



# Grid Integration of Electricity from Renewable Energy

## Technology Experts Meeting

29 May 2007

International Energy Agency, Paris



**In Support of the G8 Plan of Action**

## Discussion Paper

### Introduction

The efficient integration of electricity sourced from renewable energy sources (RES) into transmission and distribution networks is of high priority. To this end it is likely that networks themselves, and the rules by which they operate, will need to be modified to take into account the specific characteristics of renewables.

Variable output technologies (VOTs), such as wind, ocean energy, solar photovoltaic and run of river hydro<sup>1</sup>, are of particular relevance to this project, which aims to provide policy recommendations to the G8 for their summit in 2008. At the 2005 Summit in Gleneagles, the G8 recognised that one important option to improve energy security and mitigate greenhouse gas emissions, is to increase the production of electricity from renewables, and accordingly requested the IEA to address this issue.

Other renewable energy technologies, some of them with capacity factors comparable to conventional sources of electricity - such as biomass, geothermal, reservoir fed hydropower and solar thermal technologies (with integrated thermal storage) - should also receive attention. Large plants, such as offshore wind farms as well as small, embedded generation are to be addressed.

Prior to the advent of large scale electricity generation from renewable energy sources, existing electricity transmission systems were developed to link a relatively small number of large, centralised power stations with electricity flowing outwards towards the load. While this system largely remains, newly added generation from RES is in part connected to lower voltage distribution networks, with power flowing in both directions, while some, in particular large wind farms, tend to be connected to the medium to very high voltage network.

Variable output technologies<sup>2</sup> also represent a degree of departure from traditionally dispatchable generation technology. Such developments, and others, such as uptake of demand side response measures, call for identification of the tasks along the road to integrating RES electricity.

While the related technological challenges may largely be seen as universal, they nonetheless vary from one power control region to another, according to a range of technical parameters governing the structure and flexibility of a given electricity system, such as the amount and structure of dispatchable capacity in the generation portfolio, the storage capacity available, the extent of interconnection with neighbouring systems, the size of the balancing area, geographical dispersal of variable output generation, network strength, and the degree of penetration of the technologies in question.

Assessing a power system purely according to political boundaries is likely to provide only a partial picture, particularly with increasing cross border power flows. Nonetheless, political boundaries presently play a dominant role in the integration of renewables.

---

<sup>1</sup> Although run of river hydro involves a different degree in fluctuation of output, it nonetheless lacks the same degree of output control as reservoir fed hydro.

<sup>2</sup> Most renewable energy technologies are 'variable' on some timescale, but for the purposes of this paper 'variable' refers to those technologies with output fluctuations on a minute to 4-hour timescale: wind, wave, ocean, solar photovoltaic and run of river hydro.

## **Objectives**

1. To identify the principal technological challenges inherent in the grid integration of electricity from renewable energy sources. Differentiate between challenges which are essentially resolved and those which require further work.
2. To identify paradigms based on existing international experience, and to relate the technology tasks identified under Objective 1 to these paradigms.

This paper addresses only technology aspects of the grid integration of renewable energy technologies. Market and policy related aspects will be addressed at a later stage in the project. The paper is intended to provide background information to the Technology Experts Meeting to take place on May 29th 2007 at the IEA in Paris. At various points in the text, specific box queries are directed at participants. Please feel free to provide input before, during and after the meeting.

## **1. Identify and classify technology tasks (Objective One)**

### **Five groups of tasks**

For the purposes of this meeting; technology tasks are divided into five groups: Groups 2, 3 and 4 constitute the focus.

1. Past challenges – this category includes issues whose resolution is in principle understood, and which are no longer considered to be challenging from a technology perspective.
2. Opposing views – where there is some understanding of the challenge, but where opposing positions exist as to its resolution: how? who? when?
3. Agreed challenges – where the challenge has been identified, some resolution has been achieved but further work is still required.
4. Potential showstoppers – where the challenge has been identified to some extent, but has yet to be addressed.
5. Longer term R&D challenges – on the radar, but not yet essential, becoming increasingly so at very high penetrations, beyond that seen to date.

