THE EUROPEAN INTERCONNECTED NETWORK: CASE STUDY OF INSTITUTIONAL REQUIREMENTS FOR A SUCCESSFUL INTERNATIONAL GRID INTERCONNECTION

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NISHEETH SINGH
OCTOBER 5, 2020

I. INTRODUCTION

In this Special Report, Nisheeth Singh presents a case study of the European interconnected electricity grid network, including its origins, organization, current status, governing institutions and principles, and data exchanges between partners that allow the network and associated power markets that allow the network to function smoothly, reliably, and in a secure manner. The report includes an epilogue on the impact of the pandemic on power grids

A summary of this report follows. A downloadable PDF file of the full report is here

Nisheeth Singh is Founder, SPECS GmbH, Switzerland.

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Banner image: Interconnected European grid network, courtesy of ENTSOE-E

II. NAPSNET SPECIAL REPORT BY NISHEETH SINGH

THE EUROPEAN INTERCONNECTED NETWORK: CASE STUDY OF INSTITUTIONAL REQUIREMENTS FOR A SUCCESSFUL INTERNATIONAL GRID INTERCONNECTION

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Contents

List of Figures

1 Summary

After a brief description of development of European Electricity market, this report describes the current framework for governance and cooperation among European countries. The Transmission System Operators (TSOs) manage the operations and support the electricity markets in their own control areas and coordinate their activities through their association European Network of Transmission System Operators-Electricity (ENTSO-E). The European Commission provides the regulatory basis for a Pan-European Internal Energy Market, where energy producers and

consumers can trade energy without consideration of national borders. The principles of transparency, non-discrimination and open access are adopted to provide a level playing field for all market participants, TSOs, ENTSO-E and regulatory bodies.

This report describes some of the tools and processes used by TSOs for data modeling and exchange to maintain security of electricity supply in an efficient way while maintaining power quality in terms of voltage and frequency. Activities of TSOs are illustrated through various examples. The challenges posed by environmental concerns and high penetration of distributed generation sources are outlined. In the concluding chapters the report summarizes the practices of European Energy markets and shows the requirements for developing and operating a successful interconnection crossing national boundaries.

2 Description of the European Interconnected Network

2.1 Introduction

Electrification of Europe started in the late 19th Century. Several countries moved forward with the development of their networks. Multinational connections started between Austria, Yugoslavia, Germany and France, Germany and Switzerland. Originally, the connections were required to provide power to cities and other loads from power plants located on or near the common boundaries of the countries.[1] Such was the case on Rhine river where first hydro plant was built in 1911 and was followed by a plant at Laufenburg, completed in 1914, with a dam that spans a channel of the Rhine between South Germany and northern Switzerland. Similarly, a hydroelectric power plant was built between Austria and lower Bavaria. In 1958 the first multinational interconnection at 220 kV connected France, Germany, and Switzerland, and a second interconnection completed in 1958 at Laufenburg, including a switching substation that later came to be known as the “Star of Laufenburg”.[2]

The Union for Coordination of Production and Transmission of Electrical energy (UCPTE) was formed in 1951 with eight countries (Belgium, Germany, France, Italy, Luxembourg, the Netherlands, Austria and Switzerland). UCPTE slowly grew to cover most of continental Europe. The “P” in the acronym, which stood for Production in the name, was removed and the name was changed to UCTE in 1998 as per a European Commission directive reflecting the unbundling of electricity industry.[3] In parallel, the UK, Scandinavia, and Ireland formed three distinct interconnected regions. In 2009 all of the regions joined together to form a Pan-European interconnected network under the name European Network of Transmission System Operators-Electricity (ENTSO-E)

In its current state in 2019, as sketched on the cover page of this report,[4] the European network has grown to connect the whole of Europe and parts of neighboring continents. The interconnections to Africa in the south (connecting Spain and Italy to North Africa) and to Asia in the north (via Germany, Hungary, Turkey ...) are either high voltage DC (HVDC) connections or isolated connections to large power plants or substations. Historically, the interconnection has been built to cover a region of synchronously operated areas that are connected over HVDC lines. The interconnected network caters to a population of over 600 Million in more than 40 countries, and is the largest interconnection covering the biggest electrical energy market in the world.

Initially, grid interconnections in Europe were put in place to profit from lower reserve requirements and higher resilience, sharing these common social benefits. The electrical networks grew in a federal structure where electricity companies planned, developed and operated the network in their control areas. The cross-border operational and planning activities were carried out at a regional level, and several regional security centers were established to plan and recommend network operations.

The large number of interconnections bring advantages of lower required reserves and helps all participants during unplanned outages of generation systems and transmission lines. The volume of connected generation and load creates a large inertia in the system, which increases the inherent stability of the system. As an example, an outage at a large nuclear or hydro plant of 1200 MW will cause less than a 20 milli-Hertz (thousandths of a Hertz) dip in frequency thanks to the interconnected system. All the interconnections are shown in 2019 in Figure 1.

Figure 1: Interconnections in Europe

The development of and responsibility for the national networks remains with the national TSOs, but the cross border interconnectors are agreed to, planned and implemented in mutual agreement between national operators, as described in Section 5.2.1 of this report.

Although the large interconnection brings lots of advantages, managing operation of such a large system is very challenging and requires considerable efforts for coordination and a number of agreements among the participating countries. It also requires that most of the interconnected countries follow the same framework and policies in electrical energy generation, transmission and distribution. In the European context most of the interconnected countries are member state in the European Union, and the European Commission thus fulfils this role in providing common policies. Even the non-EU countries follow the same rules of the energy union related to keeping the energy situation secure and reliable. The next chapter of this report describes the major actors and governing framework for this large interconnected system.

3 Governing Framework and actors

3.1 Major actors in Electrical Systems

3.1.1 Transmission System Operators (TSO)

Typically, each country has one TSO with some exceptions where more than one TSO manage the nation's high voltage network. The ownership of the network is with the TSOs in most of the European countries, where the TSO owns, maintains and operates the network. Some countries have Independent System Operator (ISO) that carry out operational activities whereas the network assets are owned and maintained by a TSO.

Transmission System Operators in Europe are responsible for their control areas, covering the 380/220 kV transmission network, and in some exceptional cases 132/110 kV lines and substations, and are in charge of at least following tasks:

- Energy and power balancing
- Congestion management
- Voltage and frequency control
- Switching
- Assuring system security
- Maintaining security of supply

TSOs are not allowed to trade in energy but can buy and sell energy for "ancillary services" to maintain frequency, support voltage, and provide congestion management and restoration services.

3.1.2 ENTSO-E

The *European Network of Transmission System Operators- Electricity*: www.entsoe.eu, is the association of all of the TSOs in Europe. Most of the countries where these TSOs are located are member-states and belong to the European Union but there are exceptions, and a few countries are not part of the political alliance represented by European Union. ENTSO-E is an association of all Transmission System Operations of Electrical networks, and is located in Brussels.

The ENTSO-E Assembly has high level representation from each TSO. The Assembly is responsible for strategy and policy for the organization. The Assembly delegates day-to-day activities to be managed by a Board that has elected members from the Assembly or from the TSOs. A Secretariat under a Secretary General supports the Board in execution of activities, as shown in Figure 2.

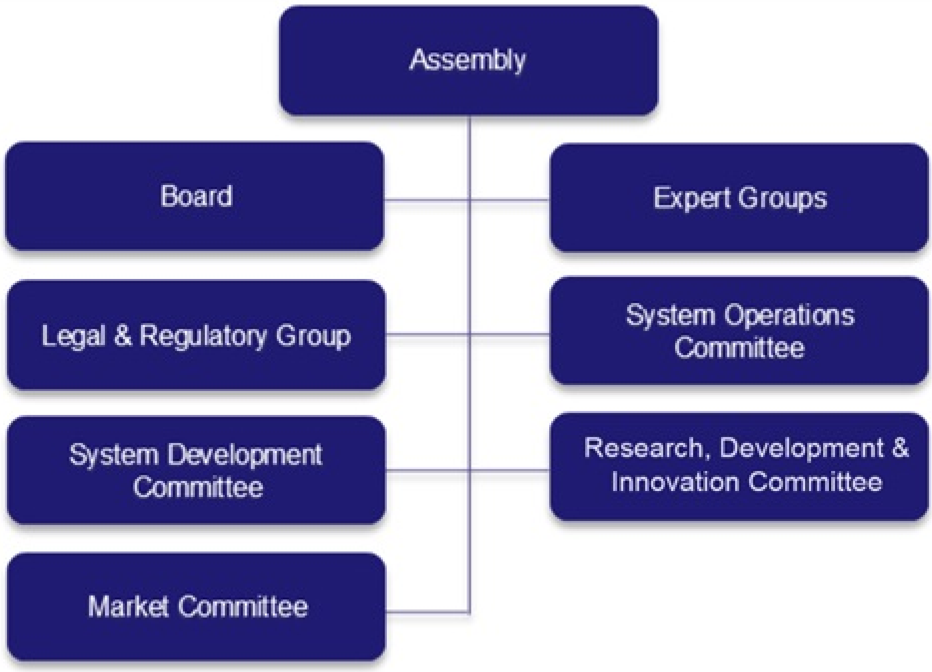

Figure 2: Organization of ENTSO-E

Various ENTSO-E Committees oversee specific business fields as indicated by their names. The *System Development Committee* (SDC) supervises network development and has representation from each of the member TSOs. The SDC prepares projected energy scenarios for the medium- and long-term and defines the requirements for and planned development of the network assets. The *Market Committee* (MC) covers all of the activities that influence energy markets and oversees market design and coordination of cross border market models. The *Systems Operations Committee* (SOC) manages power system operation including operational planning, security analysis, monitoring and control of the system. The frequency and power balance in real-time and near real-time are also responsibilities of this committee. The *Research and Development Committee* (RDC) promotes new technology and innovation in power transmission and distribution. The *Legal and Regulatory Group* (LRG) coordinates and proposes improvements and maintenance of the regulatory framework governing the system's activities. This group also represents the consolidated opinion of TSOs to the European Commission and regulatory authorities.

3.1.3 Distribution System Operators

The distribution network operators have similar roles to those of the TSOs but manage the network at voltage levels below 220 kV. Normally, distribution networks have fewer interconnections with other distribution companies than do the transmission networks managed by TSOs. In some cases, the distribution networks cover sub-transmission systems around urban centers. The distribution networks are closer to the end-use customer, renewable energy resources and demand side management.

The association of European Network of Distribution System Operators- Electricity, is in the process of being established to coordinate and increase cooperation among DSOs, and is to perform similar roles to those ENTSO-E performs for TSOs (see www.edsoe.eu).

