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# Interconnectivity: Benefits and Challenges

World Energy Council

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# Benefits and Challenges

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## Interconnectivity: Benefits and Challenges

World Energy Council

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# Foreword

One of the major factors affecting world development is energy. Final energy use has increased globally by nearly 20 percent in the last 10 years. The electric energy represents about one third of the total world energy consumption, and its production accounts for 40-50% of anthropogenic CO<sub>2</sub> emissions. Consumption of electricity grows 1.5 times faster than total energy consumption. This is supported not only by power generating plants but also by the strong Transmission & Distribution (T&D) systems which carry economic, safe and reliable supplies of electricity to industrial, commercial and residential clients. At the same time, still around 1.6 billion people in the world have no access to electricity. Various studies have highlighted the correlation between use of electricity and social development/quality of life and the role of "interconnectivity" in achieving affordable supplies by interconnecting individual plants, regions, nations and even continents. This role is becoming of paramount importance to future development of the electricity sector.

WEC decided to set up a Task Force on Interconnectivity in 2008 and after two years of intensive research and analysis, a report was produced. It includes seven chapters which cover the topics most pertinent to interconnectivity. A lot of ground work has been done by the Task Force to arrive at a comprehensive report, produced using detailed contributions of the Task Force members. These individual contributions are included in the full report and its annexes and are available in electronic format only on the WEC website at [www.worldenergy.org](http://www.worldenergy.org)

Each member of the Task Force had to cover a certain issue and all received contributions were reviewed and agreed at the Task Force meetings.

In this Executive Summary only main issues, conclusions and recommendations are included with the main purpose to bring to the readers' attention the key role of interconnectivity and the associated socio-economic, environmental, financial and regulatory aspects that must be taken into account for successful interconnection projects.

For me, it has been an honour to serve as the Study Director during these two years and work together with the Task Force comprising over 30 members from nearly 25 countries. I will cherish the memories of our stimulating meetings, the exchanges of information, points of view and even disputes – but what is most important - the amicable relations established between us going far beyond "interconnectivity". I want to thank all Task Force members for their valuable and highly professional contributions and for their friendship. Special thanks to Elena Nekhaev, WEC Director of Programmes, for her continuous guidance and assistance and her contribution to the finalisation of the report.

Alessandro Clerici, Task Force Director,  
Assistant to the President, ABB Italy

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# Executive Summary

## 1. INTRODUCTION

Access to affordable and reliable electricity supplies is a basic prerequisite for economic and social development, prosperity, health, education and all other aspects of modern society. Electricity can be generated both near and far from the consumption areas as transmission lines, grid interconnections and distribution systems can transport it to the final consumer.

In the vast majority of countries, the electricity sector used to be owned and run by the state. The wave of privatisation and market introduction in a number of countries and regions which started in the late 1980's has in many cases involved unbundling of generation from transmission and distribution (T&D). This has nearly everywhere exposed transmission "bottlenecks" limiting the development of well-functioning markets.

Transmission on average accounts for about 10-15% of total final kWh cost paid by the end-user but it is becoming a key issue for effective operation of liberalised markets and for their further development. An integrated and adequate transmission infrastructure is of utmost importance for ensuring the delivery of the most competitively priced electricity, including externalities, to customers, both near and far from the power generating facilities.

The Task Force has been covering all the main aspects of interconnections and results of their research are presented in seven main chapters:

- Chapter 1: is an introductory part explaining the background and objectives. It also sets out the main issues and discusses electricity vs primary energy (gas, coal) transport
- Chapter 2: presents an overview of the main types of interconnections, including bulk power transmission over long distances, integrated grids, integration of renewables, feeding of isolated low load areas, CO2 impacts on competitiveness of various options
- Chapter 3: discusses the present state and possible development of various T&D system components and technologies, including "smart transmission grids" and the interaction between different technologies
- Chapter 4: presents current status and trends around the world, national, sub-regional and regional interconnections, including existing, under construction and planned, trends, basic techno-economic, social and environmental drivers and issues, in the European Union, CIS, South-North Mediterranean Interconnection, Black Sea and the Caspian, Middle East & the Gulf, Australia North, Central and South America and Sub-Saharan Africa and Asia.

- Chapter 5: identifies key considerations for interconnections, such as markets, political, regulatory and legal aspects, business governance and models, barriers, economics, risks and finance, including capacity allocation and cost sharing, environmental, social, permitting and sustainability considerations, including security of supply and limits to the extension of synchronously interconnected systems and issues associated with interconnections of small countries into a large grids, human resources, technical expertise and skills, roles and responsibilities of different stakeholders
- Chapter 6: outlines key trends from the assessment of a few selected inter-connection projects
- Chapter 7: presents conclusions and recommendations

The transport of energy either as primary energy or in form of electricity has been often compared in projects where natural gas was the primary energy resource and the choice was either to produce electricity locally or transport the gas to distant power stations. When sustainable development is considered, the use of all available energy resources should be the objective, both those transportable in form of mass (gas, coal, oil) and those that require local conversion to electricity (hydro, wind, solar). All

available energy transport technologies must be evaluated considering also the environmental impact of energy transport and not only of electricity generation. This requires a solid knowledge of the possible transport solutions, regional mapping of available resources and sound methodologies for evaluation.

The general related issues include:

- 1.6 billion people in the world do not have access to electricity;
- role of environment in production and transmission of energy;
- increase of electricity penetration rate;
- increase of electricity produced by gas;
- availability of cheap hydro resources, oil associated gas and marginal gas reserves with potential use far beyond the borders of the country where the resource is located;
- availability of high potential wind and solar resources.

## 2. MAIN TYPES OF INTERCONNECTIONS

### 2.1 Interconnections in Integrated Grids

It is not always easy to identify interconnections in grids. Today, all countries have an electrical grid (mostly a transmission one) and there are a lot of cases where the national grids touch each other in some points and therefore the grids of the world are already interconnected to some extend on a continental scale.

The crucial question is for what purpose (mutual operational help, trade, generation or load), by which means (in terms of technology) and how well (in terms of capacity) the grids are interconnected and some criteria can be determined to enable categorizing different types of interconnections

- First, electrical links which are only occasionally used should not be considered interconnections.
- Second, the geographical location of grids has to be taken into account.
- Third, the function of the interconnection is within an already synchronously operated grid or between two grids which are operated independently?
- Fourth, is the interconnection a synchronous (i.e. alternating current - AC) or asynchronous (i.e. direct current – DC) one?
- Fifth, is the interconnection a part of an ultra high voltage structure overlaying the existing grids?

