Communication with and within Distributed Energy Resources

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Abstract **– The increasing contribution of Dispersed and Renewable Energy Sources (DER) to the peak power balance of up to 60 % and the goals of the European Community for the year 2010 require innovative approaches in order to maintain the sustainability of the power supply.**

Sustainability in this context requires that DER significantly support system services like frequency control, power balance, voltage control or supply restoration after failures. For this, remote information exchange with the respective DER units will become necessary. Consequently, interoperable and scaleable communication solutions play a key role for sustainability in power systems with an increasing share of DER.

The "Network for energy and communication" (NEaC) which was founded by the German Federal Ministry of Education and Research, is a consortium that elaborates requirements, specifications, systems, standards and related technologies for inter-networked DERs.

A communication network with diverse physical communication media is considered for a typical medium/low voltage network with industrial, commercial, rural and household customers each with typical load profiles. A variety of DER units like wind power plants, fuel cells, photovoltaic plants or CHP units is considered. It is demonstrated how an optimized communication network, complying with technical and economical requirements, can be realized. NEaC strongly supports international standards and shows that IEC 61850 fulfils all related selection criteria for DER communication systems.

I. "NETWORK" FOR THE SYSTEM INTEGRATION OF DER

The research network energy and communication "NEaC" [1] was established to approach the challenges caused by the changes of the energy supply system in the near future. The main goal of this "network of people" is to contribute to an ecological, sustainable, economical and efficient energy supply system by promoting the system integration of DER. In the first priority this means: The growing share of DER in the power balance (up to 60 % of the peak load coverage by 2010 in Europe [2]) requires their significant contribution to the system services. Today the system services are mainly provided by transmission system operators (TSOs). In the future the TSOs will also be responsible for the lead but more and more system services will be provided by the distribution level (Fig. 1)

In this context, the objective of the NEaC is the optimization of the DER use by means of sophisticated communication technologies. This is achieved by offering a platform for universities, commercial enterprises and research institutes in the field of energy and communication technology.

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Frequency stability:	**FP – Primary control power (<30s)**
	FS – Secondary control power (< 5 Min.)
	FM – Minute reserve power (7–15 Min.)
Power Balancing:	**PD – Scheduling and Dispatch**
Voltage Stability:	**VT – Tap changer control**
	VQ – Reactive power control
Restoration of supply:	**RB – Black start capability**
	RI – Island operation
Further system management:	**SQ – Power quality assurance**
	SO – operational and asset management

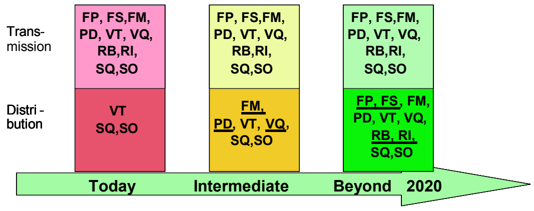

Fig. 1. System services and their provision today and in the future

The network NEaC comprises four working groups (WG):

WG1: decentralized power quality and grid management,
WG2: communication structures and technology,
WG3: power management, operation control strategies and
WG4: information management.

Working group 2 plays the central role for the future integration of DER technology into distribution grids. The further considerations in this article are mainly focused on results of this WG.

For this purpose the NEaC developed a typical model of a distribution network which is shown in a simplified form in Fig. 2. Along a 10 kV feeder, eight low voltage networks are connected and a wind power plant (1.2 MW) at the end of the feeder feeds in.

The low voltage networks have different load profiles in accordance with the profile types of grid operators in the German Network Society (VDN). Various dispersed energy sources and storage units are distributed in the low voltage networks as shown in Fig. I.2. They provide their specific generation profile partially depending on weather conditions.

The peak load in this network is 3460 kW. The installed generation capacity is 3008 kW, but 1468 kW come from intermittent sources (wind, photovoltaic).

