Technical University of Denmark

Secure operation of sustainable power system

WP1: future scenario description, system in context and specifications

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CENTRE FOR ELECTRIC POWER AND ENERGY

SECURE OPERATION OF SUSTAINABLE POWER SYSTEM (SOSPO)

WP1: FUTURE SCENARIO DESCRIPTION, SYSTEM IN CONTEXT AND SPECIFICATIONS

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WORK PACKAGE DESCRIPTION

The main objective of this work package is to provide the necessary specifications for the future sustainable power system and the integrated functionality of the SOSPO operational tool. Establishment of such specifications contributes to a successful development of the SOSPO tool. Since the interaction/interface between the modules is specified, the development of each individual module becomes less depended on the progress of other modules.

The project provides an operational solution for the future power system, where the power production mostly based on uncontrollable green energy sources. In Denmark, the energy strategy is defined that in the long term all the energy is produced by renewable resources therefore eliminate the dependence on fossil fuels. A significant part of the project focuses on the utilization of intermittent distributed energy resources for improving the wide area security of the system operation in real time. It is therefore of importance to provide a realistic description of a future scenario where among others the following is addressed:

- How will be the electricity produced?
  - Generation portfolio, such as intermittent renewable energy resources (RES), micro CHPs, and other distributed energy resources, and conventional generation plants. This implies which types of RES are expected to be deployed.
- Characteristics of the consumptions in the future system?
  - Demand side management, share of controllable loads vs. uncontrollable loads;
  - Energy and power consumption patterns given to new types of loads, such as EV, and heat pumps;
  - System support capabilities from the loads, eg. demand side management, load shedding schemes, et;
- Characteristics of the network
  - Transmission facilitates such as cables, HVDC links, FACTS devices for power regulation;
- On-line wide-area system monitoring, protection and visualisition
  - Different types of measurement systems, impact on system observability;
  - Protective relays, operational characteristics as well as possible new functionalities and requirements;
- Operational scenarios, role of system operators and level of automation
  - Market mechanism, expected time frames for fulfilling a specified energy demand
  - Basic controls, such as generation controls, load-frequency control;
  - Arrangement of system reserves regarding the MW/MVar;

The establishment of specifications for the above mentioned points provides necessary background information for the establishment of a mathematical model for the new control object. Information regarding the future system contributes to increased understanding of the characteristic system dynamics of the future power system. It is important to be noted that the information provided from this report shall be used as basic requirements for setting up the future systems, and only represents the view from this project.

FUTURE POWER SYSTEM PERSPECTIVES

The electric power system has undergone significant changes over the last two decades; from operation as a vertically–integrated system to a liberalised electricity market, from production based on large centralized fossil–fuelled plants to distributed production based on renewable energy resources, from centralised generation dispatch to demand side management, virtual power plants, and microgrid operation. Following the trend of the prevalence of the green technology, such as wind and solar energy based production, it can be foreseen that the future energy portfolio of power system will move toward more diversified scenarios, for instance, the mixture of generation, variable energy outputs from different resources, etc, rather than the traditional scenario where most of the energy coming from fossil-fuelled steam units.

Different renewable energy strategies have been proposed at different areas in the world. In Europe, in 2007, the EU commission sets the '20 − 20 − 20' targets which define the goal of 20% EU energy consumption supplied from renewable resources in 2020. Ambitious objectives have been set on CO2 reduction by different countries. In Denmark, government has expressed a long term target of achieving a Danish energy supply based on 100% renewable energy by 2050, and hence eliminate the dependency on fossil fuels. Fig. 1 shows the Danish roadmap towards the green future. Profound changes are taking place in the system operation and control.

Given the current energy strategy, the future Danish system can be characterised by high penetration of renewables as well as the cable transmission system, with strong interconnection with the surrounding systems. From the low voltage side, the introduction of solar energy will significantly change the load profile of the system while for high voltage side; the impact from the variability of wind can be handled by introducing stricter grid codes for wind farm interconnections and expansion of storage capability in order to replace the conventional power plants. This chapter starts from a collection of the government strategies, to a prediction of the most possible future system operation scenario, and hence provides a framework for the system development, demonstration and test.

CHANGES IN DANISH FUTURE SYSTEM

Foreseeable changes will be taking place in the Danish power system in the next 10–20 years, mainly due to the increasing share of renewables. In 2009, wind turbines in Denmark produced 6, 721 GWh equal to 19.3% of the total electricity demand (34, 823 GWh). The government 'Energy Strategy 2025' implies that the contribution from renewables is expected to cover over 30% of electricity supply in 2025, with wind accounts for the major part [9]. The government reached new Energy Agreement with the political parties and energy companies that clearly mentioned a 12% reduction of gross energy consumption in 2020 in comparison to 2006, and a share of 35% renewable energy in the gross energy consumption (including the sectors other than electricity) while 50% wind energy in Danish electricity consumption by 2020 [10]. The share of renewable energy grew from 20.1% to 22.3% in 2010, and the production of electricity from renewables accounted for 33.1% of Danish domestic electricity supply in 2010. Of this figure, wind power accounted for 20.7% [11]. The current wind installation capacity is around 4 GW, with the total demand between 2 GW to 6 GW[12]. Fig. 2 shows the installation status of wind turbines in Denmark. Meanwhile, given the governmental promotion and economic incentives [13], there is also a foreseeable trend on fast

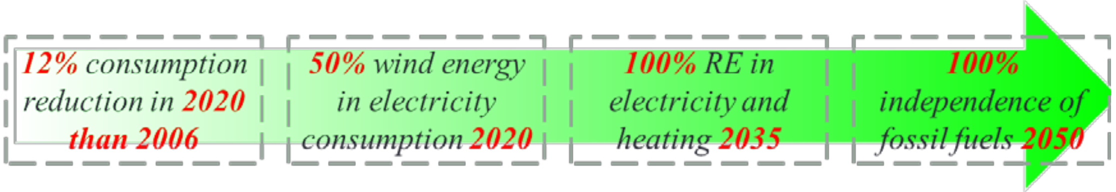

Figure 1. The Danish renewable roadmap to 2050

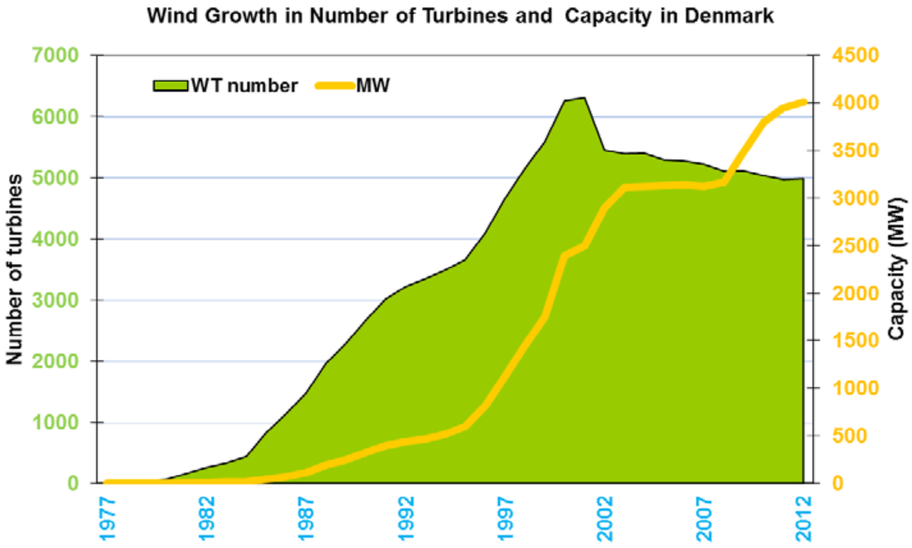

Figure 2. The growth of wind turbine installation in Denmark [12].

adoption of photovoltaic solar systems. In this section, a brief discussion is given to illustrate the future Danish power system dictated by SOSPO.

The vision of the SOSPO project looks at the scenarios of Danish power system beyond 2025. Development scenarios of the future Danish power system have to be established to identify the problems advised by SOSPO. A realistic scenario must be made in order to perform the modeling and laboratory realisation work. Part of the roadmap for the Danish system has been mentioned in the action plan of the government energy strategy [9], [14]. Meanwhile, Denmark is operating with two different electricity markets, Nordic and European respectively, hence the evolving of Danish grid is nevertheless associated to the operation of the surrounding systems. The Danish TSO Energinet.dk released the scenario report in 2007 to support decisions in the long–term planning of the expansion of the electricity and gas infrastructure. According to the environmental emphasis and level of internationalisation, four extreme scenarios are formulated [15]. These scenarios will be valuable for SOSPO to specify the testing cases. Beside the analysis in the report, considerations are also given to the network characteristics such as the transmission facilities, consumption level, and data acquisition infrastructure in order to mimic the whole process of supervision and security assessment in the control room. The influencing factors include, roughly, the production of generation mix, network, consumption expansion and monitoring system.