#### **Terrestrial interconnection of separately operated grids**

In case of two well developed grids which are not operated synchronously, interconnectors can be put into operation to enable significant mutual support and power exchange and both AC and DC links are worth considering. However, if the rated frequency, the margins of frequency regulation or the balancing means

(i.e. lack of secondary control in one of the grids) are different, DC links are the only solution, prevent propagation of disturbances from one grid to the other and can be realized without a deeper analyzes of grids' operational characteristics. En example for this type of interconnection could be the envisaged interconnection of the ENTSO-E grid with the grid of IPS/UPS (CIS – Commonwealth of Independent States encompassing Russia and the states around it)

#### **Submarine interconnection of separately operated grids**

When the two grids which are not operated synchronously are separated by a significant natural barrier like a sea with a considerable distance between the shores, they can be interconnected only by using the DC technology.

An example of interconnection of 2 large grids is the one between ENTSO-E (continental part of Europe) and NORDEL (Scandinavia) and several DC interconnectors are already realized.

The DC interconnector between the ENTSO-E grid (France) and the grid of Great Britain is an example for the submarine interconnection of a large and a relatively small grid. Other examples are e.g. the connection of Balearic Islands to the Iberian Peninsula and of Sardinia to the Italian Peninsula.

The DC interconnector between Great Britain and Northern Ireland is an example of linking two grids of relatively small size.

### Firm and weak AC extensions of a grid

If a relatively small well developed grid needs to be interconnected with a large neighbouring well developed grid, in most cases a synchronous (AC) solution will be implemented and the operational standards of the smaller grid will have to be upgraded in order to fully comply with the standards of the integrated grid. An example is the synchronous interconnection of the ENTSO-E grid with Turkey under implementation..

If the small well developed grid doesn't need to be fully integrated into the neighbouring well developed grid, the synchronous solution for the interconnection still may be used, but it will be a weak one and the small grid won't overtake the operational standards of the grid. Disturbances originating in the small grid won't have a significant impact on the grid and the single interconnector will be disconnected by the protection system. An example is the link between the ENTSO-E grid and the grid of Maghreb countries (Morocco, Algeria and Tunisia). In order to ensure a safe operation of this extension an "Interface Cooperation Agreement between the Interconnected Networks of Morocco, Algeria, Tunisia and Spain related to Conditions for the Networks Synchronous Operation" was signed

### AC interconnection within a synchronous grid

Every new transmission line between any two

countries and an internal new transmission line within any country is a kind of interconnector to increase the interconnectivity of the existing grids. Two categories of AC interconnectors can be differentiated: overhead and underground lines(or lines which are only partially built with underground cables). Some recent examples for this last case are in Italy and Austria.

### DC interconnection within an integrated synchronous grid

Two countries may be geographically close to one another and operated within the same synchronous grid, yet still only weakly or not interconnected.

An example for a relatively weak interconnection is the one between France and Spain where an additional interconnector is envisaged as an underground DC line for environmental reasons.

The planned DC submarine interconnections between Italy and Croatia and Montenegro are examples for reinforcing a synchronously operated ENTSO-E grid.

### Interconnection to isolated large production units

To connect that kind of production, AC and DC interconnectors may be envisaged. AC lines are mainly eligible if a terrestrial solution is feasible and there are examples for this in Brazil and China. Large off-shore wind farms, such as envisaged in the North Sea, which will have to be connected to their neighbouring grids (and possibly to one another) by the means of DC submarine interconnectors, are other examples.

### **Overlaying interconnection**

If the amount of power to be exchanged and the distances to be covered are of such an extent that existing transmission lines cannot solve the problem, an overlaying higher voltage level grid can be considered and it may consist of AC and/or DC lines and a clear example is China with both AC 1000kV and +/-800 kV DC

Examples in the past have been the 400 kV or 500kV AC grids superimposed to the 245 kV system in Europe and US respectively and the 700-765 AC grid in Russia and other CIS countries and in US

There are visionary projects to realize a Super Grid in Europe encompassing the territory of ENTSO-E and NORDEL countries as well as Great Britain and Ireland, and connecting them with off-shore wind farms all around Europe, and with North Africa where Concentrated Solar Power plants could be installed in the future. Such a Super Grid could be even extended to Near East, Middle East and Caucasus regions.

### **2.2 Bulk Power Transmission**

With "bulk transmission" it is intended the transport of "large amount of power" over long distances and 2 main types are considered:

- OHTLs/systems

- sea crossings and cable systems

The values of "large power" and "large distance" have got a substantial increase, following development of the electrical components.In this chapter the power transfer

of around 1000 MW and above is termed bulk electricity transmission.

Overhead lines longer than about 500 km require shunt compensation and series compensation to a degree that depends on network characteristics(see section 3).

HVDC represents today an attractive alternative. For capacity exceeding 1000 MW; bi-pole systems typically at ±500 kV level are today a standard solution (e.g. Three Gorges in China), but ±800 kV level is under commissioning in China.

### **Bulk energy transmission with over-head transmission lines (OHTL's)**

The cost of the bulk transmission system can be split mainly into:

- overhead line cost

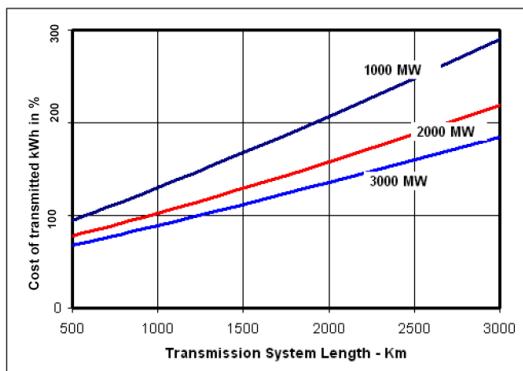
- terminal cost (converter stations for HVDC, substations and compensation substations for HVAC)

- capitalized cost of losses

The choice between HVAC or HVDC depends mainly on the capacity and transmission distance. Generally HVDC is considered less expensive when applied to capacity over 1000 MW and distances over around 800 km. This is due to the higher cost of the terminal substations and lower cost of the line that apply to HVDC

The cost of a transmission system clearly depends on local costs and on environmental

and logistic conditions; differences of around 1 to 2 for the same type of system can be found in different regions .A case by case study is therefore indispensable to get precise data .In addition, in the present turbulent situation for raw materials costs, it is difficult to define even ranges which could be considered valid for few years



**Fig.1** provides the cost of the transferred energy by changing the amount of power and the OHTL length,. reports a typical case study for a medium value of cost of losses.

For 1000 MW , the cost of transmission over 1000 km could be in the range 10-20% of the total energy cost at the load side. The same 10-20% applies to 3000 MW transferred over 2000 km

With reference to land transmission ,in the past various projects have been implemented such as the James Bay in Canada, the Itaipù and the Norte - Sul interconnection in Brazil, the Guri in Venezuela, Inga – Shaba in Congo ( HVDC Line with its 1750 km), Cahora Bassa-Apollo in

Mozambique/South Africa and Three Gorges and other projects in China and India.