### **Tasks fall into three areas**

Technology aspects under consideration in this study include a range of measures to increase overall power system flexibility, such as:

- Identification of the amount of energy sources (that can provide power but are not necessarily dispatchable) versus power sources which are dispatchable, for balancing, etc.
- Flexible (and dispatchable) generation: scale, availability, power regulation capability.
- Demand side response and management.
- Interconnection among synchronous areas.
- Reversible storage technologies, in particular pumped hydro: scale and availability. To what degree are compressed air storage, electric vehicles and batteries also already helpful?
- Aggregation of geographically dispersed variable output plants into “virtual power plants.” ‘Virtual’ concept also applies to dispersed generation (micro-CHP), and to dispersed consumers with heat pumps and battery capacities. (Is this a technology or purely a market issue?)
- Security aspects of distributed systems, and micro-grids.

Aspects related to specificities of renewables:

- Variability, predictability and forecasting of supply and demand.

- Technology aggregation or hybrid renewables generation.
- System balancing and ancillary services.
- Power electronics and control.
- Challenges and benefits of distributed generation, including bi-directional flows, and impacts on energy losses.
- Application of grid codes (e.g. fault ride through).
- Communications technologies

Aspects related to network hardware and software:

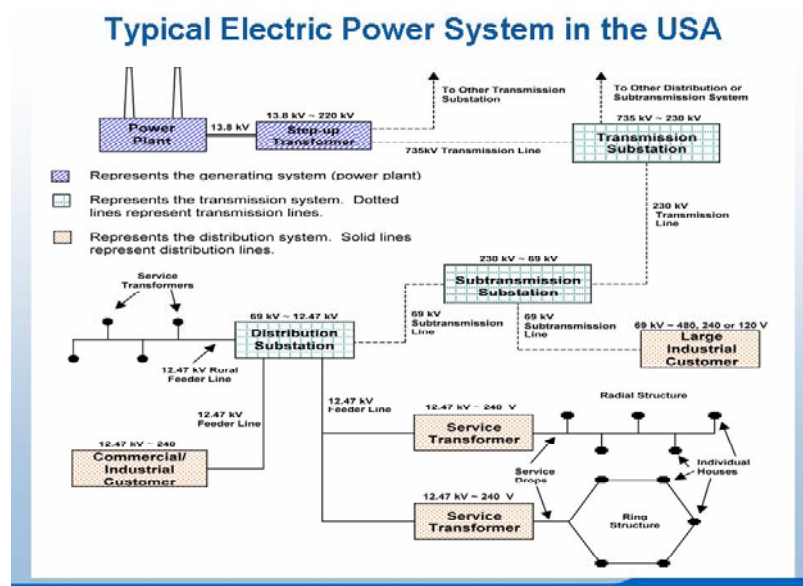
- Optimisation of existing grid hardware; new grid capacity and design; dynamic rating of grid assets to increase grid capacity.
- Cabling technology: HVDC, marine cable (and other elements of offshore transmission), etc; overhead vs. underground cabling
- Automation, data acquisition, and intelligent grid monitoring and control.
- Integrating wind power plants into utility Automatic Generation Control (AGC) systems.
- Real-time dispatching

? What aspects are missing from this list?

### The existing power system

Due to the wide variety of renewable energy options, depending on resources available, there will be a wide range of technology solutions. It follows that a priority for one country / control area will not necessarily be so for another that is reliant on a different generation portfolio.

The integration of electricity from renewable energy should not be addressed in isolation from the other elements of, and challenges facing, modern electricity systems (see figure). These consist of many machines coupled together in an increasingly complex system, including such elements as power electronics and DC links.



Source NREL, 2007

Additional generation equipment should meet engineering requirements with respect to voltage, frequency, waveform purity, ability to rapidly isolate faulty equipment from the rest of the system, and a "reasonable" ability to withstand abnormal operating conditions (fault ride through). On the other hand, a need for compatibility should not overshadow the fact that electricity systems as a whole will probably require significant optimisation to provide the flexibility needed to allow penetrations of RES-E on a very large scale, as well as to accommodate other changes in production and consumption patterns.