3.1.4 Regional Security Coordinators (RSCs)

The heavily interconnected network results in requirements of a higher level of effort for coordination of common security concerns, capacity allocation and measures to carry out congestion management. The TSOs in different regions realized the need to join hands in different regions to coordinate planning and operations of the interconnected network. These Regional Security Coordinators (RSCs) are companies established by the TSOs in regions as legal entities with constituent TSOs as shareholder of the RSCs.

Currently there are five regional security coordination centers supporting regional management of interconnections in Europe. The first RSCs were formed in 2008, between Coreso (based in Brussels) www.coreso.eu and TSC (Munich) www.tscnet.eu in Continental Europe. This was followed by in 2015 when a RSC was created as the Security Coordination center for South East Europe in Belgrade, www.ssc-rsci.com. Four TSOs in Scandinavian countries, the Nordic TSOs, established the Nordic RSC www.Nordic-RSC.Net, and three Baltic counties created the Baltic Regional security center www.baltic-rsc.eu, in 2016-2017.

Each TSO has nominated one or more of these RSCs as their service provider for producing a common grid model of the type described in section 5.3 of this report. Further service based on the Common Grid Model (CGM) at a pan-European level are also performed by the RSCs.

3.1.5 Multinational Energy companies/ Power Pools / Energy exchanges

Most bulk energy trades are carried out bilaterally, but the share of trading over power exchanges has been increasing. The European Power Exchange (EPEX) is one of the larger exchanges covering various power markets such as SPOT, Day Ahead, Intraday, Hourly ahead, flexibility market etc. Roughly thirty energy exchanges have joined together in forming an Association of European Power Exchanges EuropeEx. These exchanges work closely with TSOs to make sure that limits imposed by the physical characteristics of the transmission systems are respected in the market planning horizons. The network capacity on various interconnections is computed and published for utilization by the market players.

3.1.6 European Commission / Energy

The Energy department of the European Commission ec.europa.eu/energy oversees all energy-related issues in Europe. The Department establishes Commission-wide energy strategy for secure and efficient energy supply and sets up targets for member states. Promoting the use of renewable energy in reducing environmental impacts and increasing sustainability of energy supply using new technologies and innovations are a few of the guiding principles of the Department. These mandates include reduction in use of and dependence on fossil fuels (oil, gas and coal) and safe operation of nuclear energy for civilian use.

The energy department also safeguards the interests of consumers and the functioning of energy markets. The development of infrastructure and cooperation with other international agencies in energy matters is also one of the responsibilities of this department. The targets set by the European Commission in an energy context are challenging. The Energy efficiency target is to increase efficiency by 20% over the “Business as Usual” level (as projected in approximately 2012) by the year 2020, and aim for an improvement of at least 32.5% in 2032. The share of renewable energy is targeted at 20% or more in 2020, and 32% in 2032. These targets are mandatory for member states and other European countries that are not part of the European Union (such as Norway and Switzerland). The targets cover all sources and forms of energy.

3.1.7 ACER – Agency for cooperation of Energy Regulators

The Agency for Cooperation of energy regulators (www.acer.europa.eu) was formed in 2011 under the so-called Third Package under which the Agency should oversee the integrity and transparency of wholesale energy markets *REMIT*. The agency was entrusted with establishing guidelines for trans-European energy Infrastructure in 2013. *Regulation (EU) No 347/2013*. This was in addition to the Agency's responsibility for the coordination of regional and cross-regional initiatives promoting market integration, working toward the objective of creating a single EU energy market for electricity and gas. ACER monitors the work of ENTSO-E and develops EU-wide network development plans.

The Electricity Department within ACER has the following key areas of work

- Framework Guidelines and Network Codes
- Electricity Regional Initiatives
- Infrastructure and Network Development
- Market Monitoring

with the objective of creating a competitive, secure and sustainable European Electricity market. The current seat of ACER is in Ljubljana, Slovenia.

3.1.8 Council of European Energy Regulators (CEER)

While ACER is an agency established by European Commission under Energy, the national interests of each participating nation are looked after by the National Energy Regulation Authorities in each country, typically working under national Ministries of Energy. The National Regulators monitor performance of various actors to ensure that consumers interests are protectors, and that electricity users receive energy in a secure, efficient and sustainable manner. The National Regulators have formed an association called the Council of European Energy Regulators (CEER, www.ceer.eu). CEER is a non-profit organization complimenting the work done by ACER. While ACER focuses on Legislation, CEER coordinates the National Regulatory Authorities in fostering energy markers and empowering energy consumers.

CEER is more consumer-oriented and has proposed a 3-D Strategy for Digitalization, Decarbonization and Dynamic regulation with a corresponding 3-year work program to implement this strategy.

3.2 EU Regulation and Network Codes

The European Commission differentiates between "Directives" and "Regulations" as follows:

> *A "regulation" is a binding legislative act. It must be applied in its entirety across the EU. For example, when the EU wanted to make sure that there are common safeguards on goods imported from outside the EU, the Council adopted a regulation.*
>
> *A "directive" is a legislative act that sets out a goal that all EU countries must achieve. However, it is up to the individual countries to devise their own laws on how to reach these goals. One example is the EU consumer rights directive, which strengthens rights for consumers across the EU, for example by eliminating hidden charges and costs on the internet, and extending the period under which consumers can withdraw from a sales contract.*

Source https://europa.eu/european-union/eu-law/legal-acts_en

Based on these Directives and Regulations, for ENTSO-E the European Commission has published network codes under the Third Package, which is a collection of regulation and directives pertaining to the management of electricity interconnections.

3.2.1.1 Connection codes and Guideline

3.2.1.1.1 Demand connection code

The Demand connection code is focused on Distribution System Operators and closed distribution systems that are connected to high-voltage networks. It also ensures that renewable power generation sources are integrated well in the system and that demand response mechanisms are promoted to provide flexibility in internal energy markets.

3.2.1.1.2 Requirements for generators

The technical capabilities of the connected generators influence system security, and thus the code for generators harmonizes the grid connection rules in the participating countries and ensures that there is close cooperation between generators and system operators. Both synchronous and asynchronous connections of generators have been specified. The required automatic response and regulation capabilities of the generating plants are also specified.

3.2.1.1.3 High Voltage Direct Current Connections

This code establishes requirements for grid connection to high voltage direct current lines for power parks that are DC connected. These regulations are necessary to allow free flow of energy in the internal energy market, allowing fair and transparent competition among all participating actors.

3.2.1.2 Operation Codes and guidelines

3.2.1.2.1 Emergency and Restoration

This code focuses on what happens during disturbed conditions of power systems and prescribes how the actors in the interconnection should behave in emergencies. Once the cause of disturbance or blackout is identified and rectified, the restoration process defines how to restore the interconnection and grid to normal conditions. The tools and facilities for doing so, including communication protocols, are defined in this code.

3.2.1.2.2 System Operations

The System Operations code provides guidelines on operational security, data exchanges between TSO-DSO-Generators, scheduling between control areas, and outage coordination, as well as a framework for load-frequency control. Furthermore, training and certification of system operations are also laid out in this code.

3.2.1.3 Market Codes and guidelines

3.2.1.3.1 Capacity Allocation and Congestion Management

The guidelines for cross-zonal capacity allocation and congestion management in the day-ahead and intraday time frames are established in this code. The methodologies to determine capacity available within bidding zones are also specified

3.2.1.3.2 Electricity balancing

Guidelines for electricity balancing are provided in this code. These include common principles for frequency containment reserves, frequency restoration reserves and replacement reserves. Common methodologies to activate these reserves are also included in this code.

3.2.1.3.3 Forward Capacity Allocation

Cross-Zonal capacity allocation in the forward markets and common methodologies to determine cross-zonal capacity are included in this code. The guidelines aim at providing a single allocation platform at the European level for long-term transmission rights and their further exchanges in subsequent forward capacity allocation among the market participants.

ENTSO-E has packaged all of the above codes in an application called “E Codes” available on IOS or Android smart devices. Individual articles and explanations can be accessed for each of these codes.

3.3 Clean Energy Package (CEP)

The Fourth Package of regulations, also known as the Clean Energy Package (CEP) includes the directives and regulation listed in the table below. The focus of the Fourth Package is on energy efficiency, environmental issues, integration of renewable energy, and governance of Internal Energy Markets. The directives and regulations published under clean energy package are summarized in Table 1 below.

TOPIC	PUBLICATION DATE	Official Journal Publication	Contents
Energy Performance in Buildings	19/06/2018	Directive (EU) 2018/844	Energy efficiency of building, renovation of old buildings, guidelines for new buildings.
Renewable Energy	21/12/2018	Directive (EU) 2018/2001	Renewable electricity, cleaner heating and cooling, decarbonized transport, empowered consumers and at least 27% renewables in the EU.
Energy Efficiency	21/12/2018	Directive (EU) 2018/2002	Setting a target of 32.5% by 2032.
Governance of the Energy Union	21/12/2018	Regulation (EU) 2018/1999	Ensuring that the policies and measures at various levels are coherent, complementary and sufficiently ambitious.
Electricity Regulation	14/06/2019	Regulation 2019/943	Provide final customers – household and business – with safe, secure, sustainable, competitive and affordable energy.
Electricity Directive	14/06/2019	Directive (EU) 2019/944	Organize competitive electricity markets across country borders, to deliver real choice for all Union final customers, competitive prices, efficient investment signals and higher standards of service, and to contribute to security of supply and sustainability.
Risk Preparedness	14/06/2019	Regulation (EU) 2019/941	Increase the resilience of the EU electricity system, each EU country is required to define Risk Preparedness plans to be ready to respond to for unexpected situations.
ACER	14/06/2019	Regulation (EU) 2019/942	Stronger role for the ACER Agency, which coordinates work among national energy regulators ensuring that decisions are taken for making best use of an integrated EU energy market to the benefit of all EU citizens.

Each of these documents have been approved by the EU parliament and are classified either as a Regulation making them mandatory or as a Directive defining best practice. The implementation dates for most of the member states are defined in the regulation or directive.

4 The market and operational framework used

This chapter describes the basic principles of the power system and market operation for the European Interconnected system.

4.1 Network

The use of transmission networks in Europe must follow the regulations associated with *unbundling*, that is, the transmission companies are not allowed to engage in energy trading themselves and should be established as a formal entity responsible for operation of the Transmission network. These companies also manage cross-border power flows and are responsible for balancing power and energy exchanges in their areas. The transmission company must follow the principles of *open access* and allow the use of the network for energy exchanges from all parties registered within the Internal Energy Market. These exchanges should be operated without discrimination and independent of the location of the connected party. These transmission services are operated by monopoly providers and transmission network charges are thus *regulated* in most of the countries. Regulated transmission services may have cost-plus models or incentive models depending on national policies. The transmission service charges include asset service costs and operational costs. New investment may have to be approved by national regulators to be recovered through transmission usage charges. Since the geography and topography of Europe vary widely over the continent, the costs of constructing overhead lines or underground cables vary over a large range.

