Status and Prospects of European Renewable-Based Energy Systems Facilitated by Smart Grid Technologies

Yi Ding, Jacob Østergaard, Poul Ejnar Sørensen, Peter Meibom and Qiuwei Wu

Abstract Renewable energy plays an important role in the future energy framework of the European Union. The European Union will reach a 20 % share of renewable energy in total energy consumption and increase energy efficiency by 20 % by 2020. Smart grids will be the backbone for facilitating the integration of renewable energy resources into future energy systems. The plans and status of renewable energy resources development and energy policy in Europe are introduced in this chapter. The development of smart grid technologies for facilitating the renewable-based energy systems in the European Union is also discussed. The role of Denmark, one of the leading countries for developing smart grid technologies and using renewable energy resources, has been emphasized in this chapter.

Keywords Renewable energy · Wind power · Smart grid · European union · Denmark

1 Background

Two of the major challenges facing the world are climate change caused by global warming and security of energy supply. The European Union (EU) has realized that its future economic growth and jobs are relying on the efficient and sustainable use of natural resources [1]. The EU2020 agenda deliverers a clear European framework for promoting the use of renewable energy resources and reducing

Y. Ding (✉) · J. Østergaard · Q. Wu
Department of Electrical Engineering, Centre for Electric Power and Energy,
Technical University of Denmark, Copenhagen, Denmark
e-mail: yding@elektro.dtu.dk

P. E. Sørensen
Department of Wind Energy, Technical University of Denmark, Copenhagen, Denmark

P. Meibom
Danish Energy Association, Rosenørns allé 9, 1970 Frederiksberg, Denmark

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greenhouse gas emissions for 2020: The EU will reach a 20 % share of renewable energy in total energy consumption and increase energy efficiency by 20 %. In the future energy framework of EU, renewable energy plays an important role tackling the challenge of the climate change as it is an ideal energy source to decarbonize the generation of energy, as well as a means of improving the security of our energy supply by drawing upon inexhaustible sources of energy [2, 3].

However, the existing EU's energy infrastructure cannot cope with the high penetration of renewable energy efficiently and effectively. Without serious upgrading of existing electricity network, monitoring and metering systems, and operation and control strategies, the use of renewable energy generation will develop at a much slower pace and system security may be jeopardized. Opportunities for energy saving and energy efficiency will be missed [1].

Smart grids will be the backbone of the future electricity network of EU, which will facilitate the integration of the high penetration of renewable energy and vast amounts of electric vehicles (EV), heat pumps, and other distributed energy resources with a considerable potential to provide balancing capacity and other flexible services to the power system. Moreover, smart grids provide a possible solution for improving the reliability and security of electricity networks. The Commission of EU is encouraging the implementation of smart grids because it provides an opportunity to boost the future competitiveness and worldwide technological leadership of EU technology [1].

Denmark is also a driver in the way in energy-efficient and energy-friendly economy in EU. In 2012, 30 % of the total electricity consumption came from wind power (Energinet.dk Market Data) [17]. The Danish Energy Agreement of March 2012 (Accelerating green energy towards 2020) [7] sets ambitious targets for 2020, including that approximately 50 % of electricity consumption should be supplied by wind power, and more than 35 % of total energy consumption (including electricity, heat and transportation) should be supplied from renewable energy sources. Danish experience illustrates that dependency of fossil fuel can be reduced without adverse effects on the economic development through positive energy policy and technology development for enhancing energy efficiency.

This chapter discusses the plans and status of renewable energy resources development and energy policy in Europe. The challenges faced by future power systems with high penetration of renewable energy resources are briefly described. Solutions for developing smart grid technologies for catering high requirements of balancing power in the future are discussed.

2 Plans and Status for Renewable Energy Resource Development and Energy Efficiency Improvement

The EU commission has endorsed the European strategic energy technology plan (SET-Plan) to develop and deploy low-carbon technologies during the next 10 years in Europe. The corresponding technology roadmaps are proposed as a basis for strategic planning and decision making on a transition to a low-carbon economy, which includes the following main sectoral targets by 2020 [3]:

- Up to 20 % of electricity in EU will be produced by wind energy resources.
- Up to 15 % of electricity in EU will be produced by solar energy resources.
- The electricity grid in Europe can accommodate the integration of 35 % renewable electricity in a seamless way and effectively maintain the reliable and secure operation.
- Cost-competitive and sustainable bioenergy will occupy at least 14 % of the EU energy mix.
- The framework of CO_2 emission allowance will be effectively developed with carbon capture and storage technologies.
- Around 25–30 European cities will be pioneer of the transition to a low-carbon economy.

