual microgrid this limit is over 100 kW.

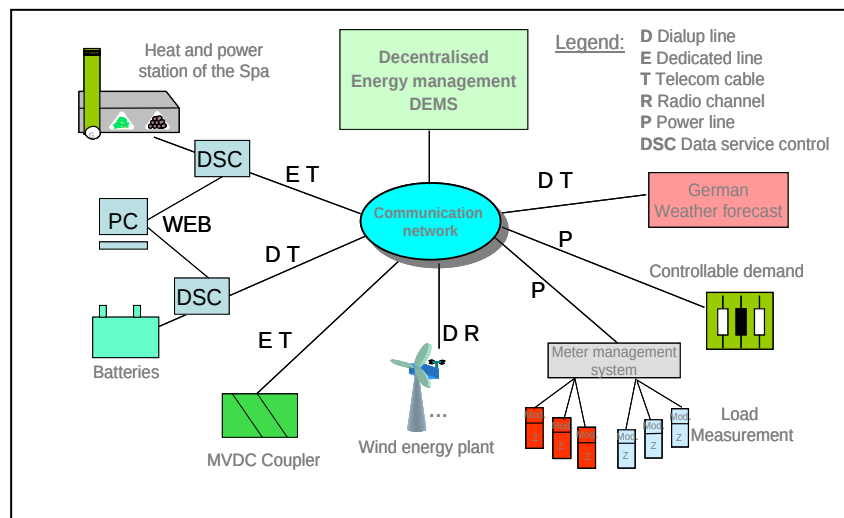


Fig. 9 Communication network for DEMS dispatching

The communication with the weather forecast service was established via dialup telecommunication lines.

Figure 9 demonstrates the different communication solutions which are based on the existing communication capabilities of the suitable equipment.

The DEMS and the SCADA PC of the MVDC Coupler are both based on the industrial control and monitoring PC software WINCC.

The internal WINCC data exchange is used via a

dedicated telecommunication channel by means of integrated OPC services.

For the wind power plant the mobile phone services are used for the transfer of measured power output and power target values if the restriction of power output is requested.

The load management is based on the existing ripple control system in combination with the metering data communication capability of the especially equipped meters.

All other DGSC units use a Data Service Controller (DSC) which was developed for gateway, COM server and SCADA functionalities. The DCS is a PC based system acting first of all as a gateway between PLCs controlling the technical processes and the DEMS PC. Mostly the PLCs have no interfaces for connection with a PC based control system. For this reason the DSC is able to connect

the PLC over the installed field bus like Modbus TCP or industrial Ethernet. For the communication with DEMS the DSC provides a java based web service which understands XML formatted enquiries, enveloped in the SOAP (simple object access protocol) and exchanged over HTTP (hypertext transfer protocol). Here the DSC is a service provider for DEMS and all involved DGSC units and acts as a COM server.

The integrated web server is able to create dynamical web pages containing self refreshing objects that show the latest data of the process. Further more, the possibility to generate trending diagrams for the retrospective process data development is available. This SCADA functionality can be used locally or via web remotely.

However, the building of the communication network on the base of the existing technologies and their communication capabilities was connected to high expenditure in engineering work. For the future dispatching of microgrids the use of a communication standard is mandatory. The new standard IEC 61850 defines an object oriented data model and suitable services on the application layer. This standard shall be used for the uniform communication on different physical communication channels in the future.

8 CONCLUSIONS

As the main message it shall be stated that the increasing share of renewable and dispersed generation has no technical limits if **Conformity - Reliability and Dispatchability** in the context of figure 7 can be ensured.

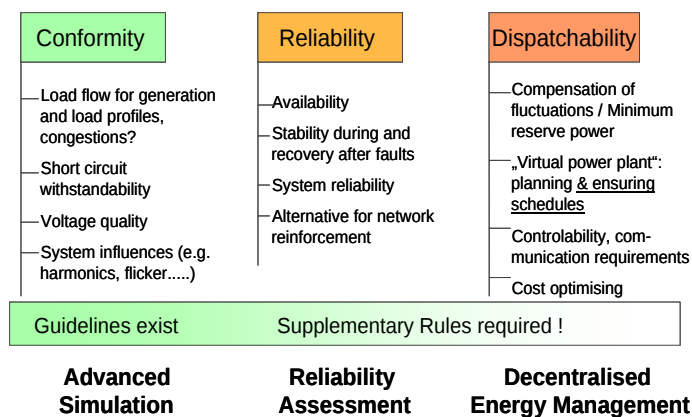


Fig.7 Main requirements for further growth of renewable and dispersed generation

Further more, on behalf of a pilot project it is demonstrated that the dispersed generation, storage and network coupling is able to contribute in the improvement of voltage quality and reliability. Additionally, it offers an economical alternative for network reinforcement.

From the technical point of view all needed tools for network planning and operation with large scale integration of renewable energy sources are available.

Experience is gained in operation of innovative technologies like fuel cells

or MVDC couplers and in the use of an advanced communication network providing a virtual power plant in a 20 kV microgrid. However, further communication standard activities shall direct their focus on the wide spread dispersed generation units and controllable loads. The existing standard IEC 61850 shall be mapped to different physical communication media.

Now the authorities are requested to establish the legal framework for the power system conform development of the renewable energy generation and high efficient power cogeneration by CHP. New rules are requested for ensuring a high availability and the dispatching of all dispersed sources with a significant weight in the power balance.

9 REFERENCES

- [1] Green Paper „Towards a European strategy for security of energy supply“ European Communities 2001
- [2] Amtsblatt der Europäischen Gemeinschaften C343/195, DE 5.12.2001
- [3] B. Buchholz, I. Huebel, D. Povh, M. Weinhold; “Medium Voltage Direct Current (MVDC) Coupling in the liberalized market”, in Proc. 2002 CIGRE; paper 14-203, Paris, 25th-30th August 2002
- [4] Eigenerzeugungsanlagen am Mittelspannungsnetz, VDEW Verlag, 2. Ausgabe 1998