The *Independent System Operator* (ISO) or Transmission system operator (TSO) models coexist in Europe. Several Independent system owners may own individual or multiple interconnectors. The operational responsibilities for interconnection remain with the national TSO. The voltage levels of 220 kV or higher is in the jurisdiction of TSOs, with DSOs operating the portion of the grid at voltages lower than 220 kV. Some city networks have a 200 kV or 110 kV ring that may be operated by DSOs. The DSOs must participate in maintaining voltage and security for interconnecting with the higher voltage level networks. The authority to switch elements are covered and harmonized between DSOs and TSOs within in each country.

The European network is highly interconnected, which is good for reliability and security of supply but puts more responsibilities on TSOs to maintain cross-border exchanges and reduce unwanted loop flows. As in most part of the world, there is a strong opposition to building overhead lines and new sub-stations. Most of the countries have a rigorous process for permitting “rights of way” that takes into consideration the opinions of local populations. Environmentalists are forcing more and more new transmission lines to be built as underground, which adds to the cost of the transmission system and also adds more complexity in its operation. As a rule, new substations in urban and suburban areas have moved to the use of more compact gas-insulated switchgear, saving on expensive land prices while reducing the impact of substations on the urban skyline.

As explained in the previous chapter, with the development of the transmission networks and the interconnection of more and more nations, Europe slowly developed a large synchronous HVAC area operating at a frequency of 50 Hz. Large blocks of synchronously operated AC networks were interconnected with HVDC submarine cables. The connections to the UK, and from Scandinavia to continental Europe, brought the UK power system and the Scandinavian power system closer to a common energy market, increasing capacity and allowing European nations to profit from the increasing diversity in the generation mix. In the last few years more and more HVDC connections have been developed, strengthening the continental grid and increasing its capacity. UK to Holland, UK to Norway, and Sweden to Poland are some of these new HVDC connections.

High Voltage network operations are quite well coordinated across European borders, and have been providing high-quality energy with high reliability to the continent. In 2003, however, a large disturbance occurred causing islanding and a large blackout on the Italian Peninsula.[5] This blackout had revealed some of the weaknesses in the operation of such a large system, and several reforms were introduced in Italy, Switzerland and other neighboring countries as a consequence. For example, Switzerland, which had seven transmission operators, decided to consolidate the operation of its HV network in one company to provide clear control responsibility.

4.2 Generation

Current generation in Europe is based on large hydro plants, run-of-the-river smaller hydro plants, and coal- and other fossil fuel-fired thermal plants (mostly natural gas-fired plants in recent years). Nuclear power has also provided a significant portion of the electrical production in Europe.

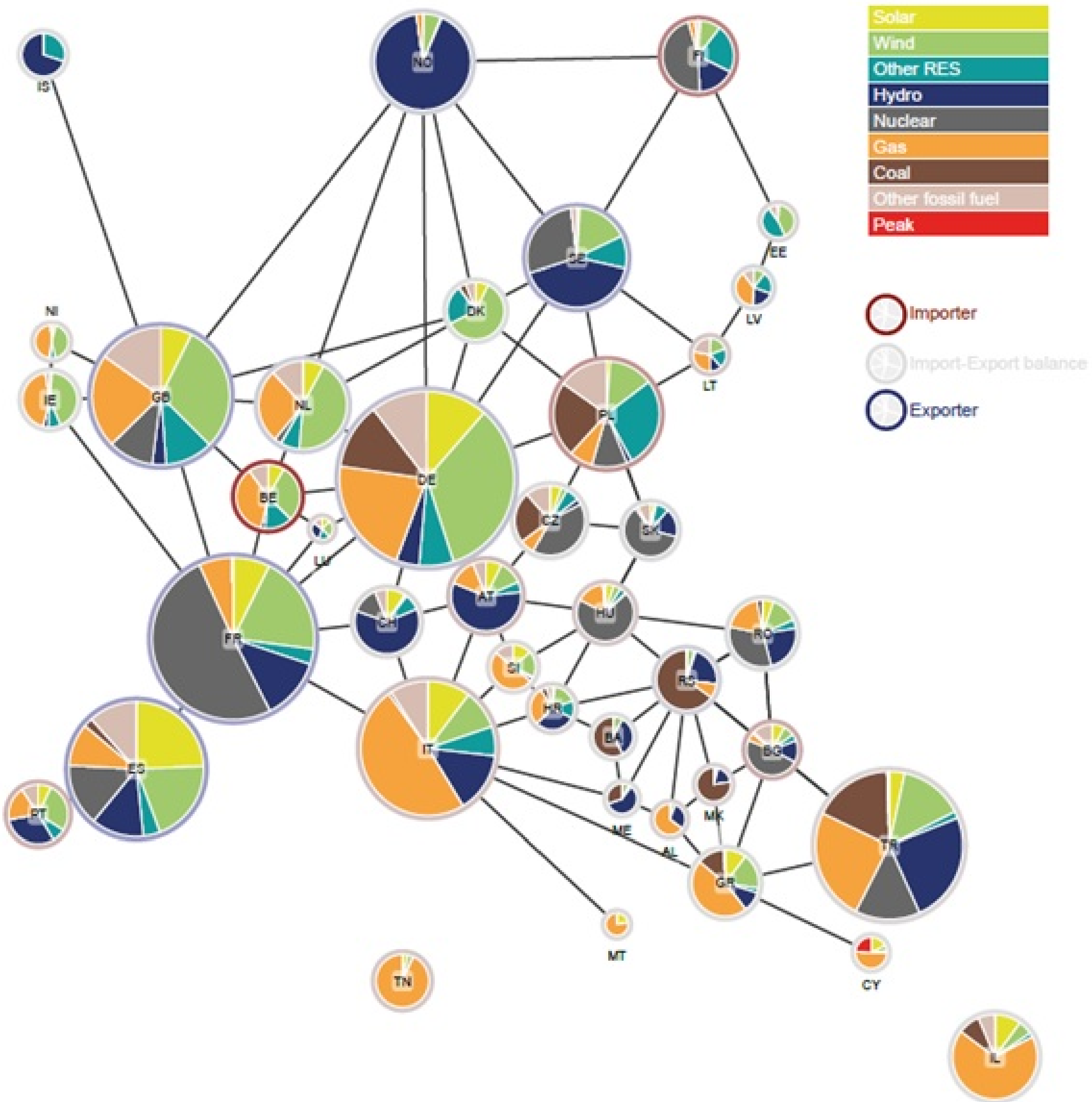

Figure 3: European future generation mix in 2030

However, safety concerns in nuclear plants, especially after the accident at the Fukushima nuclear plant in Japan, have raised a very strong public reaction in Europe. Some of the countries decided to stop using nuclear energy immediately (most notably Germany), whereas others put a moratorium on their plans to build new nuclear plants. Safety procedures for nuclear power were upgraded. The useful life of nuclear plants was reduced and a timetable to remove nuclear plants from the network was announced. Figure 3 shows the expected generation mix in the year 2030 in each of the European countries. By 2030, the share of nuclear and coal will have noticeably diminished from current and historical levels.

The share of renewables and gas has increased in the future scenario. What is remarkable is that renewable resources have reached a high degree of penetration in electricity markets in a relatively short period of time. This is quite clearly visible from the German example as shown in Figure 4. [6]

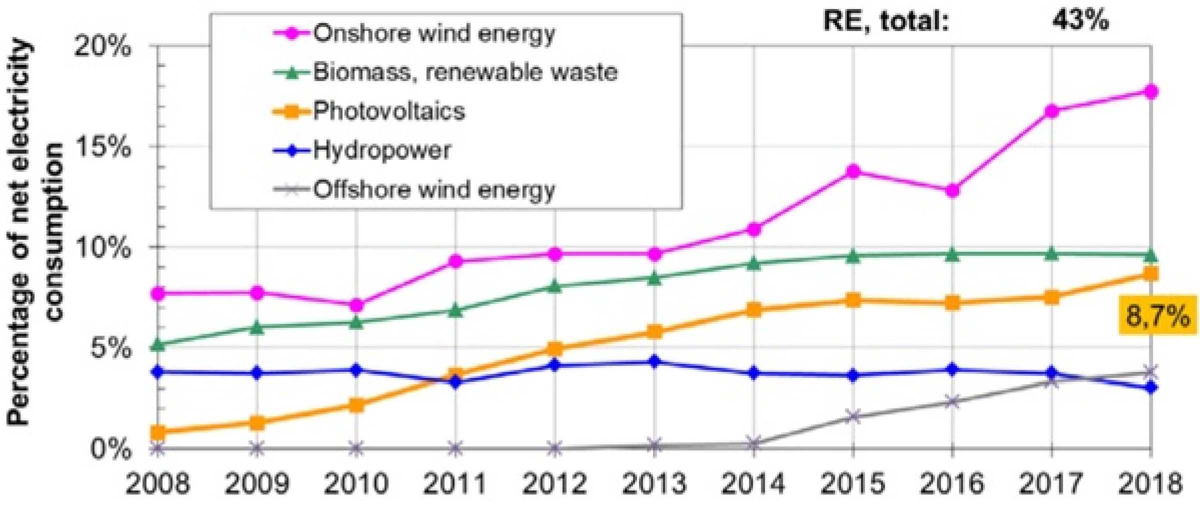

Figure 4: Renewables in Germany

4.3 Distribution/ consumption:

Electricity consumption in Europe has been increasing over the decades, but in recent years the rate of consumption growth has fallen. In most of the countries electricity consumption has remained stagnant or even gone down a little. The reasons for this stagnation may be a combination of the economic slowdown, the use of more efficient electrical equipment, the increasing impact of demand side management, and low (and in some cases negative) population growth. Energy consumption in each country is governed by national policies and interests and is less dependent on wholesale electrical energy trading between countries.

Electricity pricing is dependent on national policies and governed by national regulatory authorities. Following the European transparency directive for electrical energy markets, network usage costs and energy costs must be clearly defined in pricing. Domestic electricity pricing in European countries vary over a wide range, as can be seen in Figure 5.