For achieving these objectives, new generation of more efficient and more reliable wind turbines and photovoltaics/concentrating solar power plants will be implemented. The offshore resources and deepwater potential of wind power will be exploited. The technology competitiveness for large-scale penetration of solar power generation will be improved.

Meanwhile, an unprecedented European research, development, and demonstration program will be conducted in the next 10 years, which will cost between 58.5 and 71.5 billion euros. Table 1 illustrates the cost estimation of renewable energy development and smart cities initiative [3].

Among EU countries, Denmark is a leading country for developing renewable energy technologies and using renewable energy resources [4]: In 1957, an experimental wind turbine was installed in Denmark and connected to the electricity grid. In the 1980s, the first generation of wind turbines was mass-produced by machine manufacturers. Since then, the Danish Government has encouraged the large power companies to construct wind farms for providing electricity. In the 1990s, the government provided attractive incentives for wind power development, and more and more private individuals join the investment in constructing wind farms and producing wind power because of favorable profits. In the past three decades, wind power generation capacity has grown from nearly 0 to almost 3,500 MW. The Danish electricity grid has also been operated effectively and securely with the high penetration of wind power.

Figure 1 illustrates hourly wind power generation and demand in October 2010 in the western Denmark (DK1) provided by the Danish transmission system operator [5]. The annual wind generation was 27.1 % of the annual demand in DK1 in 2010. Still, the figure indicates that the hourly wind generation exceeded the hourly demand in the nights of and October 3 and October 13. This was the case in 71 of the 8,760 h in 2010, corresponding to 0.8 % of the time.

Besides increasingly using renewable energy, a wide range of energy-saving initiatives and energy efficiency improvement have also been included in the Danish action plan [6]: Denmark is among the countries in the EU with highest energy efficiency. Since 1980, the Danish economy has increased by 78 %.

Table 1 Cost estimate of renewable energy development and smart cities initiative

European industrial initiatives	Total (b€)
Wind energy	6
Solar energy (PV and CSP)	16
Bioenergy	9
Carbon capture and storage	10.5–16.5
Electricity grid	2
Sustainable nuclear energy	5–10
Smart cities	10–12
Total	58.5–71.5

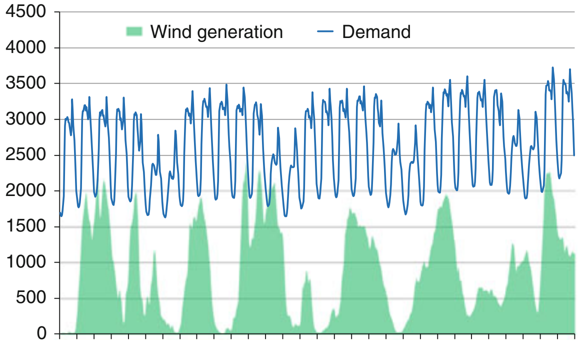

Fig. 1 Wind power generation and demand in November 2010 in the western Denmark

However, energy consumption has remained approximately constant and CO_2 emissions have been reduced with 24 % [18].

The Danish gross energy consumption has been decreased by 2 % from 2006 to 2011 based on the target of Danish energy policy and still further by 2020. Energy consumption from buildings and vehicles is primary target to be reduced. Comparing with current standard, energy efficiency requirements for new buildings will be much stricter. Electric vehicles (EVs) will cover 10 % of the road transportation, and 15 % of energy consumption from road transportation will be supplied by electricity [8]. EVs will also constitute a flexible demand resource enabling smoothing of the power fluctuations from renewable energy resources.