## 2. Identification of electricity system paradigms (Objective 2)

Paradigms are clusterings of objects or entities that display certain shared characteristics. Their use in this piece of work for the G8, in the form of simple, qualitative models, is intended to highlight similarities among national and regional electricity experiences with renewables in grids; as well as to point out differences among them, and the industry characteristics that underlie these differences. Such paradigms represent typical situations based on the experiences of individual countries. Appropriate classifications could facilitate exchange of experiences and support mutual learning.

Effectively a triage process, the paradigms are considered to be helpful in enabling policy makers - at whom the study is targeted - to recognise their own circumstances. Their elaboration is intended to demonstrate the specific issues and tasks associated with a given degree of penetration into generation portfolios.

Electricity industries are too diverse to be addressed by one set of recommendations. A degree of differentiation is necessary to make analysis meaningful, particularly as an element of the recommendations for one country with certain characteristics, may not yet / ever be relevant to another country with a different set of characteristics.

It is important to mention at this stage that the intention of the paradigms approach is not to artificially cluster countries. The issues are very complex and vary in a subtle way from country to country and control area to control area; clustering is to clarify the issues for policy makers without over simplifying them, although a degree of generalisation may be necessary for practical reasons.

Thus, a country with only very small RES-E (electricity from RES) penetration, but which has the necessary resources to target 10% penetration, should be able to look at a "10% RES-E Paradigm" to see in broad terms what this would mean in terms of technology, power system studies, requirements and adaptation of procedures and methodologies. Similarly, a country or control area aiming at 20% or 30% should be able to look at the 20% or 30% RES-E Paradigm.

In Phase Two of the project – to be carried out after the summer – market and governance elements will be added into to the paradigms.

Finally, if time and resources permit, a final phase (Three) will construct one or two further paradigms that demonstrate what sort of penetrations would be feasible given ideal characteristics all round - i.e. more abstract, and looking in the future. These paradigms might take into account targeted penetrations of renewables extrapolated from CO<sub>2</sub> reduction targets and other environmental objectives.

In other words, the paradigms are about the present, about indicating to national governments what is already fully feasible with today's know-how. Each should be based around one or more national experiences. In the final report to the G8, each will include distinct recommendations.

### **How might the paradigms be identified?**

The first step of Phase 1 is to identify clusters of countries that today demonstrate similar orders of magnitude of short term variable RES-E penetration, and long term variable penetration (geothermal, hydro, biomass) as a share of overall electricity production. It is intended, at present, that penetration levels will provide the foundation of the paradigms.

It has already been mentioned that the issue of cross border power flows rather “muddies the water” when it comes to assessing the consequences of high penetrations of variable output RES-E. For example, Denmark presently produces in excess of 20% of its electricity from wind energy. It might therefore be said that Denmark has successfully achieved this penetration and resolved the technology

issues associated with it. However, it is also true that sudden excesses or deficits of wind power can be smoothed out via interconnectors to Northern Germany.

A crucial indicator of the effectiveness of systems falling into each paradigm is their ability to balance supply and demand effectively. In Phase 2, when market and policy aspects are added to the paradigms, economic benefit will be a second crucial indicator. This will enable the paradigms to be assessed in terms of balancing effectiveness versus economic effectiveness.

Included in the description of each paradigm would be a list of countries that today fit within the parameters of the paradigm; countries with a similar resource, which could potentially achieve similar shares; and a description of the technology tasks this would entail.

### **Proposed paradigms**

The following constitute a proposal for the paradigms – to be discussed at the technology Experts Meeting on May 29<sup>th</sup>.

1. RES-E production including VOT share of 10%.
2. RES-E production including VOT share of up to 20%.
3. Regional and / or national production from VOTs peaking on a scale of 30% and above.
4. High VOT (RES) production within isolated / nearly isolated systems (e.g. large islands).
5. Hybrid RES production within small isolated systems (particularly developing country context)

Recent discussions within IEA WIND Task 25 suggest that a suitable metric for establishing penetration in ‘realistic’ terms is generation MW / (Min load MW + Available interconnector capacity MW). Another reference that might be considered is the size of the balancing area.