The increasing penalisation of electricity production from fossil fuel plants can foster the use of remote hydro and other RES with respect to coal/gas power plants close to the load areas. With CO<sub>2</sub> penalties above 25 €/tonne, transmission of energy from hydro plants even from distances of more than 2500 km is less expensive compared to production locally using gas or coal plants and even with low prices for gas and coal (corresponding to the oil price around 45US\$/barrel)

Another example of using available resources is given by Angola in sub-Saharan Africa. Existing proven gas reserves (~43 Gm<sup>3</sup>) is mostly associated gas (gas produced as a by-product of oil production that is almost 85 % flared. The commercial exploitation of this gas would yield many benefits of both economic and environmental nature and schemes have been studied to produce electricity with TG plants up to about 2000 MW and to transport this very cheap electricity to distances over 2000 km.

For the use of the huge hydro resources of the Congo river a first expansion of the Inga power station was planned for around 4000 MW with transmission of the generated electricity with HVDC lines down to South Africa through Angola, Namibia and Botswana with a total length over 3000 km ;the Grand Inga Project with the possible transmission of cheap 30,000÷60,000 MW from INGA up to Egypt (5000÷6000 km) or even Europe has been proposed many times in the last 25 years.

A third example is the system under commissioning in China to convey more than 6000 MW per circuit with HVDC at +/- 800kV from areas having cheap hydro generation costs. Always in China possible 3500 km of +/- 1000 kV UHVDC systems to convey power of around 15000 MW from wind remote farms are under study.

#### **Bulk power transmission involving sea crossings and cables**

The present limits for bulk power transmission are posed by voltage and power limits of cables(see chapter 3).For power ratings above around 1000 MW it is not possible to avail important scale effects as in the case of OHTL's .because it is necessary to duplicate or triplicate the parallel cable circuits.  
For land or sea distances of more than 60-100 km it is mandatory the use of DC. In land areas characterised by serious concerns for the environment the adoption of DC interconnections via cables has been already agreed in some cases (e.g. Spain France interconnection and merchant lines in Italy connecting Italy to France and Switzerland with cable lengths exceeding 160 km) .With the development of VSC's and the XLPE cheap cables/joints it is envisaged an extension of these applications

The NorNed (Norway-Netherlands) scheme at +/- 450 kV carrying around 700 MW is at present the longest cable connection (580 km world record).

It is under final commissioning the SAPEI (Sardinia-Italian peninsula) for 1000 MW at +/-

500 kV and 435 km long and sea depth is up to around 1600 m(world record).

Bulk cable transmission /interconnections exceeding 1000 MW and 500 km are therefore becoming a reality and 2000 MW DC crossings are under study in the Adriatic Sea. The possible development of large wind farms in the Baltic Sea or of solar plants in Africa (eg DESERTEC project) will imply substantial increase in bulk undersea transmission.

With reference to range of costs, are still valid the considerations of the previous paragraph (case by case analysis).Just for reference, from published data the OVN cost of the 1000 MW-435 km Sardinia Italy connection is some 700 million Euros.

#### **2.3 Feeding of isolated load areas with no local energy resources**

##### **Electricity supply of isolated areas having initial loads of 5-15 MW100-400 MW from isolated plants**

In many developing regions, per capita consumption of electricity and per cent of population having access to electricity are extremely low. The possible main electrical load centres in these regions may be scattered over many areas and the initial load is in the range of few MW with different growth rates.

In these situations, local diesel generation for each load centre is normally implemented fed by fuel oil transported over long distances.

Installation of a single generation plant feeding different load centres can, on the contrary, be cost competitive due to the economy of scale on investment cost and O&M costs and due to the higher efficiency of larger units. Beside the economy of scale one has to carefully consider the levelling of the load diagram and reduction of the peak load, resulting from load diversity when the different demand areas are connected to the single source.

Renewables, solar & wind could be considered for isolated areas as alternatives to local diesel generation, although some storage or back-up facilities would be necessary.

With respect to concentrated generation the comparison still holds if one considers, as power source, an interconnected system, far from loads.

With initial small loads of 5-10 MW an energy transmission from 250-450 km is more convenient than local diesel generation; this even with the minimum oil price considered and equal to 35 \$/bl. Clearly higher values of oil price and of load growth rates increase the advantage of transmission versus local generation.

The 230 kV voltage level becomes competitive versus the 138 kV one, for larger initial loads (above around 10 MW) and larger distances.

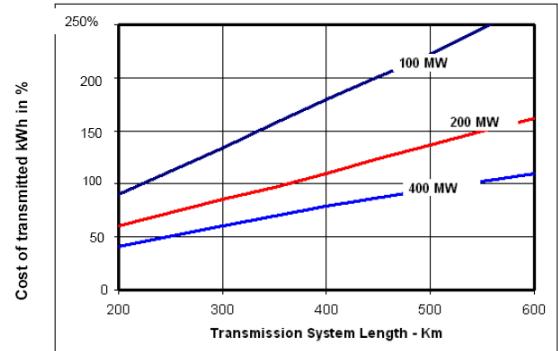
An example of possible utilization of cheap power that could be economically transferred to hundreds of km for some tens of MW is the Saida-Naama-Bechar 230 kV system in Algeria. A single overhead transmission line with appropriate RPC systems is feeding villages in

the desert 500 km far from main grid..

### **Electricity supply of 100-400 MW from isolated plants**

The same concept is valid also for consumption areas having demand requirements of some hundreds of MW.

Fig. 2



With diagrams plotted on the basis of local cost conditions (Fig 2) it is easily defined the local cost of imported energy for possible different values of generation cost from plants far from consumption areas. In particular, Fig.2 shows the transmission cost of kWh for power level from 100 to 400 MW and for distances from 200 to 600 km.

Clearly the interest is to use remote cheap energy; this may be the case for utilization of flared gas or of fields exhibiting marginal gas reserves.

Transport of gas requires very large flow to be economic when the demand of power is in the

range of 100 MW to 400 MW .This dynamic of the gas transport cost could cause to disregard gas fields exhibiting marginal reserves. An example of such a development is the Aguaytia Project in the Jungle of Peru and the field has recoverable reserves estimated at 12 Gm<sup>3</sup> of gas .The generating capacity of the plant is 160 MW and an electric power line rated 220 kV and 400km long connects the power plant to the main loads.

The same concept is valid also for consumption areas having demand requirements of some hundreds of MW.

The new VSC HVDC Technology transmission could be an interesting option for the investigated cases and should be considered to complete the picture. .