Allowance and tax schemes also work as lever for achieving the goal of energy savings. In Denmark, gasoline-based vehicles have received very high taxes, which is up to 180 % [8]. The total price of a medium-sized car is two times than that in the USA. The gasoline price in Denmark is also approximately double of that in the USA due to heavy taxes. Comparing with that, EVs have not received tax yet. From 2013, most generation companies in EU will have to purchase CO_2 emission allowance from the market, which is expected to increase the electricity prices by approximately 20 % [4]. It will encourage the electricity production from renewable energy sources, which is allowance free. Thus, the emission allowance will spur more investment in renewable energy field and EVs.

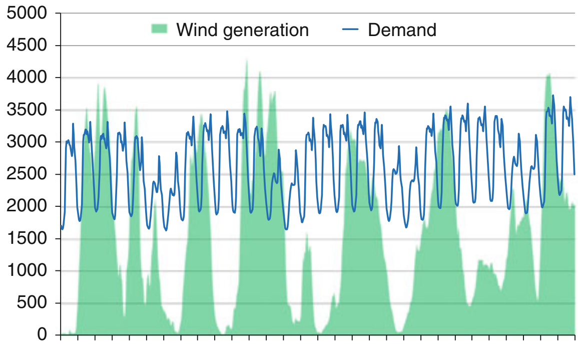

Fig. 2 Estimated wind power generation and demand in November in the western Denmark with 50 % wind power penetration

3 Challenges and Solutions

The high penetration of renewable energy resources will also challenge the power grid of EU for two reasons [9]. Firstly, the share of fluctuating and less predictable electric power production will increase significantly. The Danish balancing challenge with 50 % wind power generation is illustrated in Fig. 2, where the wind generation has been estimated by a simple scaling of the 2010 data so that wind covers 50 % of the demand.

Subtracting wind power leaves a residual demand and an overflow in November as shown in Fig. 3. With the applied simple scaling of the wind power generation, the hourly wind generation will exceed the hourly demand in 1,254 of the 8,760 h in 2010, corresponding to 14.3 % of the time. In reality, the overflow periods will probably be even longer with 50 % wind generation, because most of the new wind power development will be built as large offshore wind power plants. Experience with the operation [10] and modeling [11] of large offshore wind plants has shown that the power fluctuates relatively more than the power from the land-based wind turbines, first of all because there is a much higher geographical concentration of the offshore wind plants compared to the land-based wind turbines.

Obviously, higher renewable energy penetration in Europe will increase competition and costs for balancing power because the conventional energy resources are reduced and the need for balancing resource will increase. Also both current energy markets (spot, regulating power) and ancillary services are designed for conventional large generation, which may be too rigid as the practicability of the new-generation technologies.

Secondly, the electrification of transport and heat will put a pressure on the distribution grids in the power system; hence, the operators of the distribution grids may face two options in order to manage the subsequent grid congestions, either increase grid capacity or implement control signals, e.g., real-time price signals that reflect the variation in demand for capacity during real-time operation. However, these two options are not entirely a choice of one over the other. Some

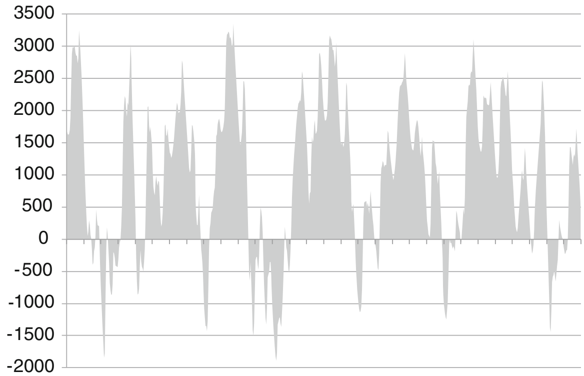

Fig. 3 Estimated residual demand and overflow with 50 % wind power penetration

additional grid capacity will be needed; however, implementing control signals will improve the utilization of existing distribution capacity; hence, the need for new capacity will decrease.

If the control signals are set as locational real-time price signals it will adapt to the local supply and demand conditions, taking grid congestions into consideration during system operation.