The paradigms will then be developed with a number of secondary characteristics (where VOT penetration is the primary characteristic).

### **“Secondary” technological characteristics of the paradigms**

A system’s capability to absorb variable electricity production from renewable energy will be affected by a number of characteristics, including:

- Degree of interconnection with neighbouring systems.
- Flexible capacity in the generation portfolio (including reservoir hydro).
- Size of power system, or balancing area.
- Available storage (pumped hydro, and other) capacity available.
- Distribution of variable output generation within the area considered - geographic “smoothing” of output.
- Short circuit capacity of the network (network strength).
- Extent to which demand side response and management measures have been addressed and may contribute. Several DSOs in Denmark are now installing meters capable of hourly settlement for individual customers. (If the price signal is made clear as well then there may be a very large potential for peak load shaving. This assumes that the benefits are not overestimated, energy price only constituting part of the total electricity bill.)
- Is necessary technology in place to facilitate facilitative markets?

- |   |
|---|
| <p>? Do you think the basis of the paradigms – energy penetrations from RES, variable and otherwise - is a practical one? What would be an alternative?</p> <p>? Do you agree with the paradigms as listed? Are the important examples represented? What paradigms are missing / extraneous?</p> <p>? What secondary characteristics are missing from the list?</p> |
|---|

? How should these characteristics be included within the paradigms? E.G. some might be seen as variables that the country in question might be able to “tweak” thus allowing a greater share from renewables.

### **Power systems of specific interest**

- Those with high regional or national penetrations of variable output technologies, and high shares of dispatchable fossil fuel generation e.g, Denmark, Germany, Spain, Portugal and Ireland.
- Nordel system – where 4 countries benefit from flexible generation portfolio, reserves, and strong interconnection – serving as a large balancing area, thus benefiting the integration of variable sources
- Those with high penetrations of non-dispatchable power, and so reduced flexibility to absorb variable output, e.g. France and UK.
- Those with high proportions of very flexible hydropower: Norway, Sweden, Canada, Austria, Tasmania
- G8 Countries: USA, Australia, Japan
- Plus Five / BRIC Countries: Brazil, India, China, Mexico, South Africa; and Russia

? What examples are missing from the above list?

### **APPENDIX: Technology R&D Priorities**

The technology experts meeting on May 29 focuses on actions that can be taken with existing technology in order to reach a specific level of generation from renewables. It does not focus on technology R&D tasks that remain to be carried out in order to facilitate generation, per se, from renewables. Nonetheless future R&D tasks will be identified in the course of the project and a concise list is included below.

- Analysis of data related to better empirical understanding of the impacts of high levels of wind energy penetration.
- Enhanced forecasting techniques that can predict not only the behaviour of individual renewable energy generators but also the behaviour of groups of generators aggregated in ways that are appropriate in a particular power system context. Such forecasting techniques should pay special attention to unusual, extreme behaviour. Integration of forecasting techniques to system operational tools is of great importance
- Greater understanding of distributed systems consisting of embedded generators, (reversible) storage and flexible demand, for management of energy flows and quality and availability of supply attributes (peak load “shaping”...)
- Communication and control systems that enable distributed systems to function effectively and have interoperability with distribution network data acquisition and control systems.
- Advanced metering and information technologies that can measure and communicate the time-varying value of ancillary service contributions by end-users and distributed resources.
- Control and optimisation technologies for industrial, commercial and residential end-use equipment that can facilitate flexible end-user response to time-varying prices and security management protocols.
- Increased capabilities of power electronics to withstand higher voltages, currents, switching frequencies and power densities - at generation sites, enhancing the support to power systems; and within the transmission system itself.
- Compact, high capacity and cost-effective (reversible) energy storage technologies.
- Modelling tools that can support the design and performance analysis of non-conventional resource systems, moving towards dynamic, probabilistic tools that integrate RES forecasting.

The need for demonstration projects includes:

- Dynamic rating of ultra high voltage overhead lines: a temperature monitoring demonstration project at 400 kV level should be carried out.