#### **2.4 Supply to islands**

When the island required load is of small/medium size, the use of gas/oil pipelines becomes uneconomical and the common choice for electricity supply is the use of local generation fed by imported fuel. The electricity transport from a hub area as an alternative to local generation is however of interest in very many cases and the transport could fulfil an increase in power demand at the island or a combination of this with substitution of old plants

Power transfer in the range 200 MW to 500 MW has been taken into account and two technical alternatives have been analysed for local generation which considers unit size in the range 100 to 250 MW

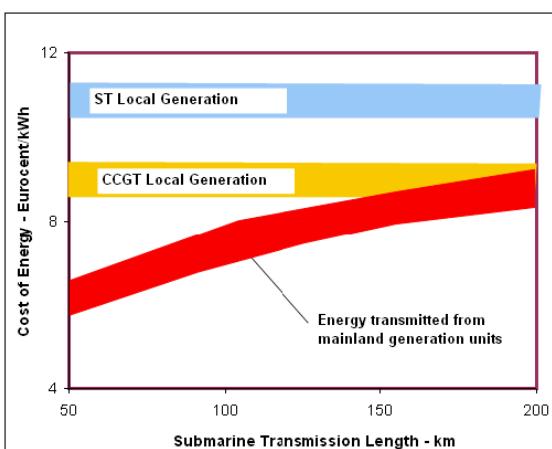
- Gas turbine combined-cycle plant (CCGT), gasoil fuelled
- Steam Turbine Plant (ST) oil fuelled.

As to the “hub” generation, it is assumed a system with large use of combined cycle units of 400MW.

For the submarine transmission, depending on the concerned distance, the most suitable technology between Alternating Current (AC) and Direct Current (DC) has been considered for each distance. Figure 3 shows how the electricity delivery via submarine transmission results economically competitive over all the distance range considered even with the low values for local oil and gasoil; higher values would increase the competitiveness.

Interconnections would reduce the CO<sub>2</sub> emissions, increasing its economic advantage as a function of cost of CO<sub>2</sub>.

Practical examples are the proposals made to supply the island of Cyprus in the Mediterranean sea with electricity from Turkey (hydro and high efficiency combined cycle plants) or Malta from Italy.

**Fig. 3**

## 2.5 Integration Of Concentrated Bulk RES Generation

The use of new renewable energy sources for electricity generation is growing rapidly and worldwide. The claims on the existing transmission and distribution systems, to be able to connect and transfer the new generation plants are enormous. To a large extent, this expansion consists of wind power, but preliminary studies also show that CSP (Concentrated Solar Power) and wave power could be significant energy sources in the future.

Electricity generation plants using wind or solar as a primary energy source will grow in size to become economically attractive. For wind power, this has been demonstrated by growing wind turbines, which are set up in groups to aggregate wind farms. Land areas that are available usually for RES generation are far from the areas where energy is consumed and

large power flows are generated from sparsely populated areas to load centers. For wind power, currently the most exploitable new renewable energy source in many nations, large offshore wind farms are foreseen, when the cheaper land-based wind power sites already are exploited as far as possible.

While investments in renewable power increase, licensing issues for transmission may in many cases determine the expansion rate possible for the renewable energy and streamlining the permit process for power grid is consequently a key issue f.

The growing amounts of wind power in the different countries are demanding new technical solutions for concentrated intermittent transmission of electricity between the existing national transmission systems which have to interact in order to equalize local variations in wind generation over large areas to allow overall optimization of the reserves in the interconnected electricity systems.

The internationally broad plans for offshore wind development in large concentrated wind farms demand the development of new offshore network technologies such as controllable meshed offshore cable networks that connects to a number of existing national transmission systems. On the other hand, the integration of onshore or offshore wind plants in the electrical systems have a direct implication on the needs of stronger interconnection capacity as well as other smart measures (storage, demand side management, electrical vehicles) providing a smoothing effect on the wind resource with respect to demand.

### Main types of interconnections linked with renewables

The expansion plans for renewables are demanding new techniques which can meet the need for controlling the intermittent power flows that this type of power resource locally creates. As a consequence discussions of integration of renewables often ends up in the possibility of developing solutions using power electronics (HVDC and FACTS) that seems to be able to solve many of the technical challenges. Some examples with characteristics are:

- Conventional LCC (Line Commuted Converter) HVDC links is being a well known solution with above 1000 MW capacity in cross-border applications
- VSC (Voltage Source Converter) HVDC links, where possible capacity is now at about 1000 MW of transmission appears to be realizable at the moment. The favourable characteristics of active and reactive power controlling capability in the VSC-converter in parallel with the fact that it demands no outer voltage source for its function makes this solution important in the large scale integration of renewables. Multi-terminal interconnections using the VSC technology are today possible to use in meshed offshore wind networks interconnecting several national transmission systems. These so-called "super grids" interconnecting asynchronous international subsystems over long distances, are also seen as a future opportunity to achieve intercontinentally linked generation systems containing a substantial proportion of renewable energy sources.

- FACTS (Flexible AC Transmission Systems). In order to comply with grid codes when large integration of renewable production in networks with varying strength / short-circuit power controllable reactive compensators are used. SVC (Static Var Compensator) and STATCOM (Static Synchronous Compensator) are both examples of that kind of equipment. At the same time, following the demands from the grid codes the similar functionality is developed in the wind power turbines.

### International cooperation: the key to successful integration

In order to succeed in integrating the large amounts of renewable power in the existing transmission system, it is essential to have an international focus. Harmonization of trade rules for short-and long-term exchanges of electricity between geographical regions is a key factor.

Regarding planning of new transmission systems, it is crucial for a successful integration of renewable energy that long-term plans and so called grid codes are made with a sufficient focus on the cross border flows of electricity that is needed for total power system optimization.

Authorities in different countries and regions have an important task of achieving effective regulatory framework for sufficiently rapid licensing of new transmission facilities.

Regarding the interconnectivity the different stakeholders in the Baltic area are considering the special opportunities given by mixing the

hydro dominated northern power systems with the thermal based systems in central Europe and in the UK. Exchanging thermal power sources with renewables drives the need for enhanced trade between the two systems concerning for example regulating services like reserve-pooling and short term balancing as well as exchanging power day-night.

The systems on either side of interconnections benefit from the increased interconnectivity as the security of supply can be kept on a high level with less total production capacity installed. In the light of the mentioned considerations a lot of new interconnections are discussed beside the ongoing discussions about future offshore grids that aims to interconnect many states via multiple HVDC systems. Awaiting planning results for meshed offshore grids options many different two-state transmission projects are discussed or decided on in the Baltic area.

An ambitious plan for an electricity "super-grid" in the North Sea has been developed by a group of 10 leading European companies. Such a super-grid connecting the UK, Germany and Norway is expected to cost €34bn (£30.5bn).