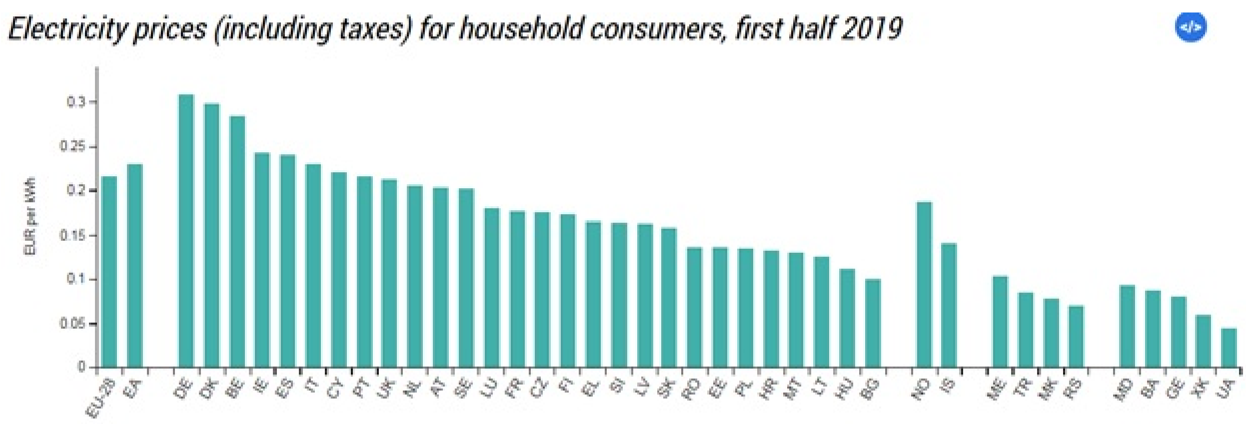

Figure 5: Electricity prices for Household customers in Europe: (Source Eurostat)

The European average price of one kilowatt-hour of electrical energy at the household level is roughly 21 eurocents. The spread across nations is quite large, however. On the higher side is Germany with a price of the order of 30 eurocents, compared to 10 eurocents in Bulgaria.

4.4 Swiss power systems specialties and integration in Europe

4.4.1 Structure of the Swiss Power industry

The Swiss power system is in the middle of Europe in a landlocked country. Swissgrid is the Swiss TSO responsible for 6700 km of 380/220 kV lines, and has roughly 140 Substations under its control. The Swiss power system is monitored and operated at various levels by Swissgrid (national control), provincial energy utilities (Cantonal energy companies, 26 in number) and numerous distribution companies. Cantonal companies operate some portions of the 132/110 kV network at sub-transmission levels. Some of these companies serve larger cities and agglomerations, such as Zurich, and Basel, and have their own ring networks in and around these areas. The distribution companies in Switzerland are in a phase of transition and consolidation, as historically a group of villages or a large village/town would have their own distribution company. Out of 630 energy companies in Switzerland, roughly 70% are electricity distribution companies.

4.4.2 Swiss Power system characteristics

Switzerland, due to its location and level of technological advancement, has one of the most interconnected electrical systems in the world. Despite the small geographical area of the country there are 42 interconnections with the neighbors, and the Swiss network is very heavily loaded by transits from neighbors. Figure 6 shows the transits over Swiss network in a typical day. These values can be seen in near real-time on the Swissgrid website. Italy is a high electricity price country and energy producers from north, east and west of Switzerland sell their energy to Italy, resulting in heavy transits over the Swiss high voltage network.

Switzerland, being an Alpine country, has heavily invested in hydro power plants. Around one thousand small hydro plants and 650 hydroelectric power stations with output of 300 kW and above form the bulk of Swiss power production.[7] In addition to hydro power, Switzerland has four operational nuclear plants. Its oldest nuclear plant was switched off in December 2019. Switzerland's other nuclear plants will be operated as long as they fulfill security requirements, and then will be gradually removed from service.

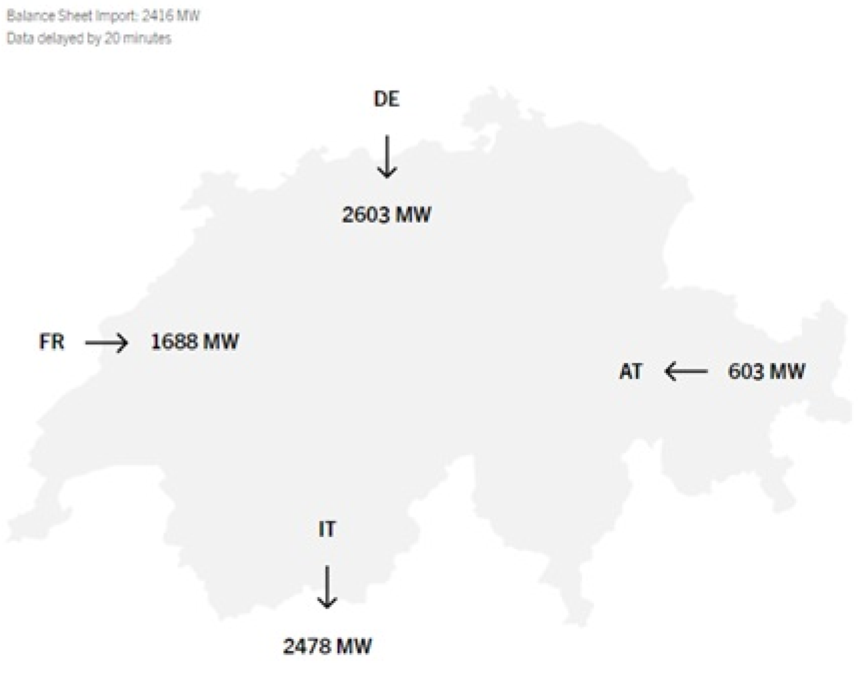

Figure 6: Typical transits over Switzerland electrical system

Roughly two/thirds of the electricity consumed in Switzerland comes from renewable energy, with the major share of the country's electricity (60%) coming from hydro power and 8% supplied by a combination of photovoltaics, wind, small-scale hydropower and biomass as of 2018. Although nuclear generation accounts for 33.5% of the electricity generated in the country, only 15% of Switzerland's electricity **consumption** can directly be traced to come from nuclear energy, with and about one percent from waste and fossil fuels. The origin and composition of remainder of Switzerland's electricity is difficult to determine, due to Switzerland's extensive electricity imports and exports, and this fraction is often referred to as "grey energy".[8]

The Swiss are very much environmentally conscious and are willing to pay premium prices for renewable energy. With the same concerns there is also opposition to new rights of way for overhead transmission lines. Although the cost of laying high voltage underground cable is several times higher per kilometer than the cost of overhead transmission lines, the Swiss are ready to pay higher cost for the underground cable network development.

4.4.3 Integration of Switzerland in the European energy scene

Although not part of the political European Union, Switzerland has a significant role in the European electrical industry. Switzerland has a few large pumped-storage hydropower plants that can pump water back to higher level during low load/ low price periods. Pumped storage facilities can provide generation during peak periods when loads are high, and prices are significantly higher. Use of these plants helps in peak shaving of energy demand and in keeping peak-period prices lower. Switzerland has been accepted as special case for congestion management capacity allocations in the code in Article 1/84. Swiss electrical companies can participate in the European Internal Energy Market and have invested in generation companies in many countries in Europe.

Switzerland is part of the central European system and is a part owner/member of the Regional Security Centre www.TSCNet.eu. The TSCNet coordinates cross-border security issues and responses to outages, and works as the service center for Swissgrid. Switzerland, as a pioneer member of UCPTE/UCTE, has been instrumental in establishing a cross-border scheduling and accounting center. Swissgrid coordinates the scheduling in the south of the Regional Group Continental Europe (RGCE), with Amprion in Germany providing the same support for the north of the RGCE.

5 Data Exchange and Modeling

5.1 Data exchanges in online mode

5.1.1 Electronic Highway (EH)

The European TSOs started exchanging real-time data over a TSO-owned private network, known as the "Electronic Highway",[9] in the late nineties as the Partner Information Exchange system involving 6 TSOs. Within a few years this network was rolled out to the whole of continental Europe, and is used to exchange real-time measurements among neighbors using the Inter Centre Protocol (ICCP) of IEC-TC57, also known as TASE.2.[10] Receiving measurements from neighboring substations substantially increases the observability and accuracy of the state estimation, resulting in a good quality online network model. Neighboring TSOs mutually agree on the data set that is to be exchanged with the partner TSO's network. Partners are free to demand data from substantial portions of neighboring networks whose operation may have high impacts on their own operations.

Wide area measurements (see Figure 7) have been used in Europe to detect and analyze power system oscillations.[11] The fast sampling rate provided by Phasor Measurement Units (PMUs) is consolidated in using Process Data Converters (PDC) where only a few angles are exchanged by individual TSOs using the Electronic Highway. The angular difference visualized on the map gives very clear flow directions, damping and stability margins even without knowing the detailed topology of the network.[12]

Figure 7: European wide area monitoring shown on-line

The Electronic Highway is also used to exchange network models used in congestion management, security analysis and capacity calculations. For more than 15 years file-based network models based on an ASCII bespoke format (UCTE-DEF) have been exchanged over the Electronic Highway using a file transfer protocol. Currently, work is in progress to move from this format to a CIM-based Common Grid Model exchange standard as described in Section 5.3 of this report.

5.1.2 European Awareness System (EAS)

The lessons learnt from a large disturbance in November 2016[13] emphasized the need to provide a global overview of grid status and a simple process for operators to warn neighboring TSOs. To fulfil this requirement a European Awareness System[14] was proposed and implemented. All of the TSOs are connected to a dual SCADA system in two different geographical locations. The TSOs send on-line measurements and topological changes to the central systems using the TASE.2 Protocol. The central systems process those data and compile a global Pan-European map that is shown in all control centers of all the TSOs. TSOs can decide which is important data for them and deliver or subscribe to that data. The common visualization generated by EAS helps TSOs to keep track of the status and changes in system conditions.

In addition to the measurements above, a simple signaling system has been introduced where individual TSOs can change the status of their system from Normal to Disturbed or Emergency as shown by Green, Amber or Red lights for that specific country. It is left for the national TSOs to decide the criterion for disturbed or emergency conditions resulting in the change of status. It is also left to their discretion if they wish to automate this process or keep control through manual operation.

5.2 System development

5.2.1 Network development planning

The planning for growth of infrastructure in the European grid is a complex and challenging process that is further complicated by its multi-national character, uncertainties in the future generation mix, reachability of decarbonization targets, growth in society, competing projects, coupling across sectors, and limited resources. Planning requires a thorough knowledge of transmission and storage projects and methodologies to tackle the uncertainties in future scenarios that may develop due to unpredictable factors such as public acceptance and the availability (or lack of availability) of financing.

ENTSO-E regularly performs a Ten Year Network Development Plan (TYNDP),[15] where transmission and storage projects are compared and proposed based on cost benefit analysis (CBA) results for the candidate projects. The projects are collected "bottom up" through the member TSOs and the cost-benefit analysis is performed to estimate the impact on costs, the increase in reliability, and the reduction in environmental emissions/damage. The possible generation mixes are formed in scenarios and the coupling of electricity and gas transmission systems is reflected through collaboration with the European Network of Transmission System Operators- Gas (ENTSOG). The results of CBA after public consultation are submitted to the Agency for the Cooperation of Energy Regulators (ACER) according to Regulation (EC) No 714/2009 for approval and publication.

Indications of the number of projects in different geographical corridors in Europe and the projects on which work has started or is in different stages of development are provided in Figure 8.