GENERATION CHARACTERISTICS

As seen from the government strategy, wind apparently will have been contributing to the major part of the electricity consumption by the year 2025 and 2030 given the figure 28% in 2011. According to Energinet.dk, wind energy will cover more than 90% of the consumption excluding the electricity for heat pumps and transportation [16]. By the time it is expected that all the central coal–fired power plants will be phasing out. Initiatives have been taken to expand the current wind capacity regarding the government goal, and there will be 1500 MW offshore wind turbines being commissioned in the near future, plus a net increase of 500 MW onshore turbines to guarantee the increasing electricity production from onshore wind notwithstanding the decommissioning of the old turbines. It can be envisaged that the grid impacts from the wind will be mitigated by introducing stricter grid codes for wind farm interconnections, transmission system reinforcement, and the expansion of storage facilities in order to replace the conventional power units.

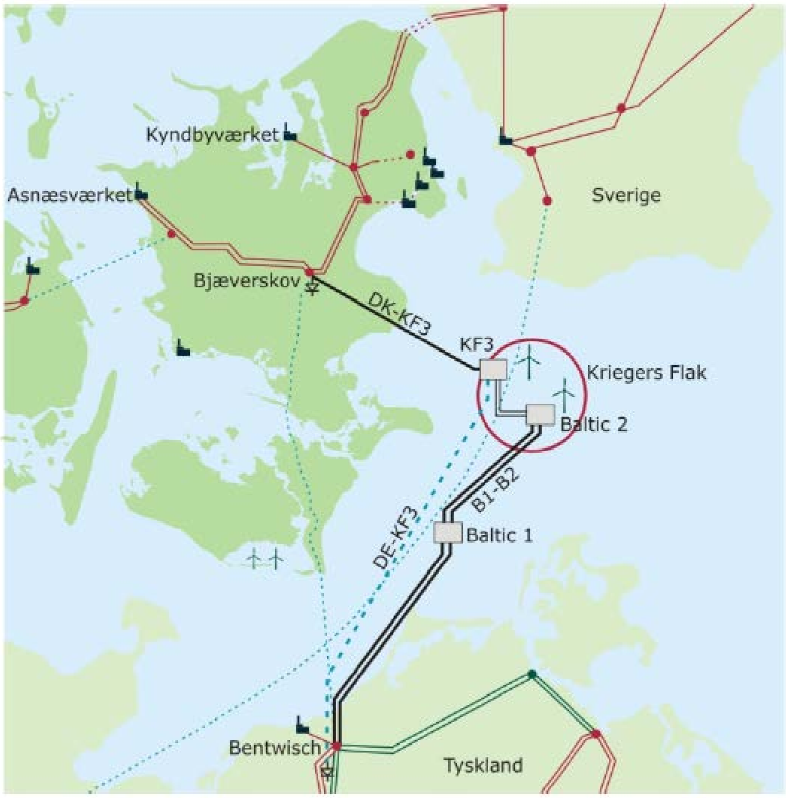

Figure 3. The planned new offshore wind farm at Kriegers Flak before 2020 [28].

In addition to wind, solar energy is expected to play an important role in the future electricity supply, as to the economic incentives such as government subsidies and ever decreasing costs of photovoltaics (PVs) and inverters. A fast expansion of roof–top PVs is taking place in Denmark. As seen from Table 1. The solar installation status in 2010-2011., before 2012, the installed capacity of solar has been very low, however, there was a drastic increase in the last 1 year that till November 2012, there have been 223 MW PV systems rolled out due to the subsidies provided by government. The government therefore changed the subsidies scheme from 2013 which provides a heavy braking on the rolling out. However, it is believed that in the long run solar energy will still take significant role in the future energy system as due to the decreasing cost per kWh.

Besides wind and solar, an increasing use of biomass in centralized combined heat and power (CHP) plants for electricity and district heating is expected. In 2010, biomass contributes to 68% of the total renewable energy production. This number maybe increase in the next 15 to 20 years however will depend on the price of other energy resources as well as the ever increasing share of other renewables.

Solar Energy	Denmark		
	Grid connected	**Standalone**	**Total (MW)**
2010	**6,3**	**0,7**	**7,1**
2011	**15,0**	**1,7**	**16,7**

Table 1. The solar installation status in 2010-2011.

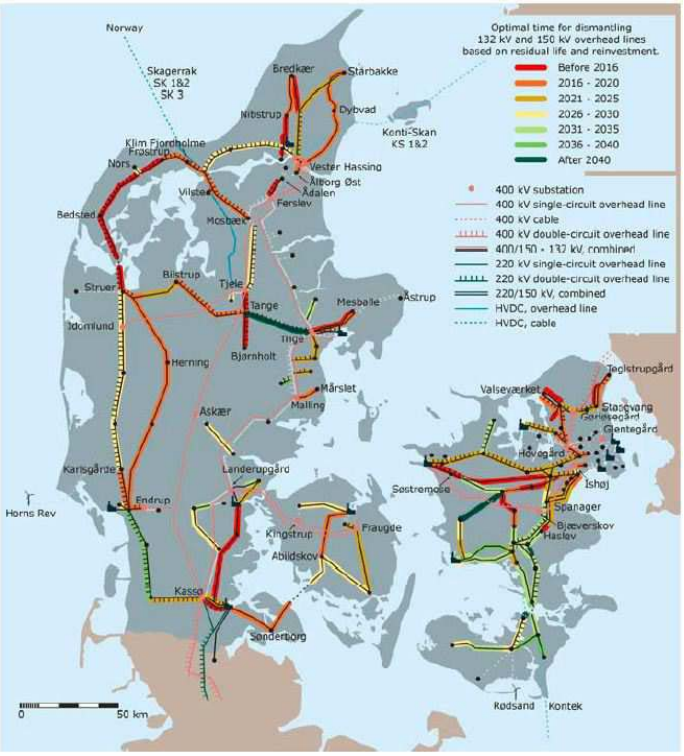

Figure 4. The future Danish transmission system [17].

ELECTRICITY NETWORK CHARACTERISTICS

Foreseeable changes are happening in the electricity network, as to the aesthetic issues, as well as the change of energy production characteristics.

TRANSMISSION NETWORK

Dramatic change will take place in the transmission system. In 2008 the Danish government entered an agreement that the future new 132/150 kV transmission lines will be underground cables, and the existing 132/150 kV overhead lines will be gradually upgraded to cables [17], as to 1). Aesthetic reasons, 2). Cable is more cost effective regarding transfer capacity at this voltage level than overhead lines. Meanwhile, partial 400 kV overhead lines will be converted into underground cables due to aesthetic reasons. The high transmission capacity from the underground cables will facilitate to integrate renewable generations, eg. many wind farms are connected to the grid by this voltage level. Several interconnection links have been planned following the expansion of the wind farms to strengthen the network. The future Danish transmission system is illustrated in Figure 4.

Besides the domestic network, the international links will be of significance for modeling and security studies. There have been a few new interconnection corridors to the neighboring countries under planning to both facilitate the market operation and intensify the wind penetration. A submarine cable to Norway has been planned and will be commissioned by 2014 in order to facilitate more wind power into the system. Meanwhile, a HVDC cable to Netherland is currently being investigated and expected to be commissioned by 2016.

The underground cabling system will bring issues like voltage rise due to the surplus of reactive power during the light load period. Hence considerations must be given to having additional transmission facilities in the system to aid the voltage issues such as shunt reactors, flexible ac transmission systems (FACTS), automatic voltage controllers, which are necessary to maintain the voltage security under different operation conditions.

DISTRIBUTION NETWORK

Currently the distribution networks in Denmark are generally of mixture of ring and radial types. Take the distribution network of Bornholm as an example, the 60 kV network is of ring type, while the 10 kV network operate as radial. There are interconnection switches between the 10 kV feeders used for service recovery in the case of a fault happened at a feeder. For the 0.4 kV network it mostly works in radial type.

There is no clear indication that fundamental changes will take place in the distribution network in the next few years. As it is predicted of significant increase on the use of the unconventional components such as electric vehicles, the household heat pumps, rooftop PVs, possible changes may come on the reinforcement of current network, such as upgrade of low voltage feeder transformers, the low voltage network cables, as well as flexible configuration of feeders at 10 kV level using the interconnection switches to achieve high efficiency. However, it is also need to mention that the continuous development of the existing and new control functions within the new components, possible regulations, as well as the implementation of new operation strategies may defer these changes. For a reasonable prediction, for the 2020 scenario, we could expect that the distribution network will operate as similar as today. For 2030 scenario, more flexible operation possibility shall be taken into account.

COMING REGULATIONS

ENTSO-E is developing Network Codes in the areas of grid connection, system operation and market which state the coming pan-European requirements in those areas among others to make possible the introduction of more RES.