Ideas for a European super-grid have attracted growing political interest. Last December, nine European Union member states, including France, Germany, Denmark and the UK agreed that by the end of this year they would have a plan for building such a North Sea grid. However, the agreement noted that the cost of such a project would be "enormous".

Ireland's Mainstream Renewable Power, a wind company that is also a member of Friends of the Super-grid, has proposed a "phase one" project connecting England, Scotland, Germany and Norway, which it estimates could be built for €34bn.

Another international initiative supported by a number of companies is Desertec. In a few decades it would provide Europeans with electricity generated from the Sahara – at a cost of €400bn (\$557bn).

By joining together hundreds of solar thermal power plants and wind farms with high-voltage direct current (HVDC) transmission cables under the Mediterranean sea, the founders of the Desertec hope one day to supply 15 per cent of Europe's electricity needs.

Concentrated solar power plants use the sun's heat to generate electricity. Unlike photovoltaic solar cells, CSP plants are able to generate electricity at night or on cloudy days, by storing the heat they produce. The Desertec project would require the creation of a €45bn electricity super-grid covering Europe, the Middle East and North Africa.

The experiences have shown the important role played by the interconnections on the social-economic development for the countries. That means that electric utilities are more and more interconnected. An example is given by the European continental grid of the Union for the Transmission of Electricity (ENTSO-E), where 23 countries are interconnected and share interchanges. Too, this system is also linked

with NORDEL system and the UK, by dc lines, forming the bases of the IEM.

As a consequence, a logic question arises: is there any limit for the interconnection of transmission systems ? In principle, there are no technical limits for the extensions; however the long distance transmission of large amount of energy requires specific measures, investments and O&M costs. Then the equation which relates investment cost and savings presents a certain "breaking point". Overall, the coordinated operation and organisational issues could be a limiting factor.

### 3. THE ROLE OF TECHNOLOGIES FOR INTERCONNECTIONS

Interconnections fulfil a large variety of different operations, such as bulk transmission over long distances, enhancement of transport capacity within strongly meshed networks, feeding of small loads in remote areas, connecting "smart transmission grids", just to name a few. Therefore, all the present and future technologies (not only hardware!) should be evaluated when designing new interconnections.

The key components/subsystems include:

- OHTL's (overhead transmission lines)
- Underground and undersea cables
- AC substations
- Conversion from AC to DC lines
- AC / DC converter stations including Back-to-Back (BtB) stations
- Transmission components based on power electronics, commonly known as FACTS (Flexible AC Transmission Systems) devices
- Energy Storage

- "Smart transmission grids", protection, control and ICT.

#### OHTL's (overhead transmission lines)

The route between one point and another in an electrical network is referred to as a transmission line. A transmission line may comprise one or more circuits. The electrical capacity of the circuit is determined by the conductor size, the voltage level, the minimum clearance to ground and weather conditions. At present, the technologies of OHTL's have been developed up to 1100 kV for AC and  $\pm 800$  kV for DC.

Main obstacles to building new OHTL's are related to environmental impact including opposition to new Right of Way (ROW), electromagnetic fields (emf) and insulation in contaminated areas. Concerning new developments in OHTL's technology, an increase of voltage levels up to 1200 kV AC (India) and  $\pm 1000$  kV DC (China) is under development.

Because of the strong opposition to new lines, efforts are being made to increase the transport capability of existing lines to deal with the environmental opposition, especially in Europe. This situation makes it impossible to introduce UHV systems and creates the need to develop new types of "supergrids", mainly using cables.

Other non-conventional measures are being adopted to increase the transmission capacity without building new lines such as new types of conductors, increasing when possible the

voltage level or transforming an AC line into a more powerful DC one.

#### **Underground and undersea cables**

Underground cables in transmission networks have generally been used in areas where it is not possible to use overhead lines. This is often because of space constraints (e.g. in densely populated urban areas or within substations) or for technical reasons (e.g. for wide river and sea crossings). The benefits of overhead lines are mainly the costs and this driver becomes stronger as the voltage level increases.

The application of underground and undersea AC cables is limited, depending on voltage levels for distances about 50-150km. The DC is the only solution, and present technologies for voltages of +/-500kV for sea depth up to about 2000m and power capacity above 1000MW.

For integration of bulk RES generation (e.g. the Desertec project) higher voltage levels and power rating per cable and sea depth will be required. The development of XLPE cables is promising especially if combined with VSC's HVDC.

#### **AC substations**

The transmission network has two main elements:

- (a) Circuits (lines, cables, etc.) that enable power transmission.
- (b) Substations that enable the interconnection of these circuits and the transformation between networks of different voltages.

and performs three different functions:

- (a) The transmission of electric power from generating stations (or other networks) to load centres.
- (b) The interconnection function, which improves security of supply and allows a reduction in generation costs
- (c) The supply function which consists of supplying the electric power to sub-transmission or distribution transformers and in some cases to customers directly connected to the transmission network.

These three functions are fulfilled through different types of substations listed below:

- (a) Substations attached to power stations.
- (b) Interconnection substations.
- (c) Step-down (EHV/HV, EHV/MV, HV/MV) substations.

A single substation may perform more than one of these functions.

Substations generally comprise the following main equipment:

- (a) Switchgear.
- (b) Power transformers/reactors.
- (c) Control (local and remote), protection and monitoring /automation equipment.

Apart from limit in transport for large transformers, the present major components are in operation up to 1000 kV AC and +/- 800 kV DC and do not pose special limits to the development of interconnections.

### **Conversion from AC to DC lines**

At first glance there is no fundamental physical difference between an AC and a DC overhead line, apart the number of phases per circuit(3 for AC and 2 or 1 for DC) The most significant difference between AC and DC links is the need for converter stations at both ends. When considering the conversion of an AC circuit to a DC link, it is important to include the cost of converters, which can be expensive and, thus, can lower the profitability of such conversion.

Due to the fact that a DC system can transfer significantly more power with the same conductors, converting an existing AC into a DC overhead line may be beneficial, even accounting for the additional cost of converters. In some favourable cases an increase of power up to 4 times has been demonstrated.

### **AC / DC converter stations and Back-to-Back (BtB) stations**

Two basic converter technologies are used in modern HVDC transmission systems. These are conventional line-commutated current source converters (LCCs) and self-commutated voltage source converters (VSCs).

The invention of mercury arc rectifiers in the nineteen-thirties led to the design of line-commutated current source converters. In the late nineteen-seventies the development of thyristors further improved the reliability and

maintenance requirements of the converter stations. The first large utility application of thyristor converter valves were outdoor oil-insulated and oil-cooled valves, followed by indoor air-insulated and air-cooled valves. Finally the air insulated, water-cooled valve was developed, installed in containers or buildings. The air-insulated water-cooled converter valve design is still the state of the art.