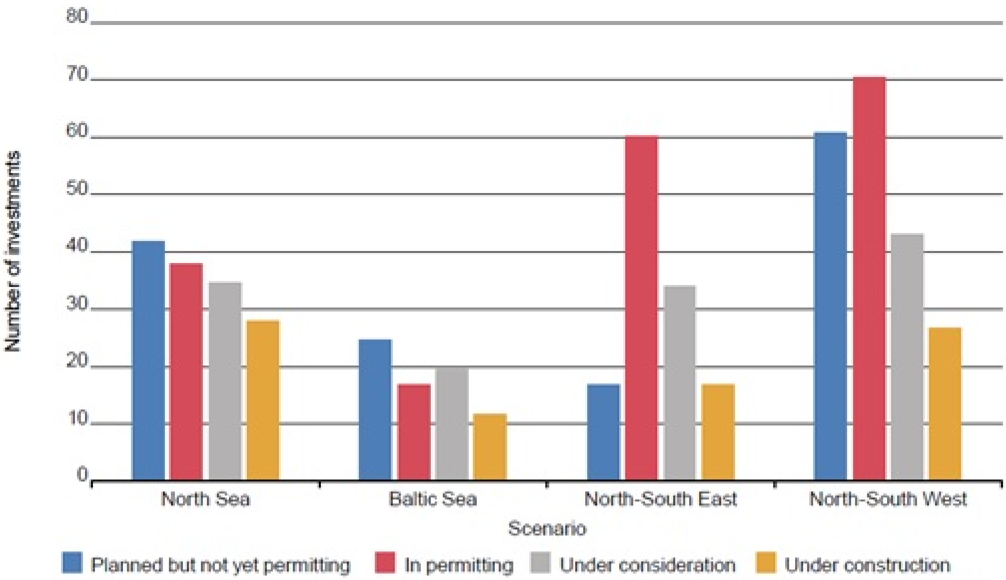

Figure 8: Number of projects in different European Transmission Corridors.

The TYNDP is 2018 considered 166 transmission projects and 20 storage projects, both pumped hydro and compressed air, with a total investment volume of 114 Billion Euros and potential annual savings estimated from 2 to 5 Billion euros in reduced generation costs.

The impact of the clean energy package on this process cannot be overestimated. The European vision focuses on deploying a clean energy future in a cost-efficient way while maintaining security of supply. It demands that the development of renewables must be better integrated in the whole planning process and closer links between the power, heating and transportation sectors must be considered in all planning processes. Not only will the generation mix strongly change with the consideration of increasing renewable penetration in the future, but better understanding is also needed from the demand perspective. New tools and methods are being developed to better understand how electricity demand will evolve and how demand-side options will become a central part of a solution for providing sustainable, environmentally-friendly, and affordable electricity service. One of the three scenarios considered in TYNPD is dedicated to exploring a future in which small-scale renewable generation, home energy storage, and demand response are widespread across Europe.

The technologies that have been considered for future transmission systems are listed below in descending orders of investments in ongoing projects:

- Overhead lines
- Substations
- Submarine cables
- Underground cables
- Compensation devices
- Phase shifting transformers
- Line commuted converter stations

The TYNDP provides a plan for Europeans that considers their vision of clean energy and fulfills their expected needs economically, politically and societally. Given the role of the Plan in informing investment decisions and providing policy support through Regulation (EC) 347/2013, the cost benefit analysis (CBA) methodology done in TYNDP brings greater confidence in the results, and provides investors and policy makers with reliable information on the value of power infrastructure considering the interdependencies of their investment decision factors and complementary national and regional electricity sector planning exercises.

5.2.2 Medium term Adequacy forecast MAF

One of the major objectives of TSOs is to make sure that there is enough energy and transmission capacity available to transport energy to consumers from the available generation resources. The time frame for forecasts of capacity could be one to ten year in the future. The Mid-term Adequacy Forecast (MAF) is performed by ENTSO-E for monitoring the pan-European adequacy of electricity supply.[16] If the availability of generators and their planned outage periods, together with energy demand, are known in the same period, this study can be straightforward. With the addition of more intermittent generation to the grids, however, accurate forecasting of output depends increasingly on the predictability of renewable electricity sources. Wind and solar generators are highly dependent on local weather conditions, such as cloud cover and wind velocity. Predictions of output for these types of generator may yield large uncertainties, or large variations in potential output, to be considered in planning scenarios. In addition to uncertainties in generation, unplanned outages of generation plants have impacts on the total availability of generation.

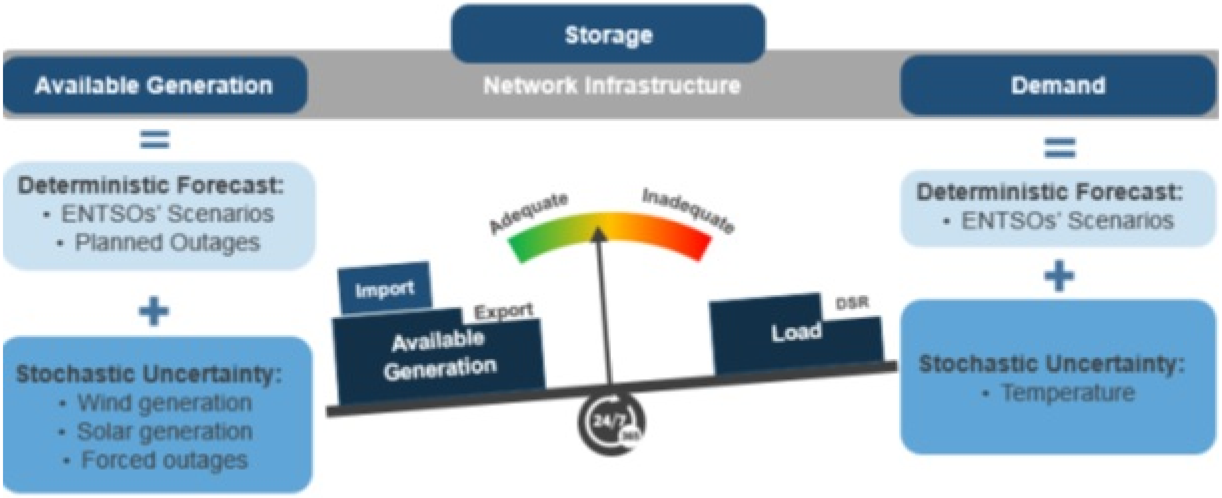

Figure 9: Overview of medium adequacy forecast

On the consumption side, the magnitude of the load in the demand sectors depends on the economic activities and growth rates in activities estimated for the area. In Europe the residential load demand varies very strongly with the changes in ambient temperature. To simulate the scenario with deterministic forecasts, advanced stochastic methods are used to consider the uncertainties mentioned above. A state-of-the-art probabilistic analysis is prepared, aiming to provide stakeholders with comprehensive support to make qualified decisions.

These studies check the availability of energy and transmission capacity for supplying energy in an uninterrupted way to the consumer. The studies monitor the continuous balance between net available generation on the one hand, and net load levels on the other, as shown in Figure 9.

The large and increasing penetration of renewable electricity sources has made it essential to improve and consider the probabilistic nature of the renewable sources. ENTSO-E has been refining and improving its methodologies and forecasts continuously and will continue to ensure that further progress on modeling of renewable generation output is made. MAF also contributes to the harmonization of resource adequacy methodologies across Europe by being a reference study for the European Transmission System Operators (TSO) and a providing a target approach for the Ten-Year Network Development Plan (TYNDP) and Seasonal Outlook studies. The MAF aims to provide stakeholders with the data necessary to make informed, quality decisions and to promote the development of the European power system in a reliable, sustainable and connected way. Various modelling tools have been calibrated with the same input data and benchmarked against one another to increase consistency, robustness, and confidence in the complex analytical results.

The current methods, if used with a detailed granularity of network data, result in a very large complex mathematical problem to be solved. This problem has been tackled by ignoring all possible network constraints within a defined modelling zone. The detailed analysis at higher granularity of the modelling zone might be used to complement the MAF results in order to detect local resource or network constraints.

5.3 Operational planning based on Common Grid Model (CGM)

Operational planning is typically performed by TSOs for their control areas. However, in a highly meshed system such as European interconnection, network planning cannot be completed without considering the conditions of the neighboring network. To provide a reliable network model the TSOs have agreed to exchange their network model based on the international Common Information Model of International Electrotechnical Commission standards.[17] A Common Grid Model exchange standard (CGMES)[18] has been established to exchange Individual Grid Models (IGM) by each TSOs in different time frames. The TSOs prepare their network models in planning time frames of Year Ahead (Y-1), Month Ahead (M-1), Week Ahead (W-1), Two days Ahead (D-2), Day Ahead (D-1) and Intraday (ID), as shown in Figure 10.

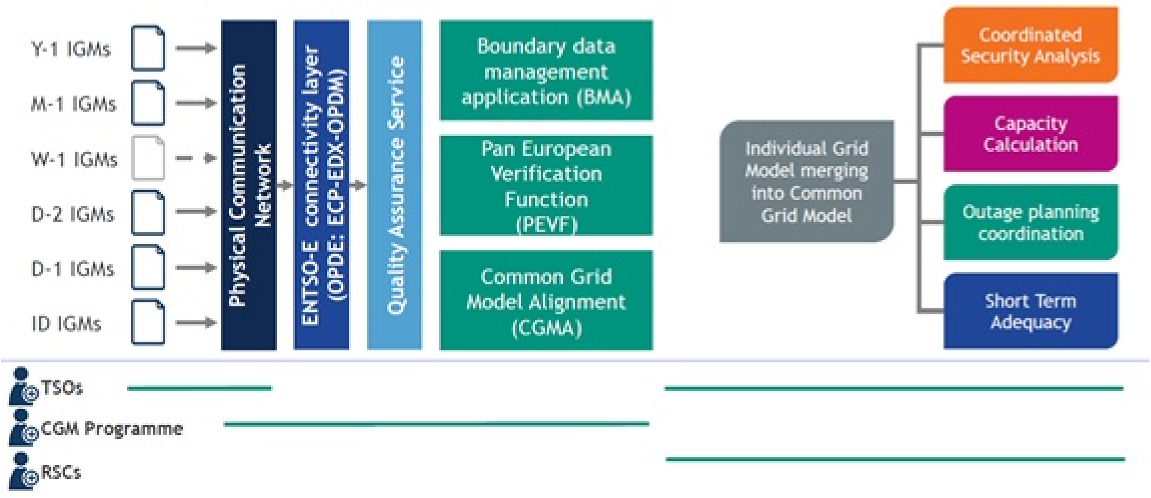

Figure 10: Common Grid Model (CGM) increasing security and reliability in planning

The IGMs are published over a Physical Communication Network owned and operated by TSOs over an ENSTO-E connectivity layer based on the Market Data Exchange Standards of ENTSO-E.[19] The Energy Communication Protocol (ECP) and the Energy Data Exchange (EDX) are the middleware components developed for secure and monitored data exchange over a communication network. The publishing and access of data is managed in Operational Planning Data Management (OPDM).