Demand side management is foreseen with controllable loads of 12 x 20 kW in the industrial network, 10 x 2 kW in the shopping area and 40 x 2 kW in the business center. In strong wind situations this network can operate as an "island network", in weak wind situations the island operation requires additional load shedding. In island operating

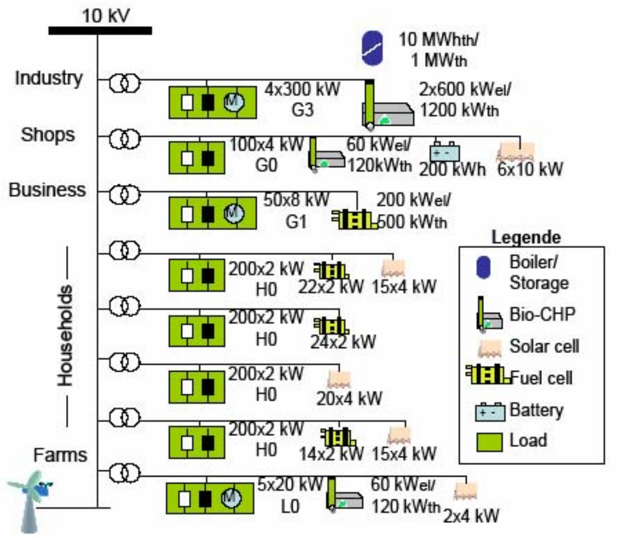

Fig. 2. Distribution network pattern of the NEaC. G3 – industry, G0 – Shopping center, G1 – Business center, H0 – household profiles, L0 – rural farm

mode, no external power is available. In order to maintain supply security, all controllable loads are assumed to be permanently available for demand-side management.

II. GRID SUPPORT VIA DER

Distributed energy resources (sources and sinks) are – especially if controllable via some communication infrastructure – a powerful tool. Depending on who gets the authority to control it, different parties in the energy business can take advantage of this tool.

In general, such a system has two differences to traditional power systems:

- Power generation is partially distributed in "the field".
- Power consumption can partially be influenced.

Both aspects are not perfect. We will not get totally distributed generation, and only a small percentage of consuming installations and devices allow interruption. In total, however, such a system offers more flexibility than a static centralized one that is optimized by means of statistics and that relies on a calm development and environment. A flexible system can cope with many problems that get more and more relevant in recent years like partial power outages, transmission line overload or even wind power overload.

Subsequently three examples of exploiting the power of a flexible, networked DER system are given.

A. Power Quality

Power quality (PQ) is a non-scalar property of power systems whose aspects range from availability up to the power factor. Two well-known and important parts of power quality are

- voltage stability and
- frequency stability.

Both properties are typically considered to degrade, if DER reach a significant percentage in a grid: a prejudice, disproved by experiences made in Denmark with a share of wind power stations, three times higher than expected to be possible. A new trend goes into the direction of using DERs for supporting power quality. Weak and critical parts of the grid can be supported by distributed generation like gas-powered micro-turbines or even renewable energy sources.

The benefit of distributed generation for the sake of power quality becomes even more evident, if the DERs are under control. Having a global view of the distributed energy sources and having (partial) influence enables the "global DER operator" to intentionally take influence on PQ in the grid. This influence is as fine grained as the DER system and can, if the respective communication system offers (near) real-time commands, significantly support grid operation and PQ management.

B. Grid Schedules

The distribution grid for electrical energy is – in the deregulated European energy market – split into balance zones and control zones. The operators of these zones typically agree on certain schedules for exchanging and transporting energy. These schedules are negotiated 24h in advance, any deviation from these agreed schedules costs money.

Unscheduled – because unexpected – power flows, if they are not a technical problem, are more a financial risk. Such expensive "balance energy" must then be bought on energy markets. A grid that offers the opportunity to drop off load or to feed in more energy can help keeping the scheduled load chart.

C. Customer oriented operation

Distributed energy systems do not only contain energy sources but can also include customer loads that offer one or more degrees of freedom like

- shiftable loads,
- interruptible loads,
- load that can be scheduled and
- highly inertial loads.

Such loads can be used as "virtual energy storages". By means of logistics and scheduling these storages can be filled and drained. Combined with ordinary loads, the customer has – if supported by flexible automation and communication technology – more flexibility in when to consume energy. This results in a more "elastic" behavior, in macroeconomic terms [3].

III. STANDARD COMMUNICATION WITH DER

The experience of the first virtual power plant (VPP) projects [4] underlined the need to apply communication protocols based on common standards for all channels used. Otherwise, the engineering expenses will grow and the operation of the communication network will become inconvenient, error-prone and inefficient.

In contrast to traditional systems, where power generation is concentrated on a rather compacted area and therefore information and data is transferred on local area networks, the units of VPPs will be spread over a rather wide area. For economical reasons any existing infrastructure of communication channels has to be used. Consequently, a variety of transport channels like radio frequency, fiber optics, power line carrier (PLC) and telecommunication cables will be applied within one network.