Especially the Network Codes on Connection of Generators and Demand and on System Operation contain provisions which the models and simulations of SOSPO have to respect. As such the provisions can also be used to construct models and simulations if needed [22-23]. The same holds true for the ENTSO-E Defense Plan for Continental Europe [24].

Every 2nd year ENTSO-E also produces a so-called Ten Year Network Development Plan (TYNDP). This contains also the forecasted developments of the transmission grids outside Denmark. Figure 5 shows the ENTSO-E's perspective of the flow exchange in Europe by 2020 [25].

OTHER EMERGING TECHNOLOGIES

There are a few technologies which can be highly influential through the years to 2030, driven by the current smart grid initiatives.

STORAGE AND DEMAND SIDE MANAGEMENT

Currently the storage technologies are under rapid development, and there are obvious need and advantages of having storage in both large and small scales for hedging the intermittency from renewable energy resources. The current barriers restraining the penetration lies in the high investment cost, lack of solid business cases, as well as government subsidies, as currently for the renewable generation. The penetration of PVs may accelerate the application of stationary storage at home. Besides, one of the most promising storage capable devices is EV, which is seen to be used widely in the next 20 years in Denmark and worldwide. It is also discussed in detail below as a load.

According to [16], the total electric consumption will slowly increase along the planning horizon and will achieve around 10% by the year 2030, mainly coming from the individual heat pumps and electrical vehicles (EVs). The most uncertain parameter is the electrification of the transportation sector, as the development of electrical vehicles will be dependent however not limited on the following factors,

- Development of battery technologies;
- Increasing efficiency of conventional oil–fuelled vehicles;
- Price of gasoline and electricity;
- Laying of charging infrastructure;
- Stress on environments;

Therefore, the estimation of the electrical vehicle consumptions can be subject to high uncertainty towards year 2030. Though the total energy consumption of EVs may only account for approximately 3% of the total consumption, the penetration level of EV can significantly change the demand profile during the charging hours therefore the distribution network operation. Considerations must be given to EVs when formulating extreme scenarios.

The demand side management can be a valuable component given the current smart grid research. The principle of demand side management has been developed for years. Conventionally it was mainly towards industrial or commercial users, eg. contracts can be made with the system operator regarding the interruption of the services. The current smart grid research pushes the concept forward to more diverse demands, eg. the uncritical appliances of residential customers, with control flexibility on the consumed power and the time of being used. Such loads include electric heater, refrigerator, washing machines, dish washer, etc. This will be an important feature in the

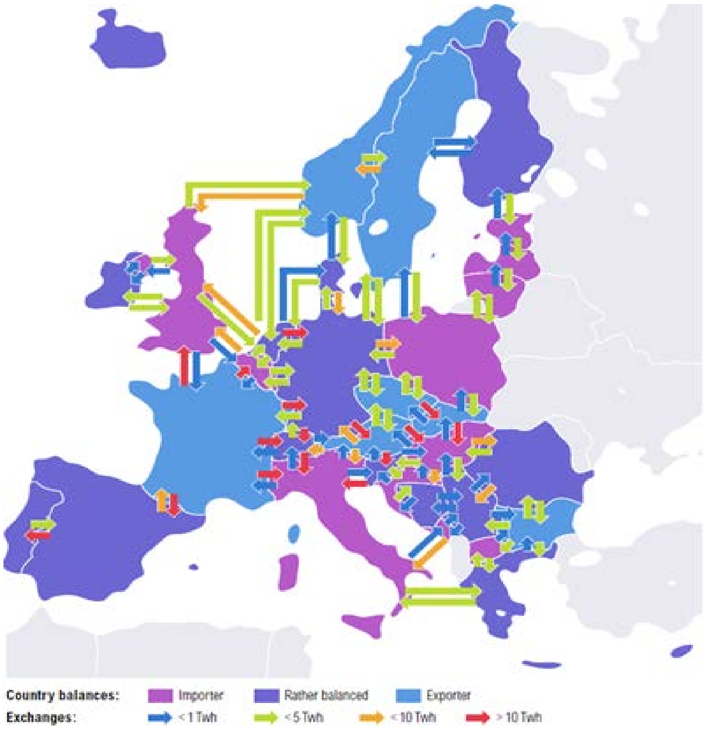

Figure 5. The forecasted flow exchange in Europe by ENTSO-E [24].

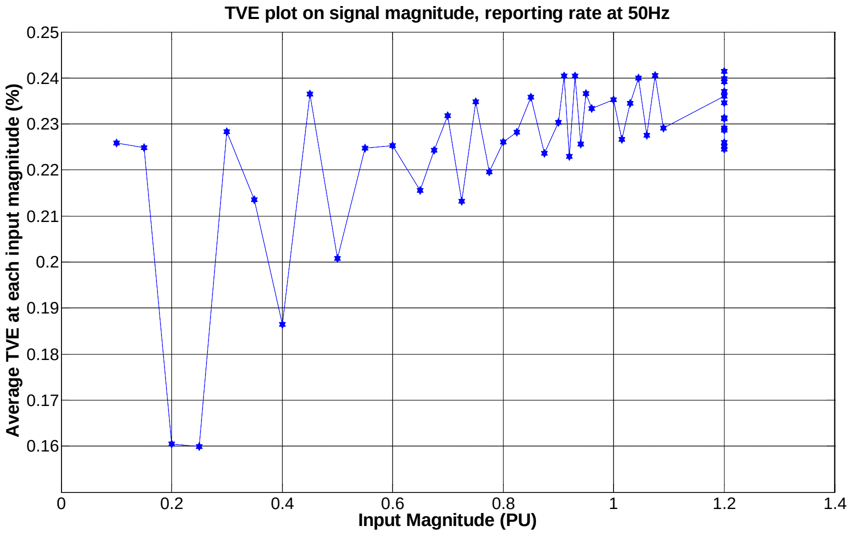

Figure 6. TVE analysis on voltage magnitude on a PMU.

future distribution grid to hedge the intermittency from renewables.

MONITORING AND DATA ACQUISITION SYSTEMS

Monitoring and data acquisition systems: The monitoring system is envisaged to be more advanced than today. In SOSPO, it is assumed that the synchrophasor measurements are available at any substations with high accuracy, which is an educated assumption according to the current development of phasor measurement capable devices, standardisation efforts and the time synchronisation technology. The operator is able to obtain the phasor information at the control room from any busbars of interest in real time manner. In SOSPO, efforts are given to testing of current measurement devices compliancing to the latest IEEE standards, the removal of artifact measurements, the instrumentation failures, noise, etc. It is not clear whether new standards will be released in the coming years regarding the measurement quality; however it will be useful to characterize the current measurements meanwhile with a future vision. Figure 6 shows an example plot of the total vector error (TVE) error assessment for the amplitude variations. TVE is defined by the root squared difference between the mathematically defined phasor X and estimated phasor $X(n)$,

$$\varepsilon = \frac{|X(n) - X|}{|X|} \times 100\% \tag{1}$$

It is worth noting that although SOSPO intends to apply extensively phasor measurement information, other measurement systems will also play an important role for future assessment, such as the current SCADA system, the advanced metering infrastructure, etc. It is highly believed that the current SCADA system will be largely expanded to the substations at distribution system level, and equipped with sophisticated control functions for renewable power plants, different kinds of distributed generation units, and protections.

ICT INFRASTRUCTURE

The ICT infrastructure for system operation is expected to be enhanced drastically given the next 10 to 20 years, partly due to the expected boost on the required measurements for monitoring, partly due to the current research trend on the smart grid. The vision in SOSPO is that the measurements will be available at all necessary points.

CHALLENGES TO SYSTEM OPERATION

Given the current governmental energy strategy, the future Danish grid can be characterised by high penetration of renewables as well as the cable–based transmission system, with strong interconnection with the surrounding systems. Large amount of wind is fed into the system at different voltage levels, while at the end of the feeders; the fast adoption of solar energy will significantly change the power flow patterns at the distribution grids.

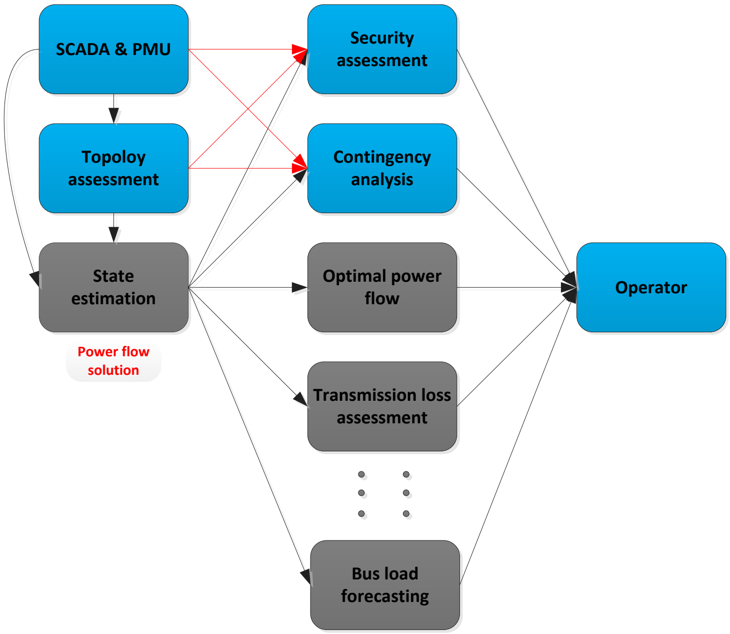

Figure 7. EMS Functions covered by SOSPO.