The quality of IGMs is checked and IGMs with poor quality are rejected. If an acceptable quality IGM is not available until the gate closing time of a process, the IGM is substituted by another model based on predefined rules of substitution. The IGMs use a procedure to model the boundary data where a tie line is cut at the border resulting in two nodes also referred to as X-nodes. The boundary data are maintained in a repository and while merging two IGMs of neighboring TSOS, a pair of X-nodes is reconnected to model the tie line. Each synchronously operating region provides their consolidated schedules for a given time frame of their constituent TSOs and exchanges. The Pan-European Verification Platform provides and synchronize the scheduled flow among the regions. The IGMs are merged relying on the Common Grid Model Alignment methodology, resulting in a Pan-European Common Grid Model. This model represents a consistent and good quality representation of complete interconnected European systems.

Based on the Pan-European Common Grid Model, any authorized agent can perform various services that improve security, improve transmission capacity, coordinate outage planning and monitor adequacy of energy resources. These services are typically performed by the Regional Security Coordinators (RSCs) of different regions for those regions. The Process and tools used for analysis are sketched out in Figure 10.

5.4 Markets Information systems and processes

5.4.1 Balancing

Electrical energy must be produced at the time of consumption to keep the system stable and to result in a good quality frequency. Typically, a Balance Responsible Party (BRP) plans to buy or sell energy in a balance area for a given planning period. The errors and inaccuracies in demand/generation prediction, natural fluctuations in electrical load, and unplanned events may cause an imbalance in the planned exchanges. That is, the missing or excess energy causes an imbalance in the balance area and results in imbalance of the control area. It is the responsibility of the TSO to maintain the balance in their area.

Most of the TSOs are not allowed to trade energy except for ancillary services. Balancing is one of the major ancillary services to be organized by the TSOs. TSOs use services of Balancing Service Providers (BSPs) to increase or decrease production/demand in their area in order to reduce the inadvertent exchange of energy. The BRPs that cause imbalances must pay for the imbalances, and BSPs are paid for the balance services provided.

Balancing energy can be provided in real-time as a part of spinning reserves and the natural frequency characteristics of the power system. Each TSO is mandated to keep a minimum specified spinning reserve, for example, the equivalent of one percent of demand, to iron out small deviations in energy balance in the range of a few seconds to a few minutes timeframe. Classically this has been referred to as primary reserves. The larger deviations that must be covered in a 10 to 15 minutes time frame by direct commands to generation is known as secondary control or automatic generation control. If the deviations are larger and time permits, these deviations are covered by ordering increased generation in the process of scheduling generation. These modifications to generation could be on time-frames of a quarter of an hour to several hours or days.

Different reserves in these time-frames are acquired by the TSOs in a transparent, market-oriented process and are subject to regulatory auditing to ensure efficiency and cost control. TSOs have established a prequalifying process to ensure that the BSPs have the capabilities to provide balancing energy, if and when ordered. All prequalified BSPs submit offers for regulating reserves that are organized in a Merit Order list based on offered prices. During operations, the dispatcher can select the volume and order the reserves on BSP without a separate acquisition process.

TSOs have devised means to increase reserves by pooling reserves to reduce the costs of reserves and increase the reliability of the system. These have been done mostly at a regional level within groups of TSOs, for example, by the Scandinavian countries in Nordpool. There are efforts, however, to increase cross border trades for reserves and increased possibilities of using available resources for global benefit. Such a system, XBID, is described in section 5.4.3. In addition to market-based exchange some TSOs have agreements to assist each other in case of emergencies. Known as Mutual Emergency Assistance System (MEAS) agreements, MEAS provide for TSO to TSO exchanges to take place without the direct involvement of market players.

5.4.2 Transparency Platform

Total transparency is needed in the listing of available capacity, pricing and planned flows in order to achieve a non-discriminatory and open access marketplace for electricity. Transparency is also needed to make sure that a level playing field is available for all parties willing to trade energy irrespective of their size and location. As an association of TSOs, ENTSO-E collects the relevant information from TSOs and publishes it for everyone interested in the electricity market.

Power flows is shown as import and export of power from each country, and different types of generation and exchange with neighboring countries are shown. Furthermore, for each country the price per MWhr and total consumption for last 24 hours is provided. This information can be visualized through an application that runs on IOS or Android smart devices. Figure 11 shows screenshots from the Transparency application.

Figure 11: Entry map and Generation mix of any country

Complete transparency helps in assuring fair and flexible practices in the electricity market and all parties can decide on placing their offers and bids to suit their business strategies. Figure 12 shows examples of graphics available through the Transparency application showing flow direction, energy consumptions and prices in each country.

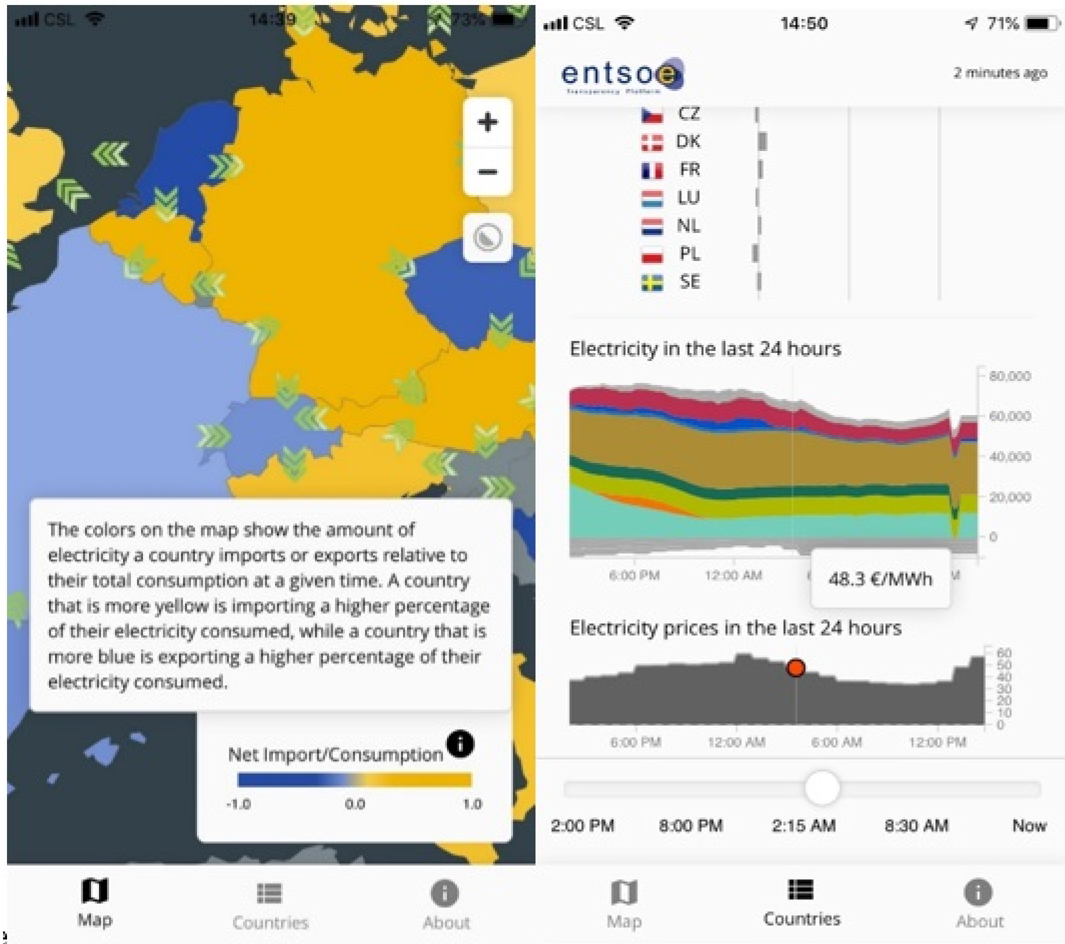

Figure 12: Flow direction, energy consumptions and prices per country

5.4.3 Cross Border Intraday Trading (XBID)

The Cross-Border Intraday initiative (XBID)[20] is an initiative started by several Power Exchanges (PXs) including EPEX SPOT (which includes the former APX and Belpex), GME, Nord Pool, and OMIE, including TSOs from eleven countries. The aim of this initiative is to create a joint integrated intraday cross-border market across national boundaries. In its final version the single intraday market will enable continuous cross-border trading across Europe. This single intraday market solution is composed of three components, namely the Shared Order Book (SOB), a Capacity Management Module (CMM), and a Shipping Module (SM). These three modules form a common IT system where orders from all participants irrespective of their location can be matched with orders submitted by market participants in any of the participating country as long as transmission capacity is available. The IT systems increases the overall efficiency of intraday trading. The system supports both explicit and implicit continuous trading and the National Regulatory authorities have their choice of either of these solutions.

Three different physical markets for trading electricity; Forward Market, Day-ahead Market and Intraday market before the delivery hour, are treated in the system, increasing market liquidity, ensuring effective competition, and lowering prices. This will also allow more efficient use of distributed generation produced by renewable energy sources and facilitate the balancing market as scheduled transactions move closer to the time-frame of actual energy exchange.

These elements are part of the EU Target model for an integrated intraday market. The Guideline on Capacity Allocation and Congestion Management (CACM GL) endorses this XBID Model. The CACM GL sets out, amongst other guidance, the methods for allocating capacity in intraday timescales, rules for operating intraday markets and the basis for the implementation of a single electricity market across Europe.

The shared order book allows transparency and facilitates the utilization of all the offers from different markets via their own National Electricity Market Operator (NEMO) trading systems. Similarly, all intraday cross border capacities are made available by the TSOs are available in the Capacity Management Module (CMM). The XBID Model is in line with the provisions of the CACM GL and the parties in the project fulfil the future requirements of CACM through their involvement.

The electricity trades are cleared on a first-come first-served principle where the highest buy price and the lowest sell price get served first. The matched orders are removed from the order book, thus updating the available transmission capacity for market.

6 Requirements for Interconnections

Legal and commercial framework: It is very important that a proper framework is defined and agreed to by all of the participants in the interconnected area. The policies for promoting renewable energy use, free transmission access, non-discrimination, high expectations regarding security of supply, and other attributes must be harmonized and agreed to by all interconnecting regions or countries. This harmonization will prevent distortion of markets and free access to all energy sources in the interconnected areas.