Some cable systems and more recently even OHTL systems with VSC' stations have been commissioned or are being deployed and can go up to 1000MW levels. This technology allows the adoption of cheaper XPLE cables and the supply of energy to the area with a low short circuit level or even with no local generation.

### **Transmission components based on power electronics (FACTS: Flexible Alternate Current Transmission System)**

Overhead lines and cables have four parameters: the conductor series resistance, the series inductance, the shunt conductance and the shunt capacitance. These parameters influence the performance of the lines in terms of transport capacity. The influence of the parameters is also different depending on the transmission solution: AC or DC. The series resistance and the shunt conductance cause losses and heating at both AC and DC, whereas the series inductance consumes reactive power at AC only, not at DC, and the shunt capacitance provides reactive power at AC only, not at DC.

FACTS devices help in increasing transport capacity over mid-long distances by acting in a

dynamic way on one or more parameters of the transmission corridors.

### **Energy Storage**

Electrical energy storage can be used for a wide range of applications on small and large networks, supporting existing and planned generation, transmission and distribution assets. Many existing power systems already use limited amounts of energy storage in their networks, mainly in the form of pumped hydroelectricity storage.

Pumped hydro is the most prevalent form of energy storage on power systems, but pressure to increase the proportion of renewable generation in power generation is leading to an opening of the market for other forms of electricity storage to be used. Coinciding with this interest is a technology push coming from many manufacturers and technology developers. Electrical energy storage systems can be classified by a number of parameters such as power rating, discharge period and technology type.

In interconnected systems the energy storage facilities, located in one area, will play a substantial role in balancing non-dispatchable and intermittent power, mostly from RES, located in another area where the conventional generation does not offer sufficient flexibility. A practical example of interconnection already (partially) exploited for providing firm capacity facing fluctuating RES production, namely wind, is presented by the NordNed HVDC submarine cable (700 MW, 580 km) linking the Netherlands to Norway. The Netherlands is witnessing an important development of wind generation, but its conventional power plants

are fossil fuelled and show a moderate flexibility; on the contrary, the Norwegian system is almost totally hydro based and, as such, can effectively balance the fluctuating generation in the Netherlands.

However as the proportion of renewable generation increases, the requirement for reserve power as a proportion of the conventional generation increases.

This is unlikely to become a serious problem until variable renewable (such as wind) generation exceeds about 20% of the total generating capacity. This is rare today, but may become more significant in the future. Low-cost energy storage may be a suitable technical solution for the challenge of providing sufficient reserve power to meet network requirements when there is a high proportion of wind power on the system.

### **"Smart transmission grids", protection, control and ICT**

To improve reliability, quality of supply and asset utilisation of transmission systems, it is essential to arrive at a transmission system operation based on real time data, "connected" clearly to generation and distribution operation data and where monitoring, protection, control and imbedded and transversal ICT are key integrated technologies.

Many things can be called "smart", but discussions of "smart grids" are often limited to distribution systems. The development of new bulk RES generation, on the other hand, and the difficulties encountered by the need for new corridors for transmission lines are pushing for quick application of "smart" technologies to

transmission systems i.e. the introduction of "smart grid" concepts. The data in real time would not be only electrical but also associated with weather conditions (temperature and sags of line conductors, possible transformer overloads due to actual temperature, etc.) and data relevant to diagnostics. ICT will clearly contribute to the successful introduction of modern systems but it cannot replace the need for development of key power system infrastructure,

#### 4. KEY ISSUES FOR INTERCONNECTIONS

All regional markets have passed through an initial phase where the participating countries were interconnected gradually. For instance, the regional market in Central America developed step-wise from the connections of El Salvador-Guatemala, Panama-Costa Rica, Costa Rica-Nicaragua, etc. Finally, in 2004 the interconnection between Honduras and El Salvador allowed the integration of all Central American countries in a common electricity market.

In the current climate, interconnections between different countries are strongly recommended as they can help achieve global energy goals. The development of interconnection capacity between two separate countries (or areas) allows greater flexibility in the generation mix. In particular, the availability of cross-border transmission capacity may help select power from cheaper units located in another area or country.

##### **Market integration issues**

Greater integration between different transmission systems increases the overall

benefits, but it also requires a greater degree of harmonisation. The development of cross-border energy trading may increase dependence on the import of resources. This may have an impact on security of supply, unless a robust and credible common policy and strategy exist. Several countries have been reluctant to depend on supply located outside their borders. Moreover, there are some examples of countries that did not honour their contractual obligations jeopardising the security of supply of the buying entity.

This is a critical issue that affects the development of numerous large-scale projects. A good example of the opposite policy approach is Thailand, which is considering long-term contracts with IPPs located in Laos. For instance, the hydro project of Nam Theum 2 in Laos, with the installed capacity of 1,088 MW, is close to commissioning. Ninety percent of the produced energy will be exported to Thailand through a long term PPA. The peak demand of Laos was 415 MW in 2007, so it was impossible to develop the project only for the internal market.

In a liberalised environment, decisions on transmission network expansion/reinforcement, as well as on investment in generation, are made by different entities and may have a different impact on each type of market participants – consumers, suppliers and electricity producers.

A number of regulators have attempted to define an incentive mechanism that would promote efficient planning by the TSO. An example of such a mechanism can be found in

the scheme introduced by the Italian Regulator for the period 2008-2011, which differentiates the ROI for the TSO, based on a recognised additional WACC for particularly strategic investments on the grid.

An alternative model for transmission expansion is based on merchant initiatives. In this case, individual investors propose specific developments that are then subject to approval by the competent authorities. The merchant investment in infrastructure is not remunerated through the tariff system, but through the benefits from the commercial use of the infrastructure. In practice, very few cross-border transmission lines have been so far developed on a completely merchant basis around the world.

There are two main organisations which can serve as criteria sources: the European TSOs Transmission Systems Operators) association (ENTSO-E) and the North America Electric Reliability Council (NERC) in USA. Both have defined the criteria and methods to calculate the transfer capability of a link between two countries (or two control areas).

In EU, ENTSO-E defines the Net Transfer Capacity (NTC), which is the maximum exchange schedule between two areas compatible with security standards applicable in both areas and takes into account the technical uncertainties on future network conditions. NTC is allocated to market participants through explicit and/or implicit auctions.

Presently most of the international markets are based on a close cooperation among the

entities responsible for system operation at national level (Central Dispatch Centre, ISO or TSO). For instance, the design of the EU internal market is based on a close coordination between the national TSOs that have agreed on all the relevant issues for cross-border trading. In countries without electricity markets, the national dispatch centres typically fulfil this coordination role.

In developing economies several cross-border transmission projects were developed in the last few years. Where the projects have political support, other barriers have been overcome. In these cases the environmental opposition is less intense (perhaps because of the need for cheap electricity) and the local organisations are prone to accept economical compensation.