The challenge for system operator has been always similar, as there is no definite justification of the system security, until the instant time has been passed. As well, the intermittency of renewable generation can rapidly degrade the supply security of the electricity due to various unexpected frequency and voltage stability issues, power quality problems, overloading, etc. It is no need to further emphasize that a good overview of potential problems caused by the intermittency of renewable generation is required for the system operator, as well as the corresponding remedy actions. This is further detailed in the next chapters.

Focus will be also given to the visualisation of measurement data, which is an essential tool to refine the data and provide useful information of the current system condition for decision support. Another major challenge is the fast changing of generation pattern as well as the load pattern will affect the protection schemes, both the component protections as well as the system protection schemes[1] [30].

Currently the operation in Denmark follows the traditional approach, where the market collects the bids, dispatches the generators, the operator manages the balancing and supply security. The system is well connected to the neighboring systems, which brings advantages such as better usage of assets, resources sharing, etc. However, the recent events, such as the 2003 Danish blackout, as well as the islanding in 2007, show that the system has been heavily relying on the interconnectors [24]. The current trend on the increasing installation of renewables and decommissioning of the traditional power plants will exacerbate the situation. This means that at most time Denmark may not be able to balance the local consumption alone and the efficiency of market as well as the resources available from the neighboring systems will be essential to the operation.

Given the increasing constructions of interconnectors, another possibility is that Denmark will act as an energy transition center for power exchange between the continental Europe and the Nordic region. Given the increasing installation of the renewable from the neighboring countries, it is foreseen that in the future Denmark will be acting as a corridor for resources sharing. Therefore, it is essential for the system operator to efficiently manage the issues such as congestion, efficiency, power qualities, etc., and prepare the protection schemes in the case of, eg. losing interconnectors. It is necessary to have well prepared defense plans to counter the intermittency and identify the potential bottlenecks within the system which potentially amplify the emergency situation due to the renewables. In this report, focus will be given to the selected functions in EMS which are related to

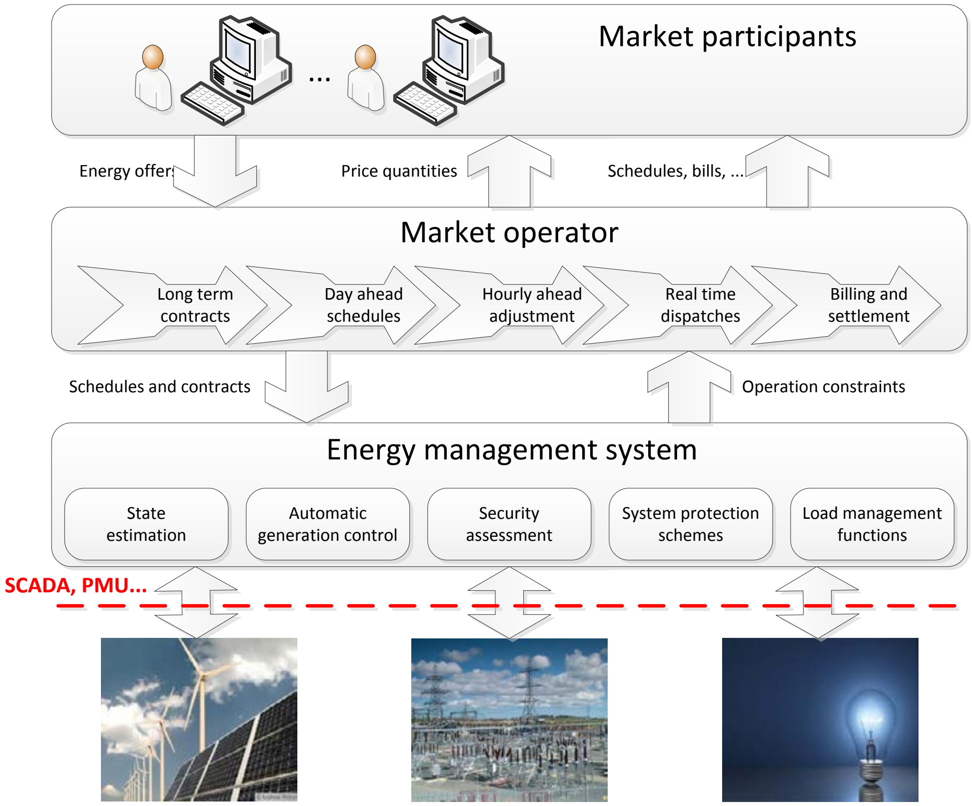

Figure 8. System operational scheme.

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1. ENTSO-E uses the term "special protection schemes" for remedy actions for the situations where the system is vulnerable however not necessarily at emergency situations; and "system protection schemes" are used maily for the emergency states.

SOSPO, as highlighted in Figure 7, to discuss the potential challenges and required changes.

NEW REQUIREMENTS

In the near future, it is expected that the system operation will be following the current configuration however the generation will be changed to renewables, as shown in Figure 8. The emerging issues in system operation demand new requirements and functions for the current EMS system. For the sake of brevity, here only list the functions which may experience significant changes.

Automatic generation functions

Automatic generation functions primarily refer to the load frequency control in system including the primary, secondary and tertiary controls. As the system will primarily contain intermittent resources, it is foreseen that this control function will be activated and actualized in a different manner as today. The technical barrier for the current renewable power plants to deliver these services is minimal; however it is economically very expensive and no business cases available. The latest regulation from ENTSO-E requires the generation units above certain size shall be able to provide primary frequency control, which can be seen as an initial step to start the regulation. In addition, the market on ancillary services will be further developed, which will further activate the provision of ancillary services so that the renewable power plants will be able to provide secondary control under certain circumstances.

Security assessment functions

By the authors this is an open area both in theory and practice. The conventional generation units, which mostly are synchronous machines, will be replaced by the converter based platforms. This will give profound change to the dynamic behavior of the system. As the current stability/security assessment methods are mainly based on the traditional scenario, there would be a need to revisit the stability problems and assessment methods. All in all, fast security assessment method will be required for the future power system operation. Large computing and database infrastructure are necessary to carry out scenario calculations as well as store the results for presentation as well as decision support.

Decision making support

The decision making support scheme will primarily answer the following questions,

- What is current situation?
- What could be the worst security scenarios?
- What countermeasures shall be taken?
- Who is going to control?
  - The decisions to be taken by human operators;
  - The decisions can be taken by automatic procedures;

An efficient human-machine interface and a fast security assessment scheme will be of necessity to answer upon the first question. As the number of generating units will be highly expanded in the near future, algorithms are highly required to shortlist the possible contingencies and identify the most severe events, and further calculation shall be performed by fast security assessment methods to evaluate the possible countermeasures. The evaluation of different countermeasures will provide the operator the control options in the case that the system is running into alert or emergency situations.

To counter the challenges, one of the first tasks is to construct the test cases, which shall look into the scenarios at 2020 and 2030. The steps of implementation are,

- Outlook at the grids by year 2020 and 2030;
- Determine operation scenarios;
- Specify the test cases;

It is decided that in SOSPO project the attention will be given to the scenarios at 2020 and 2030 respectively. The base case system has been provided by Energinet.dk which contains the system topology, dynamic models, and the loading level up to date. The future system model will be generated from the current model.

The objective of this section is to provide an actual description of future scenario(s) where the functionality of the SOSPO project will be tested. The selected system is expected to be either the E-Danish system, W-Danish system, and/or the system in Bornholm. The test scenarios should be considered in respect to variations in wind/solar radiation, and various forms of system stability problems (Voltage instability, Small-signal stability, cascading outages, etc.).

The scenarios formulated by Energinet.dk are in fact 4 ones [26]:

- Greenville (Environment has high priority and Focus is international)
- Blueville (Environment has lower priority and Focus is international)
- Blåvang (Environment has lower priority and Focus is national)
- Grønnevang (Environment has high priority and Focus is national)

Since SOSPO shall address the real-time stability of power systems with a large degree of renewable energy sources (RES) the most relevant choices are Greenville and Grønnevang. If only one scenario shall be selected the most extreme one concerning RES is Greenville, therefore, the proposed testing case is primarily based on this perspective. The features of the four scenarios from Energinet.dk report are given in Appendix I.

It is necessary to mention that it is not the intention here to specify every detail of the testing systems for the rest of the project; instead it is to provide an overview on the production, consumption, as well as possible system controls, etc, to ease the implementation. The base case scenario provided in this report is based on the report [27] done by Energinet.dk, which is an unbiased prediction based on historical development, however the numbers are further revised towards the Greenville scenario.