A. Communication Requirements

The design of a communication network consisting of different physical media and link layers is a challenging task. The NEaC elaborates a mathematical model for such a communication network in order to find out the optimum design rules.

In principle, the design depends on the nature of information exchange which is always depending on the actual network structure and its units (load, storage, generation and substation). From the communication point of view these network nodes will typically act as clients and servers, providing and receiving information and issuing and accepting commands, the VPP being the “supernode” and the IT-interface to outside. Fig. 3 gives an overview of the model, used for the communication network design. The upper part of Fig. 3 represents the requirements that lead to design decisions in the lower part. These design details are subject to optimization routines. Each node must be treated individually, since their need for information exchange differs dramatically.

The amount of data for communication of a particular node with other nodes and the VPP depends on its “weight in the power balance” and its ability to be controlled. Therefore, content and classes of information have to be defined according to the specific node.

For example, a small photovoltaic unit reports metering data and status information to the VPP. Remote control is not foreseen.

The optimization of the network design includes (see Fig. 4):

- selection of physical communication channels,
- assignment of nodes to the foreseen channels and
- selection of the baud rate of the channels in accordance with the maximum data load.

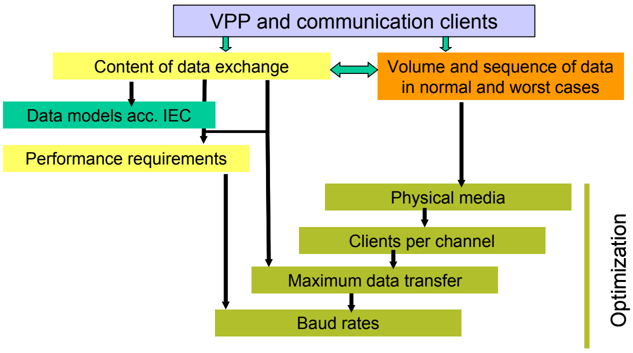

Fig. 3. Scope of communication-network design

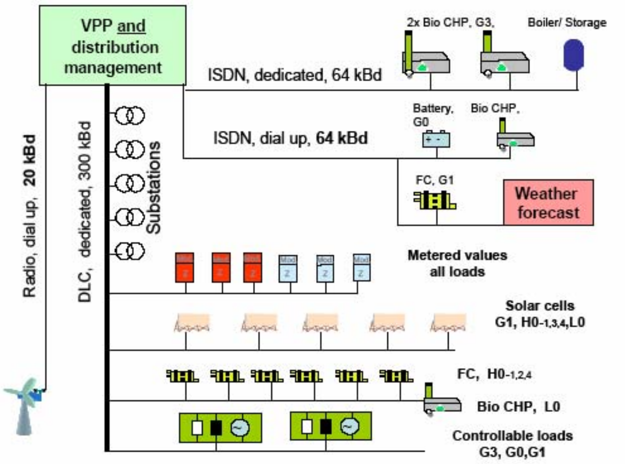

Fig. 4. Communication network example for the distribution network pattern in Fig. 2 with distribution line carrier (DLC), ISDN and radio. transmission. G3 – industry, G0 – shopping center, G1 – business center, H0 – household profiles, L0 – rural farm

A mathematical model of the communication network requirements was developed and is used for optimization. The minimum operation expenses and installation costs build the target function.

A possible design of the communication network which complies with the performance requirements and combines different physical channels is shown in Fig. 4. The performance of the data transfer has to be defined in compliance with a maximum latency time assigned to each class of information as given in Table 1.

As shown in Fig. 3 the volume and sequence of data transfer depends on operational needs for worst case and normal scenarios. In the normal case the metered values of all nodes will be transferred in a 15 minutes interval (i. e. the load profile measuring period in Germany). Once every day the target profiles (schedules) of the generation units of above 60 kW and the controllable loads as described in Table 2 will be communicated (for description of load types see also Fig. 4). In addition, 40 corrective target values per controllable client, 20 event messages and 10 control commands will be communicated per day. In the worst case (e. g. voltage dip) each network node will send a report with alarms and measured values, which has to be done within 10 s.