Good communication infrastructure: Good communication infrastructure is essential for exchange of all of the data required in real-time and in planning modes. This infrastructure should provide a flexible and high-performance mechanism to exchange data during normal and perturbed operating situation. Since new applications are being introduced for planning and operations, the communication media should be scalable to cope with increases in data volumes and throughput without deteriorating transmission times. A modern communication network based on MPLS technology provides such features. A common communication network that is managed for access and data layers by TSOs will ensure higher availability and security of data transmission. The Service Level Agreements for such a service, whether provided by TSOs or external communication providers must incorporate these capabilities.

Cyber Security, Data Privacy: Since all operational activities are based on electronic data exchange, special security measures must be in place to make sure that no unauthorized party can access the data. The unauthorized access to data can jeopardize power system security and create havoc in society if it leads to malicious or unintentional interference in the interconnected network. In an interconnected system it is obvious that **C**onfidentiality**, I**ntegrity and **A**vailability (CIA) of data exchange must be defined and maintained by proper monitoring and supervision. Most of the companies participating in the European electricity market have a Security Incident and Event Management (SIEM) system in place to maintain cyber security. In addition to cyber security, data privacy laws have been reinforced to protect individuals in various regions of the world. As the interconnected systems go lower in the voltage levels, private data protection becomes more crucial.

Clear command and control practices: Since the system security and security of supply depend on the actions of all of the actors connected to the network, it is imperative that clear lines of command and control are established. Each piece of equipment or component in the system must have a unique operator that has authority to operate, maintain and upgrade the equipment. This is extremely crucial for the safety and security of the system and its operating personnel. Typically, the energy ministry in each country has a government agency looking after safety and security of equipment and personnel. For example, the "Federal Inspectorate for heavy current installation "(ESTI) supervises and regulate high voltage installations in Switzerland.[21]

Training for normal and perturbed conditions is a critical success factor for an integrated system. The training must include all of the types of actors participating in operations and markets. The service providers that are providing ancillary services such as balancing, reserves, voltage support, and power exchanges, including aggregators, transmission system operators, distribution system operators, power plant operators and energy traders must all be involved. Practically all larger TSOs/ISOs organize such training sessions for the participants in their control area. Regulatory authorities have defined the framework for training[22] and other enterprises offer such integrated training program.[23]

Data Modelling and exchange in planning and operational scenarios are needed to plan, build and operate the interconnected system. Carrying out these functions requires that all participants follow a specific standard for data modelling and exchange to avoid mapping of external data while importing or exporting planning or operational data. Such mapping is a source of errors and inefficiency and may raise artificial barriers for open energy exchanges in a multinational environment. In the early days of modelling such exchanges were done using proprietary or bespoke protocols such as the PSSE format, UCTE-DEF for planning data, and vendor-specific protocols for SCADA systems. The International Electrotechnical Commission (IEC) has recognized this field for many years, and in the last few decades standards have been established that allow interoperability for various systems and application developed by different vendors and in different countries.[24]

Integration of renewables pose some Technical Challenges associated with the intermittency and unpredictability of distributed generation, including:

- Balancing

- Lack of inertia/ Stability
- Voltage control
- Outage and Restoration

The errors in forecasting of energy production pose requirements on the flexibility in engaging fast active resources that can provide power and energy in a short-term time-frame. The electrical systems in PV and wind power generators have very different inertial characteristics, and the missing rotating mass of large generators may cause instability in power systems. Therefore, voltage support, outage and restoration requirements and procedures must be revised in the presence of substantial amounts of renewable generation. The complexity of integration increases as the level of penetration of renewable increases. In extreme cases renewable energy may remain unutilized due to these challenges. The issues of integration have been subject of large research projects and international cooperation[25], [26] and new solutions are being sought through many research and development efforts.

TSO-DSO interaction is very important for smooth network operations and the efficient functioning of energy markets. Since most of the demand-side measures are at medium or lower voltage levels, the DSO must play an active role in establishing secure and efficient market operations. As shown in Figure 13, TSOs facilitate the bulk energy market and cross border transactions, congestion management, grid control and balancing to maintain frequency and energy balance.

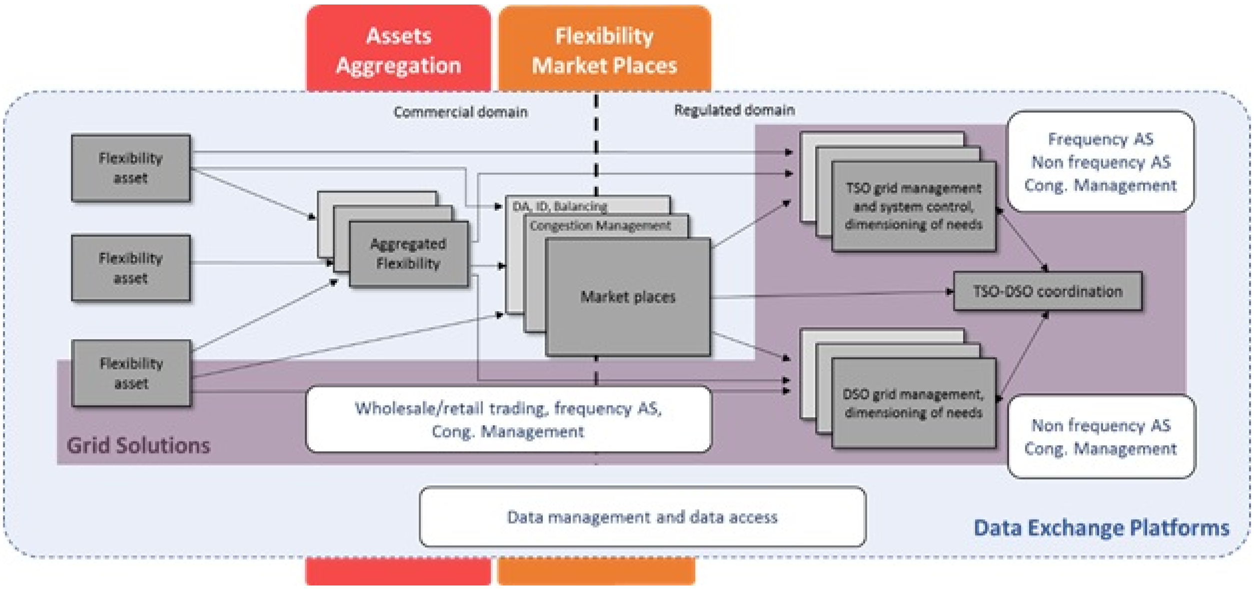

Figure 13 TSO-DSO Interaction, Source: ENTSO-E

DSOs are another set of actors in the regulated domain that provide similar services to TSOs but at the medium and lower voltage levels. In recent times, due to the intermittent nature of distributed energy sources, the role of aggregator is emerging. These businesses aggregate demand and provides ancillary services such as balancing energy and congestion management. Depending on the volume and periodicity of the loads they handle, aggregators may provide their services to TSOs or DSOs.

7 Conclusions

It is obvious that such large systems as the European interconnection do not materialize overnight. It takes political will, a common vision and continuous effort to achieve the goals of a smooth-functioning, safe, secure, transparent and economical set of interconnections. In the European case the European Union has provided the mission, the framework and the guidelines for developing an Internal Energy Market to serve the end consumer by providing reliable, secure and cost-efficient energy. A lot of work has been done and further work is ongoing to make this market eco-friendlier and more sustainable.

The countries in a region willing to establish a large interconnected system should ensure that the end consumer is served well. The common target is to have security of supply that is efficient and economical. Since most of these issues related to the development and operation of infrastructure come under governmental policies, the countries planning to form interconnections must harmonize their targets and agree on the common goal of having such an interconnection. Such a vision should pave the way for a clear legal framework providing a level playing field to all the participants in the electricity markets. It should be clearly identified what aspects of the interconnected systems lie within the jurisdiction of national actors and where coordination and cooperation is needed at a multilateral level.

The electricity market design should provide a transparent market structure offering seamless and non-discriminatory services for all of the market players. The market design must ensure that no player will have an unfair advantage due to its size or location. Mechanisms should be put in place to deter any market manipulation. In a barrierless market the energy prices for consumers should follow laws of supply and demand and result in an overall reduction in energy prices to the end consumer.

Of late environmental concerns have put restrictions on the types of primary fuel used for electricity generation and on the routing of rights of ways for transmission and distribution systems. Each country must commit to reducing environmental damage to a target value, such as reducing greenhouse gas emissions by a fraction of emissions in a previous year. The development of interconnections should be aimed at reducing the overall impact of the electrical industry on the environment while providing for sustainable economic growth. Interconnections will help in connecting efficient and eco-friendly generation sources to the load centers. The free flow of electricity across borders reduces reserve requirements for each participating country and provides the possibility of using renewable energy resources available in different parts of the interconnected system. The incentives for installing sustainable energy sources must also be coordinated across nations to promote consistent policy throughout the region. In the absence of such a policy subsidies and incentives provided in one nation will distort the price scenario in the region.

Since most electricity projects are capital intensive and require long planning horizons, the interconnected system must consider all planned development in the region. Strong cooperation and coordination are needed for planning new transmission systems and placement of new generation facilities in order to maintain security of supply and reliability of the interconnected system. A fair mechanism should be defined to prioritize development projects in order to meet the overall targets of the interconnection. Investments in long running projects can only be expected when the investors, public or private, are assured of stability in pricing and of a fair return on investment. The interconnected nations have to develop plans for the future of the network and provide this stability for investors.

By the nature of power systems operation headquarters must be close to the physical location of generating and T&D systems, whereas the market for power can be distributed and independent of the location of the physical assets. Network operators should have clear responsibilities defined at the local, national and multinational levels. This is especially critical during abnormal or emergency situations where maintaining system security takes priority over market rules. In such situations all parties contribute to the security of system by providing mutual assistance to the network area that is experiencing disturbances. In a well-planned and smoothly-running interconnected system the energy traders, consumers and producers do not have to worry about physical flows of power and transmission paths.

Standardization in system development, technical communications, modeling and data exchange are obvious fields that must be considered and specified in the beginning of any interconnection project. Without standardization network planning and operations will be inefficient and error prone. The criticality of clear communications, modeling, and data exchange increases as operations move to real-time functions where all protection and control devices must communicate with their own or external control systems. Considerable effort has gone into planning and organizing the successful large interconnected power systems in this field. This is also illustrated by the presented European interconnected system.

A well-conceived and well-designed interconnection helps all participating countries and brings cost and reliability advantages to the end consumer while fulfilling the targets of sustainability, eco-friendliness and security of supply.

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9 EPILOGUE:

9.1 Overview of Utilities and Pandemics

Most of the electrical utilities have a crisis management program handling natural disasters, epidemics, and local disturbances. Defense Plans against a pandemic crisis were prepared and ready for previous pandemic threats, such as Severe Acute Respiratory Syndrome (SARS) in 2002/2004, Swine Influenzas in 2009 and Middle East Respiratory Syndrome (MERS) in more recent times. These plans were tested as a dry run but fortunately the utilities need did not arise to activate these plans in adapting to those earlier, largely regional epidemics. In the case of current Corona virus, officially known as COVID-19, the whole world was shocked by the unprecedented scale, speed and contagious nature of the pandemic. This created extremely hard, real-world testing conditions, and challenged the utilities to execute their crisis management programs to the best of their abilities.