ELECTRICITY CONSUMPTION

The yearly values of the power consumptions in the scenarios of Energinet.dk may be the basis for the construction of the real-time values needed for the simulations of the operation in SOSPO. The projection of the Danish electricity consumption is produced on the basis of EMMA model, which is a satellite model to macroeconomic ADAM model. Analysis period is 2011-2035.

The projection is based on the projection of production trends in 13 commercial and private consumption to the Ministry of Finance's economic projections based on ADAM model. There has been based in the Economic Survey, August 2011 [27].

Statistical values of the Danish power consumptions on a monthly, daily and hourly basis from the home page of Energinet.dk may be applied to transform the yearly values into time series i.e. hourly values. Mathematical smoothing techniques can be applied to convert time series of hourly values into series of real-time snapshots. Furthermore mathematical randomization techniques can be applied to add fluctuations occurring in practical operations.

Several data sets of power consumption have to be constructed for different seasonal and weather scenarios. These might be:

- High winter weekday (no wind and very high consumption)
- Mild winter weekday (high wind and high consumption)
- Mild summer weekday (high wind and medium consumption)
- High summer holiday (low wind and low consumption)

According to the report, the average percentage increase per. year for the period 2012-2035 is 0.2%. The increasing of the demand closely follows linear characteristics. Electricity consumption is expected to increase by approx. 6,255 GWh (ab værk) at 2035. The largest increase is expected to be in new consumption (electric and heat pumps). Details of this projection are given in Appendix II and III. The years 2020 and 2030 shall be extracted. Here, the discussion is focused on the construction of demand profile based on the information available. Following [27], where the load types are classified into classical, individual heat pumps, and electric cars. To construct the maximum demand, and consumption, the following approximation equation is applied,

$$L_{max} = c_1 * L_{cl} + c_2 * L_{hp} + c_3 * L_{ev} \quad (1)$$

Here L_{cl}, L_{hp}, L_{ev} represent the daily maximum load (MW) of classical load, individual heat pumps, and electric cars respectively, c_1, c_2, c_3 are the contribution factors of each to the total daily maximum demand L_{max}, as the peak value of each load class may not reach coincidently at the same time. It is suggested here to use a bottom-up approach to construct the total demand, as due to the new types of load class heat pumps and electric vehicles other than classical load types. Profiles of Daily, Monthly and Yearly need to be established based on the historical heating demand and driving data. The scenarios at 2020 and 2030 regarding the consumption are given below in Table 2. The calculation of maximum demand using the ENDK report value of 2-års-vinter. As in [27] the scenario does not expect the current economic crisis, therefore in this report the values are offset *-1%* as to the unpredicted economic recession during this period. The consumption data is based on the report and the energy losses are distributed to the east and west Denmark in proportion to their consumptions. The average demands can be hereby calculated. The breakdown of the demand into the three categories is given in Table 3.

From the [27], it is seen that the system maximum demand is mostly taking place at the time 17:00-18:00 in a day in January. It can be estimated that the demand in winter is usually higher which could produce the highest demand scenario. This is useful to study the situation with lack of renewable production while high demand in some days in winter. The contribution factors from three classes to the maximum demand are estimated at 85%, 80%, and 75%, respectively. At summer time, although the heating demand will be reduced in Denmark, the factor for the heating could be the same or even higher. Therefore, the factors at summer time are 90%, 90%, 75% respectively. It has to be mentioned that these factors are related to the demand patterns and less dependent on the actual demand value. These numbers may be used to construct the total system demand profile in time series for operation emulation. It has to be mentioned that the data presented here are based on the reference [27], however more values are estimated to ease the implementation in SOSPO. It needs to mention that the estimated values are empirical and based on the estimated factors using equation (1). The distribution of heating demand to the network can follow the proportion provided by [27], where the table is given in Appendix III, Table 7.

	Consumption (GWh)		**Max. Demand (MW)**		**Average Demand (MW)**	
	East DK	West DK	East DK	West DK	East DK	West DK
2020	13643	20004	2672	3750	1557	2283
2030	14866	21822	2857	4014	1697	2491

Table 2. Demand data for the base case

	Classical consumption				**Individual heat pumps**[2]				**Electric vehicles**[3]			
	East DK		West DK		East DK		West DK		East DK		West DK	
	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW
2020	13150	2435	19282	3410	431	713	632	1010	62	42	90	58
2030	13486	2497	19797	3500	1096	745	1609	1044	284	185	416	272

Table 3. The split consumption for 3 different load classes

The price dependency of the consumption has to be modelled in case market operation is concerned. A simple model might be that the consumption to some extent varies with the wind production expressing the fact that high wind production implies low market prices and thus are incentives for consumption and vice versa.

ELECTRICITY PRODUCTION

Similarly, the production portfolio at 2020 and 2030 are constructed at the basis of reference [27]. The yearly values of the power productions of small-scale CHP plants, wind farms and PVs in the scenarios of Energinet.dk may form the basis for the construction of a production system in SOSPO. Similar as for consumption, the time series production profile needs to be constructed for simulation.

According to the government strategy and [27], the conventional power plants will gradually phase out till 2030. The basic data proposed here are based on [27] however with further considerations regarding the ancillary services. Here, at 2020 scenario, it is assumed that part of the conventional plants are still participating in the daily operation and providing system services such as frequency and voltage control, given the current pace of renewable adoption. However for the 2030 scenario, as most of the conventional units will be phasing out, an optimistic scenario will be that some of the units can be operating for tertiary control and/or temporary local heating supplies. It has to be mentioned here that the report [27] provides an overview of the production; however, as the mission of SOSPO is to study the security issues in the operation time, therefore to ease the study the data provided are the maximum capacity available for the current system operation, instead of taking into account of the gross production capacity. The capacity of conventional units is provided on the basis of the date of commissioning. For the generators commissioned more than 25 years ago, it is anticipated that these generators will be offline by the year 2020 as due to the efficiency and CO_2 emission. For the 2030 scenario, it is optimistic that all the conventional generators will be used as reserve for the system operation therefore the active participation will be minimal and could mostly depends on the energy price.

For the wind capacity, the near future expansion plan is the 600 MW offshore wind farm at Kriegers Flak and 400 MW at Horns Rev, and 500 MW offshore wind turbines in coastal areas. The onshore wind farm size will be maintained at more or less the same level as there is no planned onshore wind farms in the near future, except the upgrade to the new turbines for efficiency purposes. Given the current gross wind turbine installation around 4000 MW, it is expected that the future wind capacity will reach 6710 MW at the year 2020 and 10460 at 2030. The value from report [27] directly adopted here.

The solar adoption is not easy to be predicted. In [27], Energinet has made two scenarios regarding the 2030 scenario, while from 2012 to 2020 the increasing of installation following linear characteristics. This is not exactly the case so far with solar, as the adoption can be quite fast given the government subsidies. It has experienced 200 MW adoptions in 2012 and the Danish government has enacted the new supporting scheme on solar which levels down development. The future adoption will depend on the addressing of current technical problems, such as power quality issues, efficiency, as well as the investment cost. Therefore, here the capacities of solar installation at 2020 and 2030 are based on the estimation of [27] however are reduced slightly.

The values for storage and other DGs are most unpredictable. The current storage technologies are still under fast development and it is not clear which technology could come out from the current mist for power system applications. One thing is clear is that it will be necessary to have storage when we have large amount of renewable generation in the system. Therefore, the storage capacity was given 300 MW given the current development at 2020, and 2000 MW at 2030 as to the breakthrough at the technical and economic barriers. The other DGs refers to the decentralized the combined heating and power units in Denmark. Currently there is about 2632 MW installed capacity which provides local heating outside the major heating networks. The existence of these group of generators are due to the government subsidies as well, as the support scheme will finish in the coming years, it is unsure whether there will be similar support on this from the government thereafter. Moreover, as most of them are gas turbines, the value is anticipated to decrease as to the environmental concerns.

	2020						2030					
	MWh	**MW**	**Frequency**			**Var/Volt.**	**MWh**	**MW**	**Frequency**			**Var/Volt.**
			Pri	**Sec.**	**Ter.**				**Pri**	**Sec.**	**Ter.**	
Conventional	-	1500	√	√	√	√	-	90	-	-	√	-
Wind	-	6710	√	√	×	√	-	10460	√	√	√	√
Solar	-	2300	√	×	×	√	-	5000	√	√	√	√
Storage	300	300	√	×	×	√	1000	2000	√	√	√	√
Other DGs	-	2200	√	√	√	√	-	50	√	√	√	√
Total		13010						17600				

Table 4. Production portfolio at 2020 and 2030 scenario

BASIC SYSTEM CONTROL

Detailed technical models of the components of the power system are needed describing their behaviour in both steady and dynamic states. Examples are responses to frequency and voltage deviations such as droop and fault ride-through times. This is closely related to the possibilities of delivering ancillary services. This covers components for production, transmission and consumption. In [24], the requirements for the generator dynamic performance are recommended.