### **Security of Supply and Climate Change**

Security of supply has an underlying economic value, which could be estimated by the willingness of consumers to pay for it.

Policies to mitigate climate change are introducing additional requirements to the process of planning and developing internal and cross-border interconnections. Prices in electricity markets with high concentration of generation ownership do not necessarily reflect variable costs, since dominant generators can exercise market power and raise prices above the socially optimal levels. They may also enjoy government subsidies for RES.

In liberalized electricity markets it may be socially beneficial to invest more in cross border expansion than it would appear in a centrally planned system, given the effect of interconnections to reduce market

concentration, and therefore pushing prices to competitive levels. In this case the additional cross border capacity may induce generators to bid their actual variable costs and therefore create a more competitive market. The larger the cross border capacity, the less likely it is that generators can exercise market power, of course only in case of fair and non discriminatory interconnection capacity allocation rules, which promote increased participation to the market and avoid the consolidation of existing incumbents' market power.

**Measuring Economics of Security of Supply**  
 Changes in the regulation of the electric power industry worldwide have resulted in the modification of traditional approaches to security of supply. In the vertically integrated utility, Security of Supply used to be achieved by centralised utility planning and operation, at all levels: generation, transmission and distribution.

The concept "security of supply" (SoS) (also called quality of service or supply reliability), encompasses two main attributes of the power system:

**Operational security** which refers to the ability of the system to withstand sudden disturbances.

**Adequacy** which represents the ability of the system to meet the aggregate power and energy requirements of all consumers at all times.

Adequacy has at least two dimensions:  
 Generation adequacy: enough generation

capacity to meet the aggregate demand taking into consideration the reliability of generation units and transmission facilities, as well as the availability of plants that use intermittent primary resources such as water, solar or wind.

A common measure of adequacy is the Loss of Load Probability (LOLP) or the expected number of years between events when the load cannot be met. For instance, Regional Transmission Organizations (RTOs) in the United States plan system reserves to achieve an adequacy level of one day of failure in every 10 years. Furthermore, it is impossible to design a system that never fails to meet the load. So any measure of SoS should consider probabilities.

### Climate Change and the Economics of Transmission

The focus on climate change has increased significantly worldwide. It has impacted on the economics of the transmission, basically for the need to connect increasing volumes of renewable energy. This issue has a strong impact in developed countries that have assumed commitments to reduce green house gases emissions.

Before the policies aimed at the mitigation of climate change were introduced, a significant part of the generation expansion in developed economies was based on thermal generation located relatively near the demand, which imposed less stress on the transmission system. But presently, with policies oriented towards a dramatic penetration of renewable generation, new challenges have arisen:

Most of the generation based on renewable resources (wind, hydro, solar and so on) should be located at the site where the resource is available. Because these sites are often located far from load centres, the need to expand the transmission network to connect the renewable generation to the grid is growing significantly.

The issues of distance, intermittency and availability are intrinsically stochastic, and complicate identification of the corridors that allow optimizing the expansion of renewable energy sources. A simple and deterministic approach cannot properly identify the benefits of a corridor in relation to renewable energy sources penetration.

### Congestion

Congestion is an appropriate measure of excess or deficit of renewable generation. When a region has a temporary excess of renewable generation prices go down, export becomes convenient but it may be limited by the available transmission capacity. When renewable generation is low or zero, prices increases and import becomes convenient, which can in turn be limited by transmission capacity.

Transmission planning in electricity markets has only certainty in short term generation expansion, but transmission facilities have a long life cycle. So the efficiency and effectiveness of transmission investments can only be assessed with certainty during a short part of its life cycle.

### Investment cost uncertainties

TransCos-TSOs profits arise from a regulated rate of return on the facilities that they

developed. When this regulated rate is estimated by the regulator, differences with the social discount rate may arise. In those cases, TSOs objectives (and therefore selected projects when they are in charge of transmission planning) may differ from the general welfare targets. Therefore, a sound regulatory approach is needed to guarantee an efficient calculation of such regulated rate of return by the regulator.

### Cross Border Facilities Financing

In developed economies, up to now, financing the new transmission lines often have been not really a problem due the existence of regulatory frameworks according to which financing from the tariffs (or the congestion rents) is allowed.

In case of developing economies, the financing of cross border interconnections has been achieved, or is envisaged through a wide set of different mechanisms: This is the case of the Great Mekong sub-region (sponsor Asian Development Bank) or the Nile initiative (European Bank) and again International Financial Institutions (such as EBRD, the World Bank, etc.) or the European Commission funding programmes or Donors organisations in the Balkan region.

A complementary approach relates to merchant investments, as a complement to centrally planned investments regarding interconnection capacity. This scheme is allowed under several legislations (EU, USA, Central America, etc). It implies that the investment is not made under a regulated tariff regime but under market conditions for financing and cost recovery. In all the cases merchant investments are complementary to planned ones. No regional

market in the world relies exclusively on merchant expansions.

The incentives for private parties to invest in an interconnection may clearly deviate from common public interests, which may lead to lock-in effects and long-term inefficiencies. Nevertheless, in the developing economy areas, the merchant line model could help generators to develop power plant projects that would be otherwise abandoned due to lack of regulated transmission development.

#### **Possible new PPP models for merchant investments involving local stakeholders**

A possible scheme for new interconnection implementation, particularly fit for Developing Countries (DCs), could be the Public-Private-Partnership (PPP) schemes involving local stakeholders from the transmission sector and International Financing Institutions (IFIs). This could be considered as an umbrella to develop new transmission infrastructures through gradual injection of private capital.

The proposed Public-Private-Partnership (PPP) schemes could consist of the establishment of a Consortium or Special Purpose Vehicle (SPV), composed for example by one Private Investor (PI), one or two national TSOs and, if needed, an International Financial Institution (IFI). The SPV mission would be to build and manage the new interconnection line for a set period of time.

In most cases, if in compliance with the Regulatory framework, PPP models could represent a tool for speeding up investments (in Europe the involvement of a private entity in grid development process is already allowed in

EU Reg. 714/2009 through the so-called “merchant investments”).

In some cases, transmission companies can be penalised when the performance of the facilities that they operate are below some standards. For instance in most of Latin America regulations Transcos have to pay a fine when the transmission facilities they operate are unavailable. Therefore Transcos face an operative risk that it is difficult to hedge.

#### **5. ENVIRONMENTAL ISSUES**

Modest quantities of emissions may be produced during power line construction, but the main influence of grid interconnections on air pollutant emissions will be through the impact of transmission interconnections on which power plants are run where and when in the interconnected nations. Major air pollutant emission benefits therefore accrue overall (counting all the countries in the interconnection project) if the emissions from the generation that is used with the interconnection in place is less than the emissions that would have been produced in the absence of the interconnection.