This short paper describes actions taken by European and other electrical utilities in response to the

COVID-19 pandemic, and highlights some of the issues that remain to be tackled by the industry after the pandemic is over. The sensitive nature of the ongoing crisis does not permit mentioning names of the utilities or their experts whose discussions have contributed to the preparation of this paper.

ACTIONS TAKEN

Below are some of the actions taken in response to the pandemic, and lessons learnt in the process, which may be useful for other utilities and can be established as part of standard operating procedures for utilities in the future.

Prioritize activities: All activities that can be postponed for later period must be deferred and avoided now. A typical example of such routine work is periodic maintenance of non-critical components of a switching substation. On the other hand, it is important to utilize the window of opportunity that may arise out of a pandemic-induced lockdown of residents and businesses to make key changes to the utility system. For example, during lockdown periods some of the large electrical loads in heavy industries, such as motors, smelters, and furnaces used for metals production and processing, and equipment in chemical processing plants, that would be difficult to switch-off under normal working/economic conditions may now be switched off while factories are not running. Preventive maintenance for such loads may be performed now. Changed priorities and postponed noncritical work must be fully documented and reviewed and addressed immediately after the return to normal (or largely normal) conditions.

Medical advisories from the Authorities: All over the globe local authorities have issued medical advisory notices that must be followed by all persons including commercial and industrial institutions. Utilities must follow these regulations. A few of these, such as social distancing, covering of the mouth and face, and washing hands at frequent intervals are required for the general public as well as for industrial workers. As a local employer, utilities must ensure that the work that has been ordered can be executed while maintaining these regulatory measures. Social distancing is easy to maintain in open air switching stations, but in underground and enclosed places it is difficult to maintain a two-meter distance. In such cases the clothing must include protective equipment such as masks, gloves, and head gear with visors. These must be periodically sanitized before reuse.

Resource management: This is one of the critical factors for the success of any crisis management program. An experienced work force is the most important and critical resource. Key workers must be allocated optimally, and their protection from the virus must be given top priority. The allocation of workers must assure that there is no single point of failure in the available expert team that would jeopardize its mission. The available expertise should be split in at least two teams that can each handle most of the foreseen incidents. Such team splitting ensures that if one of the experts or his team is out of action due to the pandemic the other team can handle the incident. The boarding and lodging of team members should be self-contained and sustainable for a longer period. Some utilities have even brought mobile-home containers to isolate and keep the operating staff separate from other workers. In most of the utilities, all of the employees who could work remotely were ordered to work from home and all visits were cancelled to main offices, control centers and other installations.

In case a key member of the working staff is infected by the virus, provisions must be made to isolate and quarantine the infected person. This also requires testing of the healthy team members and continuous monitoring to detect any new infections. The logistics of isolating and containment of key team members is not to be underestimated. This is especially true during times when personal protective equipment (PPE) has been in short supply, causing fierce competition between organizations and even countries to acquire adequate PPE stocks. In the future, utilities will make sure that obtaining and maintaining stocks of such equipment is part of their crisis management protocols.

Contributing to local efforts in fighting the Pandemic: The utilities have shown leadership and compassion in supporting the local authorities by donating money generously to funds supporting the fight against the pandemic. The reliability of power supply to health care institutions and emergency services has gained even higher priority than under normal conditions. In most cases utilities have suspended revenue collection activities and agreed on “No disconnections” policies during the crisis period. In some cases, utilities have introduced voluntary or regulator-ordered moratoriums for non-payment of energy bills.

Managing Changes in load patterns: In most cases across Europe, the load pattern faced by transmission system operators (TSOs) did not change much, but the maximum connected load fell significantly. As example is that published by POSOCO of India in their report and shown here in Figure 1.

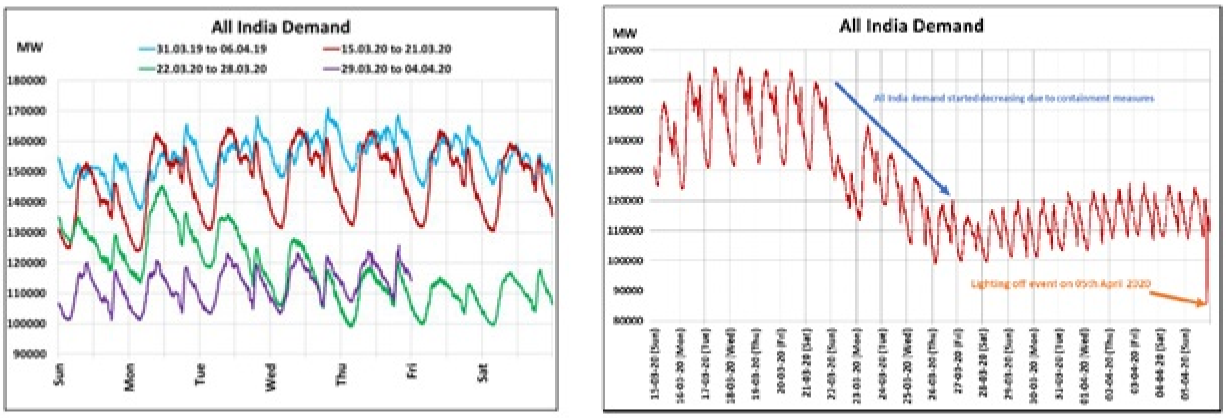

Figure 1: Demand change due to Lockdown, (ref: POSOCO (2020), Report on Pan India Lights Off Event(9 PM 9 Minutes)on 5thApril 2020, dated May 2020, and available as https://posoco.in/wp-content/uploads/2020/05/Report-on-Pan-India-Lights-Off-Event-9-PM-9-Minutes-on-5th-April-2020.pdf)

As can be seen in the graph, the maximum demand of roughly 160 TW went down to 115 TW following the national lockdown due to the pandemic, and then varied around a maximum of 125 TW in the weeks thereafter. The typical changes reported by European TSOs in maximum demand were in the range of 10 to 20 percent. The Distribution System Operators (DSO), which service predominantly residential and commercial load, had more pronounced changes in their demand patterns. The variations of weekdays and weekends did not follow the classical pattern. The demand profiles for the weekdays and weekend days appeared quite similar as a large number of individual activities were done at home. Most of the utilities had to make extra efforts to manage overvoltage during these low load periods.

Flexibility of market mechanisms to balance generation against consumption are very important. This is especially relevant when demand forecasts do not follow the expected historical trends due to lockdowns. In the bigger picture, reliance on support to and from neighboring utilities during the pandemic, transcending regional and national boundaries, has reinforced the advantage of grid interconnections.

Microgrids have also demonstrated their usefulness along with distributed generation, reducing dependence on external energy providers. Self-contained and self-sufficient microgrid areas with distributed generation may get a deployment boost in the post-pandemic future, especially for uses in critical loads centers such as health care institutions, the command and control systems of utilities, and for other types of systems that must have uninterrupted and reliable power under emergency situations. Some technical and commercial issues have appeared with respect to the operations of microgrids that need to be addressed once the situation return to a more normal state.

9.2 Points that require more attention in the future

Most of the utilities are prepared for crisis situations with a backup center, which is generally located in a separate geographical zone. This is done to provide for secure operations in the event of natural calamities such as fire, flood or earthquakes. Such a control center will also be useful when one of the main control center locations cannot be used due to local natural disturbances. Such an arrangement requires that **enough competent experts** are available who can be moved to either the main or backup location. Such a strategy, however, can fail in the case of a pandemic where a majority of critical personnel are down with illness and thus cannot be counted on to maintain critical operations. Utilities must think about staffing while planning the deployment of a backup center with a pandemic as one of the disasters that may press the backup into operation.

The globalization of technology has resulted in the fact that there are few major vendors who can deliver systems and services all over the world. With restrictions imposed on international travel and restricted use of remote access utilities, large multinational vendors may have problems in serving many sites. This has given rise to the requirement that utilities have enough of their own expertise or should be able to **organize local support** to maintain the system in case of a crisis. This requirement will affect training of the utilities' own personnel and will require the review of the availability of support options to serve in extreme cases.

Readiness for **abnormal weather conditions**: hurricanes, floods and fire occurring during periods of pandemic may stretch the available resources of any utility to the breaking point. Fortunately, such occurrences are limited to the smaller geographical area affected by the weather conditions, and support can be provided by regions that are still functioning properly. In cases where a larger area is affected, mutual support agreements with neighboring utilities should be made and activated.

Enough bandwidth and secure communication infrastructure: As more and more people started working from home during the pandemic, the sharing of bandwidth with the information and entertainment programs that home-bound residents have made much greater use of may have introduced congestion in the communication network. In the future, utilities must make sure that enough bandwidth is available for their staff to work from home. Some of the activities that require command and access to critical utility systems will need special care to defend the systems against **Increased threats from cyber criminals caused by greater use of remote access**.

The regulatory authorities for the electrical industry, normally representing government of the state or country, oversee the performance and compliance of the utilities. In a crisis the regulatory authorities should be prepared to be more accommodating and allow **relaxation of some of the market-oriented rules**. It will help in the future to define the types of extreme cases that will trigger changes in rules, and to specific which sets of rules can be relaxed in emergency conditions. This will help utilities and consumers alike, and will improve the quality of service without damaging the overall framework of regulation.

9.3 Conclusions

The pandemic Covid-19 has tested the resilience of resources and working processes in the electrical industry. We all are more than happy to see that Industry is faring well in these trying times and is ready for such crises. The pandemic has also provided a chance to see that utility operational procedures planned for crisis conditions have faced the challenges posed by the pandemic in most of cases in Europe and around the world. This experience has provided the industry with an opportunity to review their crisis management and to make improvements over the time based on the lessons learned. The COVID-19 experience will increase utility resilience by demonstrating the needs for further testing and improving existing emergency procedures, and learning how to reliably activate them in a sustainable way.

III. ENDNOTES

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[25] NREL Integrating Variable Renewable Energy: Challenges and Solutions L. Bird, M. Milligan, and D. Lew National Renewable Energy Laboratory

[26] International Energy Agency (IEA) System integration of renewables

IV. NAUTILUS INVITES YOUR RESPONSE

The Nautilus Asia Peace and Security Network invites your responses to this report. Please send responses to: nautilus@nautilus.org. Responses will be considered for redistribution to the network only if they include the author’s name, affiliation, and explicit consent.

Nautilus Institute
608 San Miguel Ave., Berkeley, CA 94707-1535 | Phone: (510) 423-0372 | Email: nautilus@nautilus.org