As the modelling of distribution grids are primarily excluded from SOSPO, the small-scale power plants, wind farms and PVs connected to the distribution grids have to be aggregated before being connected as such to the transmission grid.

For the wind farms, PVs and small-scale plants participating in the ancillary service markets there are two options:

a. Set aside a certain share of the capacity of the power plants for provision of ancillary services. This is in fact not a market solution but rather an obligation.

b. Allocate the needed capacity of ancillary services among the power plants in a market based on bids from the providers.

Ancillary services are in fact several distinct ones with different properties especially as regards response time, endurance and degree of automatic control. Option a) implies a real distribution of an ancillary service among the power plants whereas option b) may imply selection of fewer specific plants for delivery of this ancillary service. For SOSPO option a) seems to be the most extreme one involving control of most power plants if the capabilities of the plants will come up to this.

Delivery of ancillary services from consumption plants shall also be possible; however the quantities shall be carefully chosen to reflect the possible scenarios.

The models shall include controllability and component and system protection however the level of details will be dependent on the application objectives.

TESTING SITUATION SPECIFICATIONS

This section specifies the possible future Danish system operation scenarios, where several critical operating conditions could be used for demonstration and testing the SOSPO functionality. In this report, the system states are categorised into normal, alert, and emergency, specifying the possible future Danish system operation scenarios, which could be used for development, demonstration, and test the SOSPO functionality.

ENTSO-E has published a draft report regarding the operational security to reach a common definition on system operation states, and requirements on the actions by the operators at different states if required. The system states have been defined as normal, alert, emergency, blackout and restoration. The first three are of particular interests to SOSPO. Here, focuses are giving on alert and emergency states to further specify the situations occur in Danish system.

Normal state

Operation of the power system with all consumptions covered and the essential parameters of system operation (frequency, inertia, voltages, flows, rotor angles and amounts of ancillary services) are within the operational limits. Consumptions and productions fluctuate the last-mentioned being especially RES. The power system is stable and stays in normal steady state even after a contingency from the contingency list.

Alert state

Operation of the power system with all consumptions is still covered but the operational limits for essential parameters of system operation are closing to be violated. The operation may be close to the stability boundaries, e.g. voltage stability, transient stability, or the operational limits of interconnectors such as HVDC, sea cables, etc. The power system is capable of remaining stable and

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2. By [29], Alert State is defined as the operational system state where the system is within Operational Security Limits, but a Contingency from the Contingency List has been detected, for which in case of occurrence, the available Remedial Actions are not sufficient to cope with.

after eventual launch of preventive actions return to the normal steady state. One of the traditional approaches to screen the alert situation is the N-1 approach. This traditional approach is that the power system shall be able to withstand that one component is lost the so-called (N-1) criterion. More differentiated this covers ordinary (usual) and some exceptional (unusual) contingencies of one major component which may only cause a temporary shift to alert state. Some exceptional (unusual) and out-of-range (very unusual) contingencies may in fact cause a shift to the emergency state[2] [29].

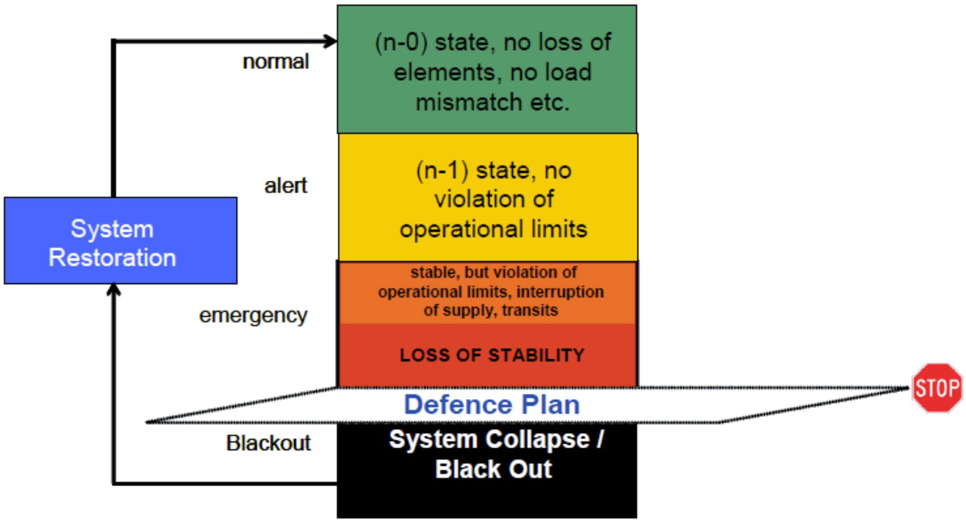

Figure 9. The system operation states used by ENTSO-E.

This approach may not be fully fulfilling the future system operation. The small scale generation units, increased energy exchange at the lower voltage levels, give rise to a situation that the system components to be studied are increased drastically. For many times, the normal N-1 assessment may not be able to cover the need for security assessment. Therefore, in this report, the consideration on the alert state is extended to the following situations

- As to the variability of the renewable energy production, a possible scenario would be the unexpected pattern change on the generation as well as consumption during an operation dispatch interval. This unexpected change can be caused due to unexpected weather change, inaccurate forecasting, which triggers the change at the production and then possibly consumption at local area.
- Lack of system reserve[3], includes active power reserve for the loss of the largest power plants, as well as reactive power reserve for voltage regulation as well as flow optimisation. It is envisaged that it will be common procedure for the operator to regulate the voltages to achieve higher system efficiency, therefore, reactive power reserve will be one of the key indicators for operation; This situation can be studied at critical components, eg. Interconnectors, large offshore wind farms, etc.
- Lack of transmission capacity, this could happen 1). When there are extensive renewable from some jurisdictions, which induce high amount of flow at the relevant transmission corridors; 2). Interconnectors where there is low production from the whole region;
- Close to the stability boundaries, eg, voltage stability, transient stability, or operation limits of interconnectors, such as HVDC, sea cables, etc;

3. According to ENTSO-E, lack of more than 20% of required reserve for more than 30 minutes and with no means to replace them.

Besides, it is suggested that the alert situation may also include that if the system cannot fulfil N-1 criterion, then the system is at alert state where the operator needs to react on these possible scenarios for a safe operation.

Emergency state

The emergency state is defined as a state with violation of system operational security limits[4] [29]. Here, the emergency situation is categorised into several situations,

- Violation of operation limits, especially as the transmission limits, voltage limits at critical buses, etc, before or after an event;
- Violation of stability boundaries such as voltage, small signal, or transient stability;
- Unpredicted weather change, which imposes a complete redispatch of the system, or sudden unbalance;

In implementation, it is required to define the operation limits, specially frequency, and voltage, according to the requirements from ENTSO-E [29]. The operator needs to formulate system defence plans regarding the situation where technical and organisational measures are to be taken to restore the system to the alert or normal state, and prevent the propagation of the emergency state outside the transmission system.

In addition, ENTSO-E also defines the blackout state which is loss of more than 50% of load at the time of the incident or total absence of voltage for at least 3 minutes in the system and triggering restoration plans.

Summary

It is required to mention that the ENTSO-E codes on operational security & operational planning and scheduling provides the minimum requirements for the security issues. Therefore it is necessary to further detail the requirements into certain scenarios which could trigger such events in Danish system. The case can be generated according to the generation demand pattern, as listed in consumption section, the unexpected sudden change from generation and major faults in the system, etc. A contingency list may be prepared in advance to facilitate the implementation. The system shall be back to normal state as soon and as close as possible.

