Future electrical energy supply for the Isle of Pellworm

Activities of future electrical energy supply on the Isle of Pellworm and other regions with a large production surplus of renewable energy sources -

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Abstract

The electric power generation, transmission and distribution are in a profound process of change, particularly related to the activities of the various regions. It is currently not clear enough for each region, what technical requirements and non-technical requirements for a successful operation of such a smart grid must be met. It is currently not known, how to build it up and what results can be achieved. This paper describes the key technical and non-technical aspects for the successful operation of a smart grid in a certain region. It takes into account the lessons learned from the activities for the development of a smart grid on the Isle of Pellworm.

1 Introduction

The electrical energy supply is in a profound process of change. Different activities go along with this technological, economical and social process. Due to this, single components, technologies and processes are constructed, operated and examined in pilot projects since several years in order to get technical and economical solutions for future energy supply that are generally accepted. The future structure of the accompanying components, technologies and processes is summarized with the term Smart Grid. This term is described as an intelligent grid, which allows the control of power generators, storage elements, electrical loads and grid operation devices within electrical transmission- and distribution grids by means of an appropriate communicative interconnection.

1.1 Classification

The six best-known Smart Grid pilot projects in Germany put their main focus point on single smart grid sub aspects. The latest findings are comprised displayed in (Walti, et al., 2012). In total, 11 fields of action are named: energy efficiency, integration of renewable energies, decentralized power supply, security of supply with avoidance of grid bottlenecks and grid expansion, market liberalisation, IT safety and data security, information- and communication technologies (ICT), intelligent measurement and e-mobility. Although the approach to concentrate only on one focus area within pilot projects seems correct, it is obviously that the establishment of efficient Smart Grids is only possible if all sub territories are examined together. Still a correct linkage of the concrete fringe conditions of the entity for which the Smart Grid is build is necessary. In this respect, the units are differentiated in size, organisation and infrastructure. A unit can be a city, a region or a municipality but also an industrial zone, an industrial park, a single enterprise or a housing complex. The fringe conditions, on which the construction and operation of Smart Grids needs to be oriented on, differentiates itself with regards to its legal, economic, social and technical aspects as well as with respect to the existing source, consumption and supply structure. The study „Reifegrad Smart Grid 2012 - eine Marktanalyse für den deutschen Raum“ correctly concludes: “Therefore not only one Smart Grid will exist but several Smart Grids which are specifically adapted to the particular requirements.” (Walti, et al., 2012). The construction of Smart Grids is especially there suggestive where the operation can lead to a significant decrease of the grid load. These are regions in which a high degree of wind energy leads to frequent grid shutdowns.

Various recent publications of the same topic show which questions still have to be clarified until a comprehensive operation of Smart Grids is possible (Walti, et al., 2012). Thus the Federal Grid Agency is assuming a stepwise introduction of Smart Metering devices whose comprehensive usage should not be earlier expected than 2020 (Bundensnetzagentur, 2010). The experiences of the operation from the already running Smart Grids have to be evaluated until then, in order to slip in those experiences from planning, establishment and operation into the development of other grids. Within the innovation study Pellworm (Schütt, et al., 2011) and within the current implementation of the project “Smart Region Pellworm” a holistic approach is chosen, taking into account the essential aspects of Smart Grids in order to enable an effective operation.

1.2 Limitation of the topic

This article describes selected technical- and nontechnical aspects for the construction of the Smart Grid Pellworm. The difficulty to win clients for the incorporation in Smart Grids on a commercial or household basis is always pointed out (Wedler, et al., 2011). The construction and operation of a Smart Grid is only possible if those people and social groups who use the Smart Grid are convinced of it. Both the inhabitants of Pellworm and the municipality are integrated in the planning, construction and operation of the Smart Grid on Pellworm. The extensive measures to reach acceptance and effectiveness are described.

The save running of the grid requires the inclusion of the local grid into the subordinated grid control system. Therefore the structure of the informationand communication technology (ICT) needs to be designed accordingly, the interfaces have to be created and the corresponding technology to exchange data needs to be available. The research of the core elements of a Smart Grid such as storage elements with a large capacity, energy management systems, smart metering devices and communication systems show a bleak picture with respect to the availability and testing. Compared to the representation in public, subsystems show very different technical characteristics, of which some are only announced but not available yet. The standardisation and determination of the communication protocols for the subsystems of Smart Grids are technically not completed yet. The presented results only include the currently available components.

The design of the Smart Grid Pellworm takes place by taking into account the available data. This particularly concerns the designing of additional central storage, which is used for the generation and load curve and considered in different scenarios. In this case the project is limited to the field of electrical energy due to the fact that the linkage between thermal and electrical energy remains reserved for another project.