To address the future needs and challenges, an efficient and effective market-based tool must be developed, which will attract distributed energy resources (DER) and active end user to provide balancing power for the transmission system operator. The EcoGrid EU—A Prototype for European Smart Grids is a large-scale smart gird demonstration project [9, 12], where a new real-time electricity market is proposed to allow the participation of small-scale DERs and small end consumers into the existing electricity markets. Today, most of the DERs and end users face barriers to supply balancing services to provide balancing services, e.g., requirements on bidding size, complex bidding strategies in the markets, complying with schedules, etc. The objective of the new real-time electricity market is to remove these barriers [9, 12].

While the EcoGrid EU emphasizes on the participation of small-scale DERs and small end consumers for providing system-wide balancing services, another Danish national project iPower—a Strategic Platform for Innovation and Research within Intelligent Electricity is more focused on the aggregation of DERs providing flexibility services, trading services for the efficient and reliable operation of distribution grids. An aggregator-based Flex market [13] has been proposed for promoting small-scale DERs to provide the flexibility services for distribution system operator such as overload and voltage management. Three possible trading setups including bilateral contracts, auctions, and supermarkets have been identified in the Flex market of iPower.

4 EU Smart Grid Initiatives

With the technology advancements, the future EU and Danish power grid have the following design objectives [14]:

- Sustainable to reduce carbon emission.
- Secure and reliable to provide electricity supply.
- Economic to reduce electricity prices and costs for other services.
- Flexible to promote customer participation.

The vision of Smart grid is defined by the European Commission Smart Grids Advisory Council as “an electricity network that grants connection access to all network users and provides efficient and reliable services in order to fulfill customers’ needs whilst responding to the changes and challenges ahead” [15].

Key components of smart grid include the following [14]:

- Smart meters: Smart meters are key enabling component for smart grids, which allow the end user to monitor and control consumption in real time. Smart meters also enable two-way communication and interaction between system operator and end users. It will in turn drive development and demand for smart controllers of electrical appliances.
- Intelligent grid management: Intelligent grid management allows flexible power generation, transmission, and active distribution. The bidirectional power flow between transmission and distribution is also possible, which allows prosumers to sell their own power surpluses in the future.
- Software-based added-value services and applications: These services allow DERs and end consumers to economically optimize their electricity production/consumption.
- System-wide oversight and coordination—the “glue” in the system: A uniform communication infrastructure will enable real-time and system-wide communication, which integrate both producers and consumers. The uniform communication infrastructure will support PMU-based wide-area measurement system (WAMS) for system security supervision and control.

There are several smart grid projects implemented in EU. Table 2 [12] summarizes the contribution and key deliverables from previous and ongoing EU smart grid projects. The assessment of technical feasibility is the focus of the majority of smart grid projects. The EcoGrid EU and iPower projects focus on market-based system operation to a higher degree, so that both DERs and end users can provide flexibility services on both transmission and distribution levels.

Table 2 Behnke and Nielsen [12]: EU smart grid project

Project title	Description	Technical R&D	Market design	Technology demonstration	Market demonstration
FENIX (EU)	Identification of the technical capabilities of DER to provide system services through aggregation using the concept of the Virtual Power Plant. Small-scale demonstration	***	*	***	
More MicroGrids (EU)	Integration of small-scale distributed energy resources through the microgrid approach design of alternative control strategy to enable autonomous operation. Small-scale demonstration	***		***	
EU DEEP (EU)	Development of innovative business models for integration of DER into current system and market operation	**	**		**
DISPOWER (EU)	Survey analyzing the present power supply system and its components including information and communication technologies. Laboratory facilities for developing, testing, and demonstration	**	*	**	
ADDRESS (EU)	New Active Distribution Networks (ADN) able to balance in real-time power generation and demand allowing all players to benefit from the increased flexibility of the entire system. Three test fields planned	***	**	**	*
EcoGrid EU (EU)	Demonstration of a large-scale real-time market participation for DER and flexible demand	**	***	**	***
TWENTIES (EU)	Large-scale demonstration of smart grid solutions until 2014 encompassing virtual power plants, HVDC offshore grids, wide-area monitoring systems, and dynamic line ratings	***	*	***	