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[4] According to ENTSO-E, the operational security limits means the acceptable operating boundaries: thermal, voltage, short-circuit current, frequency and stability limits;

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APPENDIX I. FOUR SCENARIOS FROM ENERGINET.DK

	Scenario 1, Greenville *International focus, Environment high priority*	**Scenario 2, Bluesville** *International focus, Environment low priority*	**Scenario 3, Blåvang** *National focus, Environment low priority*	**Scenario 4, Grønnevang** *National focus, Environment high Priority*
public frameworks	• Focus on environment • Close cooperation in the EU • Market-based regulation • Public-owned electricity and gas networks (not necessarily Danish-owned)	• Focus on security of supply • Close cooperation in the EU (energy and environment) • Market-based regulation • Public-owned electricity and gas networks (not necessarily Danish-owned)	• Inertia in cooperation in the EU (supply handled nationally) • Retail Regulation • Public and Danish-owned electricity and gas networks	• Inertia in cooperation in the EU (energy and environment) • International cooperation R & D • Retail Regulation • Public and Danish-owned electricity and gas networks
The market	• Confidence in the market • Electric and gas exchanges at EU level	• Confidence in the market • Electric and gas exchanges at EU level	• Do not trust the market as an instrument • Abandons fusion of power exchanges • No gas exchange	• Do not trust the market as an instrument • Abandons fusion of power exchanges • No gas exchange
Electricity and gas consumption	Demand for efficient equipment • Shifts in the transport sector (away from oil) • Gas for heating, transport and electricity generation	• Energy savings a priority • Shifts in the transport sector (away from oil) • Gas for heating, transport and electricity generation	• Energy saving important instrument in Denmark • The conversion from oil-based transportation to oil, electricity and biogas • Gas for heating and electricity production	• Demand for efficient equipment (consumers + industry) • Demand for non-oil-based transport • Gas for heating and electricity production
Generation apparatus	• High share offshore • Some gas and biomass • Good 100% of the electricity based on renewable energy	• Thermal capacity (coal + gas) • Offshore wind turbines and wind turbines • Less gas and biomass • 50% of electricity consumption in wind energy	• Decentralised CHP plants (natural gas, biomass and biogas) • Larger facilities (offshore wind, coal-fired CHP) • 50% of electricity consumption in wind energy	• High proportion of infants and small plants (natural gas and biogas) • Larger plants in the form of offshore wind turbines • 80% of electricity consumption in wind
Economics	• Progress and growth • Low interest rates and inflation	• Progress and growth • Low interest rates and inflation	• Relatively low growth • High interest rates and inflation	• Growth at reasonable levels • Moderate interest rates and inflation

	Østdanmark	Vestdanmark	Total ab værk	Nettab Øst	Nettab Vest	Total an forbruger
2012	13.909	20.586	34.495	787	1.347	32.361
2013	13.989	20.667	34.656	792	1.352	32.512
2014	14.099	20.788	34.887	798	1.360	32.729
2015	14.196	20.888	35.084	804	1.367	32.914
2016	14.283	20.987	35.269	808	1.373	33.088
2017	14.369	21.089	35.458	813	1.380	33.265
2018	14.456	21.209	35.666	818	1.388	33.460
2019	14.549	21.333	35.882	824	1.396	33.663
2020	14.653	21.488	36.141	829	1.406	33.906
2021	14.773	21.670	36.443	836	1.418	34.190
2022	14.894	21.852	36.746	843	1.430	34.473
2023	15.005	22.036	37.041	849	1.442	34.750
2024	15.123	22.207	37.331	856	1.453	35.022
2025	15.242	22.375	37.617	863	1.464	35.291
2026	15.364	22.554	37.918	870	1.476	35.573
2027	15.485	22.732	38.217	877	1.487	35.854
2028	15.605	22.908	38.512	883	1.499	36.130
2029	15.725	23.084	38.809	890	1.510	36.409
2030	15.846	23.261	39.107	897	1.522	36.688
2031	15.964	23.435	39.399	904	1.533	36.962
2032	16.089	23.618	39.707	911	1.545	37.251
2033	16.220	23.811	40.031	918	1.558	37.555
2034	16.361	24.018	40.379	926	1.571	37.882
2035	16.511	24.239	40.750	935	1.586	38.230

Table 5. Fordeling af elforbruget (inkl. varmepumper og elbiler) mellem Østdanmark og Vestdan-mark - ab værk i GWh. Der er regnet med et nettab på 6 % af forbruget an forbruger i Østdanmark og 7 %. i Vestdanmark.

	Østdanmark		Vestdanmark		Danmark	
	2-års-vinter	**10-års-vinter**	**2-års-vinter**	**10-års-vinter**	**2-års-vinter**	**10-års-vinter**
2012	2.569	2.672	3.639	3.807	6.208	6.479
2013	2.583	2.687	3.652	3.821	6.235	6.507
2014	2.603	2.707	3.673	3.842	6.275	6.549
2015	2.620	2.726	3.690	3.860	6.310	6.585
2016	2.635	2.741	3.706	3.877	6.341	6.618
2017	2.650	2.757	3.723	3.894	6.373	6.651
2018	2.666	2.773	3.743	3.915	6.409	6.688
2019	2.681	2.789	3.763	3.936	6.445	6.726
2020	2.699	2.807	3.788	3.962	6.487	6.770
2021	2.719	2.828	3.817	3.992	6.535	6.820
2022	2.738	2.848	3.845	4.022	6.583	6.871
2023	2.756	2.867	3.874	4.053	6.630	6.920
2024	2.776	2.887	3.901	4.080	6.677	6.968
2025	2.795	2.907	3.927	4.108	6.722	7.015
2026	2.813	2.927	3.953	4.135	6.767	7.062
2027	2.832	2.946	3.979	4.162	6.811	7.108
2028	2.850	2.965	4.004	4.189	6.854	7.153
2029	2.868	2.983	4.030	4.215	6.898	7.199
2030	2.886	3.002	4.055	4.242	6.942	7.245
2031	2.904	3.021	4.080	4.268	6.984	7.289
2032	2.922	3.040	4.106	4.295	7.029	7.335
2033	2.942	3.060	4.133	4.323	7.075	7.383
2034	2.962	3.081	4.162	4.353	7.124	7.435
2035	2.984	3.104	4.192	4.385	7.176	7.489

Table 6. Fremskrivning for det maksimale elforbrug 2012-2035. Tal er i MWh/h

APPENDIX III. SPLITTED CONSUMPTION DATA

År	Klassisk forbrug		Individuelle var-mepumper		Elbiler		Total	
	vest	øst	vest	øst	vest	øst	vest	øst
2012	20.464	13.827	106	72	15	10	20.586	13.909
2013	20.501	13.876	143	97	24	16	20.667	13.989
2014	20.575	13.955	180	122	32	22	20.788	14.099
2015	20.596	13.998	256	174	36	24	20.888	14.196
2016	20.608	14.025	334	227	44	30	20.987	14.283
2017	20.621	14.049	415	283	53	36	21.089	14.369
2018	20.648	14.073	498	340	63	43	21.209	14.456
2019	20.676	14.101	580	396	77	52	21.333	14.549
2020	20.712	14.124	679	463	96	66	21.488	14.653
2021	20.760	14.153	786	536	123	84	21.670	14.773
2022	20.808	14.183	894	609	150	102	21.852	14.894
2023	20.858	14.203	1.001	682	177	120	22.036	15.005
2024	20.896	14.230	1.108	754	203	139	22.207	15.123
2025	20.930	14.258	1.215	828	230	157	22.375	15.242
2026	20.966	14.282	1.315	896	273	186	22.554	15.364
2027	21.001	14.306	1.415	964	316	215	22.732	15.485
2028	21.034	14.328	1.515	1.032	359	244	22.908	15.605
2029	21.068	14.351	1.615	1.100	402	274	23.084	15.725
2030	21.102	14.375	1.715	1.168	444	303	23.261	15.846
2031	21.137	14.399	1.809	1.232	489	333	23.435	15.964
2032	21.174	14.423	1.907	1.299	538	366	23.618	16.089
2033	21.209	14.447	2.011	1.370	592	403	23.811	16.220
2034	21.247	14.473	2.121	1.445	651	443	24.018	16.361
2035	21.286	14.500	2.237	1.524	716	488	24.239	16.511

Table 7. Breakdown of electricity consumption in classical consumption, and consumption of electric vehicles and heat pumps in GWh. Note: Opgørelsen er opgjort ab værk. For Ab værk tillægges forbruget 7 % for Vestdanmark og 6 % for Østdanmark..

	Varmeprod i TJ	Forventet udbygning af varmepumper,MJ/s pr. periode		
	for det enkelte værk, i alt	2014-2018	2019-2023	2024-2030
Aalborg	2.975	12,4	12,4	12,4
Aarhus	4.250	17,7	17,7	17,7
Esbjerg	2.125	8,9	8,9	8,9
Odense	5.100	21,3	21,3	21,3
TVIS	2.550	10,7	10,7	10,7
Herning	1.250	5,3	5,3	5,3
DKVM NG V	2.765	11,6	11,6	11,6
DKVP NG V	3.570	14,9	14,9	14,9
København	13.260	55,3	55,3	55,3
Kalundborg	980	4,1	4,1	4,1
DKVM NG Ø	740	3,1	3,1	3,1
DKVP NG Ø	510	2,2	2,2	2,2

Table 8. The "big" CHP areas. Heating (TJ), and the size of the heat pump (MJ/s).

	ØST		**VEST**		**DANMARK**	
	Effekt, MW	Antal	Effekt, MW	Antal	Effekt, MW	Antal
Naturgas	429	133	1343	305	1772	438
Diesel, olie og andet	36	9	268	47	304	56
Bio	175	40	381	149	556	189
I alt	640	182	1992	501	2632	683

Table 9. Installeret kapacitet (nettoeffekt) på decentrale kraftvarmeværker pr. 1. januar 2012. Randersværket, 52 MW og Herningværket, 89 MW er inkluderet i disse tal.