A change in the energy exchange between the island and the mainland has a significant impact on the stresses of the grid infrastructure on the mainland. The effect of the measures on the mainland grid, especially the unloading of the local grid infrastructure, is no topic of this paper.

1.3 Procedure in building a Smart Grid

As proposed in the innovation study, the Smart Grid will gradually be introduced on Pellworm. Figure 1 shows the single sub steps of this introduction. First of all the core element of the Smart Grid is specified, which defines the basic elements. Those elements that can be incorporated quite legally in an energy management system are

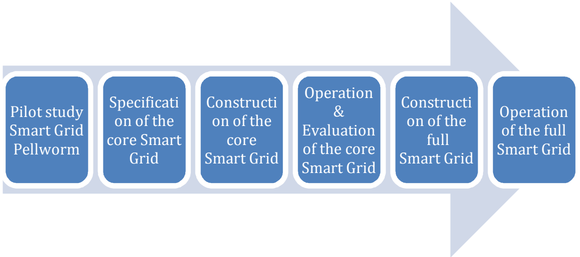

Figure 1 Sub steps for the introduction of the Smart Grid on Pellworm (Schütt, et al., 2011)

After the specification step for the core elements follows the construction, which falls into line with the operational phase. In this phase, the results from the different operational models are evaluated. The experiences will then be integrated into a further specification of a full Smart Grid. The stepwise introduction offers the possibility to await the necessary alignment within the technical characteristics of Smart Grid elements, to further article participants and to integrate controllable loads such as e-mobiles and domestic appliances. Before the extension to a full Smart Grid it is necessary to complete the investigations concerning the quality and reliability of supply. In the end it can only be shown on the basis of the operation, which additional measures need to be taken in a Smart Grid in order to guarantee consistent power quality and supply reliability. Based on the operations, quantitative declarations about emerging costs for the construction, and operation of a Smart Grid in connection with the grid load can be made. This enables the Smart Grid Pellworm to clarify key issues for the future energy supply. In particular, it could show that in areas with a substantial surplus production of renewable energy the operation of a Smart Grid with appropriate storages could relieve the electrical grid significantly.

2 State of the electrical energy supply on Pellworm

The specific technical and non-technical boundary conditions of the Isle Pellworm are brought Pilot study Smart Grid Pellworm Specificati on of the core Smart Grid Constructi on of the core Smart Grid Operation & Evaluation of the core Smart Grid Constructi on of the full Smart Grid Operation of the full Smart Grid 3 together and documented in the innovation study Pellworm (Schütt, et al., 2011). Pellworm, located on the West Coast of Schleswig-Holstein, is the third biggest North Frisian Island with 38km². Hallig Hooge is also belonging to the island and is supplied by electrical energy from Pellworm. Pellworm is surrounded by a national park and the world heritage – natural site: the Wadden Sea.

The Island is belonging to the administrative district of Nordfriesland. The ultimate territorial authority is the municipality Pellworm. On the island live round about 1100 inhabitations, which are registered in 650 households. The economy is shaped through tourism with more than 200 beds and a high amount of agricultural enterprises. With a long-term average wind speed between seven and eight m/s Pellworm is a favoured location for wind energy turbines (WET) whereof the largest part of the WET is organised in a civic wind farm.

2.1 Key energy indicators

There exist extensive data for the island, which concerns both, the energy situation of the island as a whole and the annual cycles of decentralized generators. Table 1 summarizes the key indicators of producers and consumers. Consumers are divided according to the used VDEW (Electricity Industry Association) standard load profile. The annually generated energy of round about 21GWh from wind energy turbines, photovoltaic power plants and biogas plants on the island is opposed to an annual consumer load of 7GWh. Remarkable is the high amount of night storage heaters (load profile E1 and E2) as well as the high amount of heat pumps.

2.2 Grid structure

Figure 2 shows the structure of the medium-highvoltage system and the position of the decentralised generation systems.

Besides the hybrid plant from wind- and photovoltaic power plants of

Producer	Amount	Installed output	Yearly energy production
Wind energy turbines	12	5.725kW	15.251MWh
Photovoltaic plants	87	2.742kW	02.586MWh
Biogas plant	1	0.530kW	04.453MWh
Total production	100	8.997kW	22.290MWh
Of that hybrid generation plant	1	1.072kW	01.393MWh
Consumer (Loadprofile)	**Amount**	**Installed output**	**Yearly energy procurement**
Household customers (N0)	731		3.274MWh
Industry (G0-G5)	185		1.179MWh
Electric heating (E1-E2)	148		0.815MWh
Thermal heat pumps (W1)	20		0.178MWh
Others	92		1.621MWh
Total consumption	1156		7.068MWh

Table 1 Key energy indicators of the Isle Pellworm 2010 (Schütt, et al., 2011)

E.ON-Hanse Wärme GmbH, more than 100 additional decentralised generation systems from renewable energy energize into the low-voltage and medium-voltage 20kV grid from the grid operator Schleswig-Holstein Netz AG.