TABLE 1
PERFORMANCE REQUIREMENTS FOR INFORMATION CLASSES

Information class	Abbreviation	Latency time, s	Real time requirement
Error messages, high priority	SMH	1	high
Error messages, low priority	SMN	5	medium
Messages, high priority	MH	5	medium
Messages, low priority	MN	10	low
Measured values, single	MWE	2	medium
Measured values, array	MWF	30	medium
Metered Value	ZW	2	high
Command with confirmation	BR	2	high
Command without confirmation	BO	2	medium
Setpoint value, single	SW	1	high
Profile setting (max 96 entries)	PV	20	high

TABLE 2
CONTROLLABLE LOADS IN THE DISTRIBUTION NETWORK PATTERN

Load type	P [kW]	Grid	SMN	MN	MWE	ZW	SV
Cooling plant	2 x 20	G3	1	2	1	1	1
Drives	9 x 20	G3	1	1	1	1	1
Air condition, industrial	2 x 40	G3	1	1	1	1	1
Lighting, industrial	5 x 1	G3	1	1	1	1	1
Air condition, business	10 x 2	G0	1	1	1	1	1
Lighting	40 x 0.2	G0	1	–	1	–	1
Air condition, business	40 x 2	G1	1	1	1	1	1

Summarized, the inputs for the communication network design are complete:

1. Sequence of telegram transfer for worst and normal cases.
2. Data volume of the telegrams in accordance with Table 2.
3. Maximum latency time for each kind of data exchange.

B. Communication Standards

The question arises, how a consistent communication standard can be applied for different physical layers. An analysis was provided among the existing IEC communication standards to select that standard which complies best with the following selection criteria:

- Free choice of physical and link layers.
- Plug and work without extensive engineering.
- Expandability of the data models and introduction of new models in accordance with the enhanced tasks.

Only the latest standard IEC 61850 [5] (for communication in substations, published as standard in 2004) satisfies the above mentioned requirements.

The “plug and work” ability (i. e. zero-configuration) is reached via detailed object modeling based on logical nodes (objects like circuit breaker or transformer etc.) and data (information like “status ON” or “phase to ground voltage” etc.) with the supplement of different attributes (like time stamps, validity information etc.).

All data exchange is supposed to be modeled in accordance with IEC 61850, based on telegrams. Each telegram consists of the raw data which contains the information content (payload) and overheads of the communication layers. Table 3 shows the worst case of telegram lengths, being the maximum possible number of bytes. In practice, the services of IEC 61850 build reports within a given time interval, with a log of all changed information embedded. Therefore, the net-bytes will be lower as stated. However, these figures provide a good base for dimensioning the communication network.

TABLE 3
MAXIMUM TELEGRAM SIZE FOR DIFFERENT DATA CLASSES ACCORDING TO IEC 61850 (NUMBER OF BYTES)

Data class	Raw data array	Overhead layer 7 (MMS)	Overhead other layers	Total
Status information	11	161	64	236
Control	14	1245	384	1643
Measured value	15	161	64	240
Metered value	15	161	64	240
Array (96 metered values)	1440	1320	128	2888
Target value	15	693	192	900
Profile setting (96 entries)	480	388	128	996

Based on IEC 61850, tailored to the needs of substation equipment, two new standards are currently developed. The standard for wind power plants (IEC 61400-25) [6] is available as Committee Draft for Voting (CDV). The standard for distributed generators (IEC 62350) [7] is in draft stage (Committee Draft CD).

The following procedure is the preferred one: everything already defined in IEC 61850 will be maintained. Only additional requirements are added.

In this context, the working group 2 of the NEaC plays an active part in designing and improving the standards [8] concerning these three aspects:

1. Expansion of data models in order to completely cover the demand seen in WG2 within the standard.
2. Assuring of consistency and plausibility of data models beyond all the above three standards.
3. Standard-compliant use of new physical communication media, such as radio, wired telephony or power line carrier.

IV. CONCLUSION AND OUTLOOK

Electricity supply systems may soon change from a structure with large-scale central power plants, a hierarchical and unidirectional power flow structure and a huge number of dispersed consumers to a structure with

- a lot of DER, partially feeding back into the transmission and distribution grid with intermitting power and
- consumers that can be influenced via remote demand-side management.

Innovative communication systems using existing infrastructure, based on different physical channels are required to support the contribution of the DER to the system services in the framework of virtual power plants. The mapping of the models and services of IEC 61850 to various physical media is recommended.

Based on a distribution network pattern, the approach towards the communication network design was demonstrated. A mathematical model of the communication network using different physical communication media is developed and its application will create optimum solutions to solve the communication tasks in various distribution network structures by using the existing infrastructure.

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