APPENDIX IV. STAT OF CONVENTIONAL POWER PLANTS

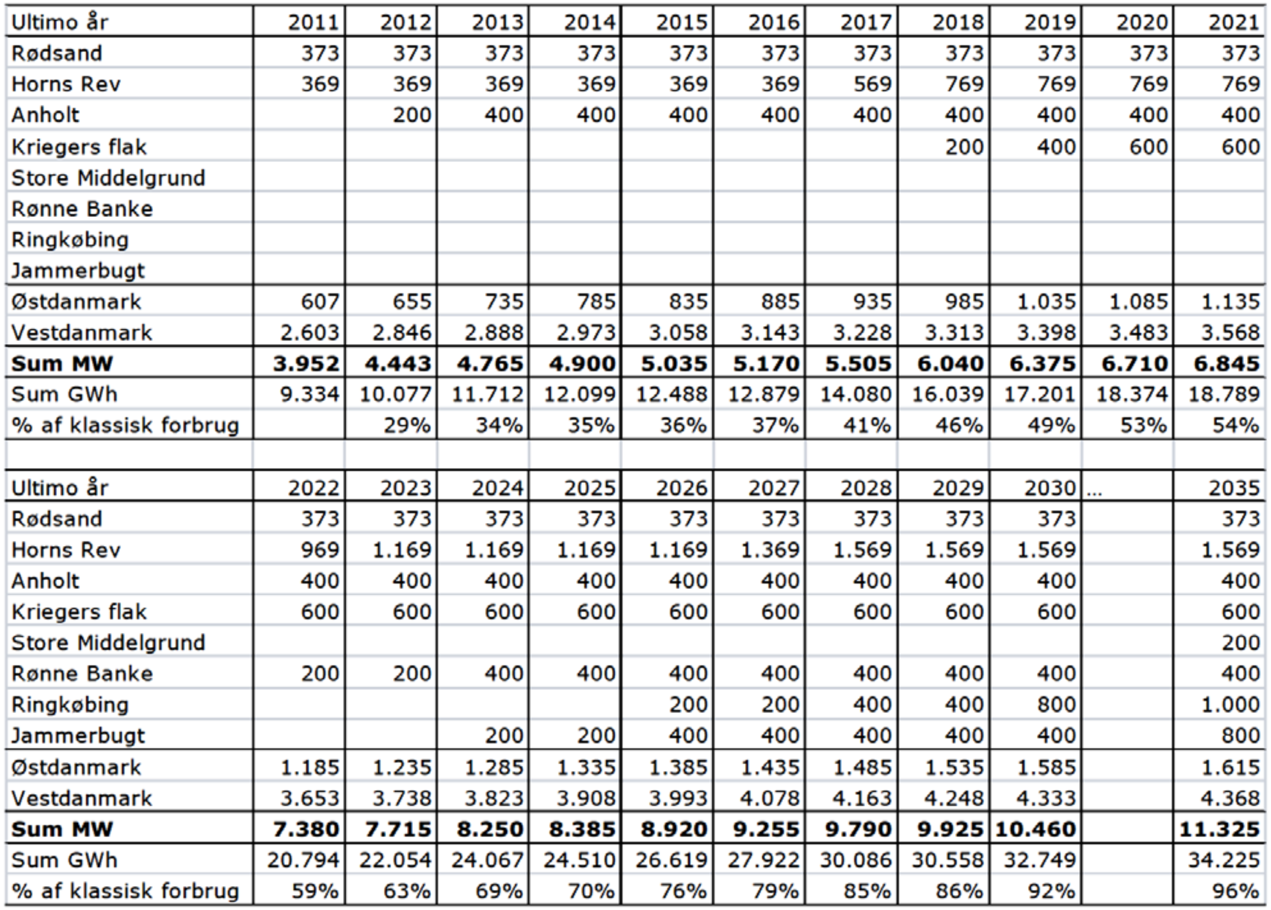
Anlæg	**El Nominelt** MW	**Idriftsat** År	**Bemærkning**
Amagerværket Blok 1	70	2009	Biomassefyret.
Amagerværket Blok 3	263	1989	Effekt inkl. overlast. Kul/olie fyret. Levetidsforlænget fra 2029
Asnæsværket Blok 2	137	1961	Mølposelagt 1. juni 2010. Kører ikke samtidig med blok 5.
Asnæsværket Blok 4	270	1968	6 måneders startvarsel
Asnæsværket Blok 5	640	1981	60 timers startvarsel. Kører ikke samtidig med ASV2. Genidriftsættes, når ASV2 lukker.
Avedøreværket Blok 1	263	1990	Kul/olie fyret.
Avedøreværket Blok 2	540	2001	Gas/halm/kul/træ fyret.
H.C. Ørsted Værket Sekt. 2 (Blok1-4)	35	1954-65.	Ombygget i 1994.
H.C. Ørsted Værkets Blok 7	75	1985.	Ombygget i 1994.
H.C. Ørsted Værkets Blok 8	23	2003	
Kyndbyværkets Blok 21	260	1974	Reserveanlæg.
Kyndbyværkets Blok 22	260	1976	Reserveanlæg.
Kyndbyværkets Blok 41	18	1973	Reserveanlæg.
Kyndbyværkets Blok 51+52	126	1973	Reserveanlæg.
Masnedøværkets Blok 31	70	1975	Reserveanlæg.
Svanemølleværkets Blok 1-3	25	1953-58	Renoveret i 2007/2008.
Svanemølleværkets Blok 7	60	1995	Naturgas/letolie fyret.
Stigsnæsværkets Blok 1	143	1966	3 måneders startvarsel. Gasolie fyret.
Stigsnæsværkets Blok 2	264	1970	Sværolie fyret. 16 timers startvarsel. Mølposelægges fra 1. jan. 2013
I alt, centrale værker 2012	**2.632**		
Østkraft	89		
Decentrale værker	**640**		
I alt, dec. og central	**3.361**		

Table 10. Nominel eleffekt for produktionsanlæg i Energinet.dk Øst pr. 1. januar 2012 suppleret med beregningsforudsætninger. De tidspunkter, der er angivet for skrotninger, etablering af biomasseanlæg og deNOX-anlæg, er beregningsforudsætninger og ikke udtryk for trufne beslutninger.

ANLÆG	**EL MW**	**IDRIFTSAT ÅR**
Amagerværket Blok 1	70	2009
Amagerværket Blok 3	263	1989
Avedøreværket Blok 1	263	1990
Avedøreværket Blok 2	540	2001
H.C. Ørsted Værkets Blok 8	23	2003
Svanemølleværkets Blok 7	60	1995
Total	1219	

Table 11. Estimated central power stations at 2020

APPENDIX V. THE PREDICTED WIND PRODUCTION



Ultimo år	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Rødsand	373	373	373	373	373	373	373	373	373	373	373
Horns Rev	369	369	369	369	369	369	569	769	769	769	769
Anholt		200	400	400	400	400	400	400	400	400	400
Kriegers flak								200	400	600	600
Store Middelgrund											
Rønne Banke											
Ringkøbing											
Jammerbugt											
Østdanmark	607	655	735	785	835	885	935	985	1.035	1.085	1.135
Vestdanmark	2.603	2.846	2.888	2.973	3.058	3.143	3.228	3.313	3.398	3.483	3.568
Sum MW	**3.952**	**4.443**	**4.765**	**4.900**	**5.035**	**5.170**	**5.505**	**6.040**	**6.375**	**6.710**	**6.845**
Sum GWh	9.334	10.077	11.712	12.099	12.488	12.879	14.080	16.039	17.201	18.374	18.789
% af klassisk forbrug		29%	34%	35%	36%	37%	41%	46%	49%	53%	54%

Ultimo år	2022	2023	2024	2025	2026	2027	2028	2029	2030	...	2035
Rødsand	373	373	373	373	373	373	373	373	373		373
Horns Rev	969	1.169	1.169	1.169	1.169	1.369	1.569	1.569	1.569		1.569
Anholt	400	400	400	400	400	400	400	400	400		400
Kriegers flak	600	600	600	600	600	600	600	600	600		600
Store Middelgrund											200
Rønne Banke	200	200	400	400	400	400	400	400	400		400
Ringkøbing					200	200	400	400	800		1.000
Jammerbugt			200	200	400	400	400	400	400		800
Østdanmark	1.185	1.235	1.285	1.335	1.385	1.435	1.485	1.535	1.585		1.615
Vestdanmark	3.653	3.738	3.823	3.908	3.993	4.078	4.163	4.248	4.333		4.368
Sum MW	**7.380**	**7.715**	**8.250**	**8.385**	**8.920**	**9.255**	**9.790**	**9.925**	**10.460**		**11.325**
Sum GWh	20.794	22.054	24.067	24.510	26.619	27.922	30.086	30.558	32.749		34.225
% af klassisk forbrug	59%	63%	69%	70%	76%	79%	85%	86%	92%		96%

Table 12. Skema for udbygning med vindkraft for 2021 - 2035. Ultimo året.