More than 50 local grid stations on the island spread the energy into the low voltage level. The island is connected with the MS grid of the mainland by means of two 20kV undersea cables. The designing of the undersea cable leads currently to a restriction of the energy exchange with the mainland. The high amount of wind energy turbines on the mainland leads increasingly to load-related grid disconnections in the grid region.

2.3 Cooperation of the operators

Remarkable is that the island is characterized by a close cooperation between the grid operators, operators of large generating plants and the large amount of consumers. The planning of large and centrally

Figure 2 Schematic overview of the decentralised energy generation Pellworm (Schütt, et al., 2011)

located energy storages, taking into account the required security of supply, grid stability and power quality, is therefore easily possible because both, the medium- and low voltage grid as well as the hybrid generating plant on the island belong to related companies of the grid operator. The design of Smart Grids is getting more difficult the more detailed the mains supply is divided und the bigger the amount of the including actors is.

3 Non-technical aspects for the construction of the Smart Grid Pellworm

A crucial non-technical aspect of setting up Smart Grids can be described with the generic term “acceptance” of Smart Grid activities. Both the energy provider and grid operator and the community as a key local authority and in particular the islanders should support the activities to build a Smart Grid and participate actively. Therefore these specific groups need to get know the key characteristics of a Smart Grid and be convinced of the benefits.

The community as a crucial authority is well informed about the possibilities of innovative energy concepts through self-initiated environmental- and energy studies (Eichelbrönner, et al., 1997) (Hemmers, et al., 2010). The community itself is taking its own steps to establish a holistic innovative energy concept. The main characteristics of Smart Grids are known and the community gets regularly informed about the project process on public events or in the local council. The acceptance of the grid operator for the construction of the Smart Grid is documented through the cooperation during the preparation of the innovation study Pellworm.

Experiences from similar projects (Deppe, et al., 2011) show that information events, mailings, information within Internet portals and email campaigns do provide sufficient information exchange. Thus Pellworm is using apart from these possibilities mainly personal interviews and approaches. The personal interviews are prepared through information in local council conferences, public information events and mailings. Within a first 20-minute survey 165 of the 650 households have taken their position with regards to renewable energy, smart grid, broadband Internet connection and e-mobility. In general the reconstruction of the electrical power supply is welcomed. Smart Metering characteristics are known and positively evaluated. The inhabitants are interested in the development of an ICTinfrastructure however only a minority wants to pay for it. The willingness to use an electric vehicle is surprisingly large. Exemplary for the evaluation of a standardized questionnaire shows Figure 3, the willingness of the inhabitants of Pellworm, to accept the measures for the construction of the Smart Grid.

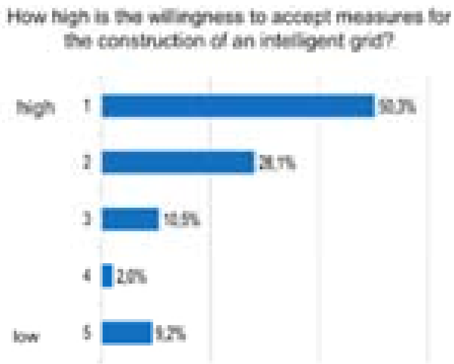

Figure 3 Exemplary evaluation of the questionnaires and interviews of 165 households (Schütt, et al., 2011)

A second personal approach has the background to contractually bind a large amount of private and commercial clients so that the load curves can be recorded to the minute and an automatic control of the electrical storage heaters and heat pumps is possible. These customers are involved in the energy management strategies to optimize the use of the storage elements. In addition to that, with these clients, it is possible to evaluate the efficacy of new tariffs and incentives. An extensive customer loyalty program and a respectively revised agreement support the acquisition of customers.

The majority of the potential and targeted households are bounded by a contract.

4 Technical aspects for the construction of the Smart Grid Pellworm

A major goal of the Smart Grid Pellworm is the maximum use of regionally based renewable sources with an optimal utilization of the existing grid infrastructure. This requires an intelligent balance of production, consumption and storage.

The innovative study describes both the future grid infrastructure as well as the endorsement of additional central storage. The future grid for Pellworm mainly includes

- automatic local grid stations,
- smart meters with advanced meter management and integrated load control functionality in particular for the usage of decentralized controllable loads in the low voltage grid,
- rapid, highly voluminous data communications with households,
- an energy management system for Pellworm and
- additional central storages in the medium voltage grid.