*** indicate a significant contribution, and * indicates a limited contribution

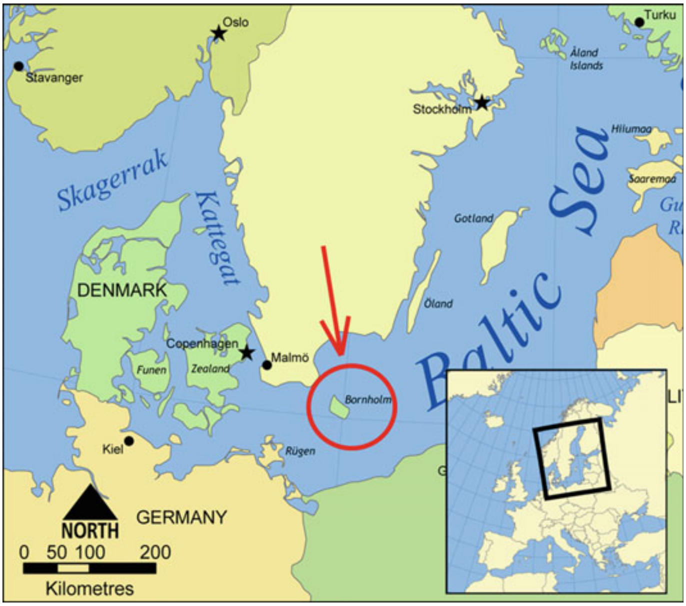

Fig. 4 The Danish Island of Bornholm [16]

5 Case Studies: Bornholm—"Fast Track" for EU Smart Grid

The Danish island of Bornholm is located in the Baltic Sea as shown in Fig. 4 [16], which is a unique test site for smart grid projects. The Bornholm distribution system is integrated in the electricity market of western Denmark (DK2) and is interconnected with Nordic power system as shown in Fig. 5 [12, 16]: The system has a peak load of 55 MW and very high penetration of renewable energy resources. The capacities of wind power and CHP units are 30 and 16 MW, respectively. In the future, the amount of renewable energy resources and energy storage devices such as PV, micro-CHP, fuel cell, and heat storage will be established for smart grid demonstration purpose.

The Bornholm distribution grid is a meshed 60-kV network, which also includes 60/10-kV substations, 10-kV feeders, and 10/0.4-kV substations. The Bornholm grid is also connected to the Nordic transmission grid through a 60-kV AC cable.

The Bornholm power system is a pioneer of future distribution systems of EU, which has very high penetration of renewable energy. The public and municipality of Bornholm support and encourage the "Bright Green Island" strategy. The goal of renewable energy resource penetration in the Bornholm power system will reach 100 %. Therefore, the Bornholm system is well suitable for testing the feasibility and robustness of smart projects of EU. The Bornholm power system will provide a very good test bed for the smart grid projects.