Where hydroelectric generation, for example, provides export power through an interconnection and displaces existing or planned fossil-fuelled power plants in the importing country, net emissions benefits will occur in most cases. The net air pollutant emissions benefits or costs for individual countries depend on which power plants run more, or less, in the presence of the interconnection, and where those plants are located.

### **Water pollution impacts**

This includes erosion and water pollutants produced as a result of power line construction and operation, and incremental water pollution from power generation, and fuel extraction/storage.

### **Land-use impacts**

Costs of obtaining permission to use land through which a power line passes should be taken into account, along with the benefits such as potential avoided land-use impacts from electricity generation or fuel extraction facilities avoided by the use of an interconnection.

### **Wildlife/biodiversity impacts**

Include costs such as the potential impacts of power line construction and operation on flora and fauna in the power line area, and benefits such as potential avoided impacts due to avoided generation construction and fuel extraction.

### **Human health impacts**

The controversial and yet hypothetic suggestions that electromagnetic fields (EMFs) created by power lines have negative impacts on humans remain inconclusive. In planning interconnections and in preparing Environmental Impact Assessments, input from a wide range of stakeholders is important, including local citizen groups from areas potentially environmentally affected by the project, national and local environmental protection agencies, and outside experts such as ecologists and wildlife biologists in academic institutions and environmental NGOs.

### **Market impacts**

When markets are introduced, investments in generation no longer are centrally decided, so the new regulation must ensure that the appropriate economic incentives exist for each segment so that service reliability is maintained at socially optimal levels.

### **Stakeholder Groups**

Competition in generation and supply also implies that private stakeholders become involved. Transmission and distribution activities may also be privatised.

The primary objective of the stakeholders' analysis is to identify and compile relevant information on the groups and organisations that have an interest or stake in a given project/policy. This information can be used to provide input for other analyses; to develop action plans; to increase support for a project; and to guide a participatory, consensus-building process.

### **End Consumers**

Regarding electricity customers, it is important to include their needs in terms of electricity supply, but in many cases they are the voice less heard. Large customers use to associate and to have access to authorities, so they can exert some influence on interconnections decisions. Small customers may have some direct representation through consumers associations, which usually deal with different sectors of the economy and have no expertise in the electricity sector where conflicts related with interconnections are not frequent. Public hearings or consultations are the only way small customers have for expressing their concerns or for supporting an interconnection project.

## Society and Environmental Organizations

However, small customers play a growing role when as residents they are affected by the construction of transmission facilities. It is relevant to consider their capacity to block the construction of transmission corridors, in many cases jointly with environmentalist organizations. In this sense, it is a strong limitation the already mentioned lack of a clear criteria to define when a line is acceptable from the environmental point of view, and how to balance the interest of the locally affected population with the benefits for electricity consumers.

## 6. CONCLUSIONS

The analysis of the insights provided by the Task Force leads to the identification of certain lessons and formulation of conclusions. The most relevant conclusions and key lessons come from the already established regional markets, like the European Union, USA or SIEPAC.

The DC interconnector between the ENTSO-E grid (France) and the grid of Great Britain is an example for the submarine interconnection of a large and a relatively small grid. Other examples are e.g. the connection of Balearic Islands to the Iberian Peninsula and of Sardinia to the Italian Peninsula.

When there is oversupply of renewable generation, prices go down and export increases but the possible increase may be limited by the available transmission capacity. When renewable generation is low (or zero) prices and import increase, and this can also be limited by transmission capacity.

Most of the transmission expansion aims to connect new generation plants with loads. In the case of integrated utilities, where generation and transmission are simultaneously planned, coordination is given. But in countries or regions with electricity markets and multiple participants, new generation expansion is based on independent (and normally non-binding) decisions of multiple investors. Thus transmission planners face structural difficulties to identify transmission needs when they only have certainty on a few generation projects. Transmission planning in electricity markets has only certainty in short-term generation expansion, but transmission facilities have a long life cycle and the efficiency and effectiveness of transmission

The present available AC and DC transmission technologies for OHTL's, underground and sea cables, stations and auxiliary systems do not pose practical limits to interconnections: the main limits are political, regulatory, financial and in an increasing number of cases especially in developed countries are the environmental impact and local opposition.

Feeding remote areas/islands through connections with interconnected systems reduces not only the cost of local kWh but also the environmental impact of local small size fossil fuel plants.

Overhead transmission technologies now in operation up to 1000kV AC and +/- 800 kV DC allow the exploitation of cheap and remote resources up to many thousands of MW per circuit with substantial cost savings and when

renewables are involved(see large hydro plants or huge in land wind farms as in China) with substantial contribution to the reduction of CO<sub>2</sub> and other emissions.

The development of both underground and undersea (up to 2000-3000 meters depth) cables and DC technologies would allow to overcome the opposition to build OHTL's and allow the additional development of sea crossing interconnections as for instance in the Baltic and Mediterranean sea with interesting potential future integration of large amounts of renewables mainly from wind and solar sources in the expectation of their cost reduction by scale effects.

Considering the different local cost conditions, regulatory framework and environmental concerns, each new possible interconnection should be considered on a case by case basis even if some basic concepts apply ,the crucial question is for what purpose (mutual operational help, trade, generation or load), by which means (in terms of technology) , how much (in terms of capacity) and when and for how much time the interconnection has to be designed /implemented ,taking care of environmental problems and financial aspects.

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transmission planners face structural difficulties to identify transmission needs when they only have certainty on a few generation projects. Transmission planning in electricity markets has only certainty in short-term generation expansion, but transmission facilities have a long life cycle and the efficiency and effectiveness of transmission .

Regional markets can operate efficiently without a uniform regulatory framework. The Central America market is a very good example, where minimum changes were introduced in the internal regulations. Bilateral contracts are the easiest way to initiate cross-border trading. A market limited to bilateral contracts can capture an appropriate part of the total benefits, with less coordination and with simple regulation.

- In all the cases, appropriate rules for congestion management are crucial.
- Optimisation of the use of the scarce capacity of cross border interconnections is necessary.
- The Environmental Impact Assessment (EIA) can help reduce overall project costs, assist in completing projects on schedule, and help design projects which are acceptable to stakeholders.
- The use of new renewable energy sources for electricity generation is growing rapidly around the world. The requirements on the existing transmission and distribution systems for integration of renewable generation are huge and costly and the application of "smart grids" concepts(and here we refer mainly to transmission projects) should be deeply investigated and

regulated (who is going to pay and in which way) for their implementation.

- The many challenges posed by the necessary expansion of transmission infrastructure in different parts of the world are usually outweighed by the benefits the interconnected systems bring to the consumers, both near and afar.



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