The local grid stations are used as data collections for the exchange of counter and control signals. The new facilities in the local grid stations are taking over monitoring, measurement and protection features.

The design of the storage is extensively described in (Nicolai, et al., 2011). At this point the key results will be summarized: the design happens through the reproduction of the generation and load profiles and the optimization with regards to determined objective functions. These producers are reproduced through existing time series and with respect to long-term meteorological data and the consumers are reproduced using the load profiles. Within the study, multiple target scenarios have been defined and studied. For the interpretation of the scenario the following objective function is selected: minimizing the energy demand from the mainland and the usage of available storage elements. Besides the availability, power, energy, charge and discharge time, efficiency, environmental impact, cost and acceptance are decisive criteria for storages. For Pellworm the investigations are limited to the usage of redox flow batteries (RFB) and lithium ion batteries (LIB). Table 2 summarizes the main results of the energy consumption bill and contrasts them to the operation without storage element (reference).

The results show that the combination of storage elements with a moderate size and the involvement of the flexible loads reduce the energy procurement from the mainland of about 90%.

The integration of the producer, consumer and storage in the grid map Pellworm and the grid calculation in Digsilent makes the inspection of the grid characteristics possible. Calculations show that the storage element can be located in the vicinity of the hybrid power plant without the need for further expansion of the distribution grid of Pellworm. Realized are now the construction, commissioning and operation of a LIB (800kW/1,6MWh) and a RFB (200kW/2MWh) on the site of the hybrid power plant with the inherent power electric for both energy flux directions.

Optimization model	Storage parameter	Energy procurement
Reference	-	336,51 MWh
Moderate RFB	800 kW / 8000 kWh	64.81 MWh
Average RFB	400 kW / 4000 kWh	130.37 MWh
Small RFB	400 kW / 1100 kWh	211.29 MWh
Small LIB	400 kW / 1000 kWh	206.77 MWh
Moderate RFB+NSH	800 kW / 8000 kWh	29.19 MWh
Average RFB+NSH	400 kW / 4000 kWh	81.31 MWh
Small RFB+NSH	400 kW / 1100 kWh	137.70 MWh
Small LIB+NSH	400 Kw / 1000 kWh	135.28 MWh

Table 2 Result of the energy import bill for Scenario 1 (Schütt, et al., 2011)

Those consumers bounded by a contract are equipped with power meters and smart meters, also including control facilities. The local grid stations are automatized and an energy management system is introduced. The automated gathering and analysis of the consumer and producer portfolios as minute values allow to adjust the charging and discharging process of the central storage in compliance with the permissible operating ranges. In the following two-year operation phase the optimal control strategy of the system components are calculated according to different strategies. The operating results are evaluated, different marketing models examined and the influence of tariff signals evaluated.

5 Summary

The realisation of Smart Grid projects depends not only on the legal, economic and technical circumstances but also mainly on the boundary conditions of the region for which the Smart Grid is planned to be realised. A characteristic example of a rural area with a large excess of energy from renewable energy generation plants is the island Pellworm. The yearly produced energy from energy, photovoltaic and biogas plants on the island is three times bigger than the annual energy required by the consumer. Apart from that, the island is characterized by a high degree of electrical thermal storage heating and thermal heating pumps. Due to the clearly bounded area and due to the supply through exactly two sea cables, Pellworm is especially suitable for the construction, operation and evaluation of a Smart Grid.

Characteristically for the construction of a Smart Grid on the island are the supplementation of the energy supply through respective central energy storage elements with an appropriate storage capacity and the usage of the existing night storage heaters and thermal heat pumps. This paper describes the design of the storage element, the selection of an appropriate technology and of a suitable location.

This article shows to what degree the proportion of the current energy supply from the mainland can be reduced by means of the proposed new structure. It points out that the ICT infrastructure must be complemented and that the automated local grid stations are crucial preconditions for the construction.

The paper describes the measures taken to establish the acceptance of all the Smart Grid stakeholders as well as the key findings. The results of a comprehensive survey conducted with the islanders show a clear willingness for the conversion of the energy supply to the Smart Grid. A contract is signed with a sufficiently large part of the approached household customers, which enables the necessary detection of the specific load curves and the automated control of electric storage heaters and heat pumps.

The realized measures are displayed in such a way that they can be converted to other regions, which have a similar high amount of energy surplus from renewable energies. The actual construction phase of the core of the Smart Grid is followed by the operation phase in which different energy management strategies and market incentives are tested and examined. The research results will give information on questions, which are still unclear, mainly with regards to effectiveness, profitability but also with regards to technical grid characteristics.

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