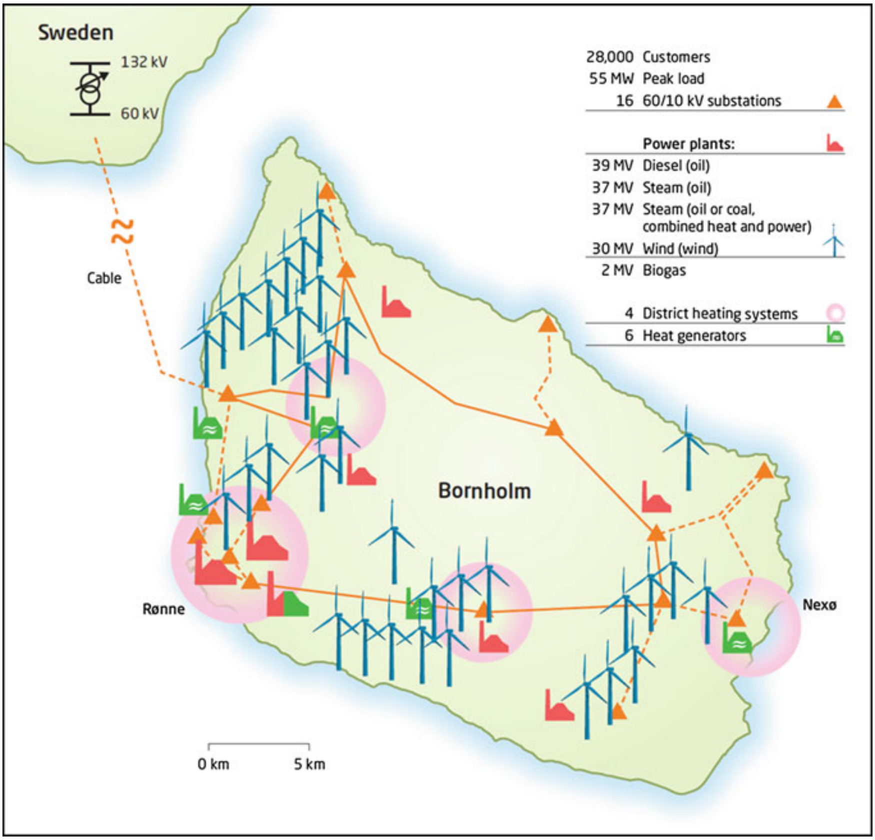

Fig. 5 The Bornholm distribution system [16]

6 Conclusions

The future EU power system will integrate high penetration of renewable energy resources, which will significantly challenge the system operation and control. Smart grid provides an efficient and effective tool for addressing the future needs. This chapter synthesizes challenges faced by future power systems with high penetration of renewable energy resources. Energy policy in EU is also summarized. Several smart grid projects implemented in EU, e.g., Ecogrid EU and iPower, are introduced.

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References

1. Communication from the Commission to the European Parliament (2011) The Council, the European Economic and Social Committee and the Committee of the Regions, smart grids: from innovation to deployment. Brussels
2. Communication from the Commission to the European Parliament (2011) The Council, Renewable Energy: Progressing towards the 2020 target. Commission Staff Working Document, Brussels
3. Communication from the Commission to the European Parliament (2009) The Council, the European Economic and Social Committee and the Committee of the Regions, on investing in the development of low carbon technologies (SET-Plan). Commission Staff Working Document, Brussels
4. Energinet.dk (2009) Green thinking in Denmark, wind power to combat climate change—How to integrate wind energy into the power system. Denmark
5. Energinet.dk (2010) Download of market data. Available at http://www.energinet.dk/EN/El/The-wholesale-market/Download-of-market-data/Sider/default.aspx
6. ENERGI (2009) "The Danish example"—the way to an energy efficient and energy friendly economy. Available at http://www.ens.dk/en-US/policy/danish-climate-and-energy-policy/behind-the-policies/Thedanishexample/Documents/The%20Danish%20Example%20Engelsk%20FINAL%20200209%20vs2_final.pdf
7. Danish Energy Agency (2012) Accelerating green energy towards 2020. The Danish energy agreement of March 2012
8. Østergaard J et al (2009) Electric vehicles in power systems with 50 % wind power penetration: the Danish case and the EDISON programme. European conference electricity and mobility, Würzburg, Germany
9. Energinet.dk (2011) EcoGrid EU—A prototype for European Smart Grids. Available at http://energinet.dk/en/forskning/EcoGrid-EU/sider/EU-EcoGrid-net.aspx/
10. Akhmatov V et al (2005) Integration of offshore wind power into the western Danish power system. In: Proceedings of Copenhagen offshore wind. Denmark
11. Sørensen P et al (2008) Modelling of power fluctuations from large offshore wind farms. Wind Energy 11:29–43
12. Behnke K, Nielsen AH (2009) EcoGrid Europe—A demonstration project for the future. Available at http://ec.europa.eu/research/conferences/2009/smart_networks/pdf/behnke.pdf
13. Zhang CY et al (2013) A flex-market design for flexibility services through DERs. ISGT Europe, Copenhagen
14. SAP AG (2011) Smart grids for Europe—Benefits, challenges and best practices. The SAP perspective
15. European Commission (2006) European smart grids technology platform. Available at http://ec.europa.eu/research/energy/pdf/smartgrids_en.pdf
16. Østergaard J, Nielsen JE (2011) The Bornholm power system —An overview. Available at http://www.dtu.dk/sites/powerlabdk/English.aspx
17. Energinet.dk (2013) Download of market data. http://www.energinet.dk/EN/El/Engrosmarked/Udtraek-af-markedsdata/Sider/default.aspx
18. Danish Energy Authority (2009) Energy statistics. http://www.ens.dk