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SUSTAINABLE INTEGRATION OF HIGH LEVELS OF INTERMITTENT GENERATION

Abstract

The sustainable development of electric power systems rely on three main drivers: the security of supply, the competitiveness and the protection of the environment. For this purpose the promotion of endogenous energy sources, mainly the renewable ones, should be underlined. Still, most of renewable energy sources raise very sensitive issues concerning the security of supply, due to its randomness and unpredictability. The wind power, currently in its fast growing development, plays a relevant role on this matter. From the demand-side perspective, there is also a lot to do regarding the promotion of more efficient use of energy as well as mechanisms that contribute to security of supply.

This paper aims to present guidelines for the selection of the most adequate solutions regarding: sustainable evolution of renewable generation technologies, based on the most meritorious resources under economic and security of supply assessments; complementary energy storage systems that allow the integration of intermittent generation ensuring adequate security of supply levels; and sustainable evolution of demand, based on DSM measures selected from different available alternatives.

ODRŽIVA INTEGRACIJA VISOKIH RAZINA INTERMITENTNE PROIZVODNJE

Sažetak

Održivi razvoj elektroenergetskih sustava zasniva se na tri osnovna elementa: sigurnosti opskrbe, konkurentnosti i zaštiti okoliša. U tom cilju posebno treba naglasiti poticanje endogenih, uglavnom obnovljivih izvora energije. Ipak, većina obnovljivih izvora energije, zbog svoje nepravilnosti i nepredvidljivosti otvara vrlo osjetljiva pitanja sigurnosti opskrbe. U tom kontekstu korištenje energije vjetra koja se danas intenzivno razvija igra značajnu ulogu. S gledišta potrošnje, predstoji još mnogo rada na promicanju učinkovitijeg korištenja energije kao i mehanizama koji povećavaju sigurnost opskrbe.

Ovaj rad nastoji prikazati odrednice za izbor najpovoljnijih rješenja: održivog razvitka tehnologija za proizvodnju obnovljive energije iz izvora koji se, s gospodarskog aspekta i s aspekta sigurnosti opskrbe, ocjene kao najpovoljniji; dopunskog sustava skladištenja energije koji omogućava integriranje intermitentne proizvodnje, osiguravajući pri tome odgovarajuću razinu sigurnosti opskrbe; kao i održive promjene u potrošnji, koje bi se zasnivale na mjerama upravljanja potrošnjom (DSM) izabranim među raspoloživim alternativama.

1. INTRODUCTION

As a consequence of the high growth of wind power integration, currently observed in Portugal (during this year installed wind capacity already increased by 60%), due to the implementation of the EU Directive 2001/77/EC - Renewable Energy Sources Directive – a major concern for the Portuguese Power System is to build capacity of compensating the effects of randomness and variability of wind power in the future.

This issue has been addressed by REN, S.A. (the Portuguese TSO) in its recent planning studies, namely through the promotion of wind power resource studies (by means of national potential for electricity generation and power delivery patterns), the development of methodologies for modelling and simulation of wind power plants, as well as the identification of solutions based on reversible hydro power systems, as complementary systems that enable such high levels of integration of wind power.

However, other alternatives shall be known and assessed regarding the compliance of the referred Directive (that may comprise other renewable energy sources), and the complementary solutions that ensure the needed support to integrating intermittent electricity generation.

This paper summarises the studies promoted and developed by REN with the objective of identifying and characterising renewable energy sources, alternative to the wind power, for generation of electricity, as well as studying complementary solutions to intermittent generation.

In this paper different sources of renewable energy were assessed in terms of current and future development. Concerning complementary solutions, alternative systems to reversible hydro power plants were identified, and demand side management measures were considered in order to promote efficiency and rational use of electricity (in line with proposal of the EU Directive on energy end-use efficiency and energy services).

2. SUSTAINABLE EVOLUTION FOR RENEWABLE GENERATION TECHNOLOGIES

2.1. Methodology

The first step was to identify and study the most relevant available renewable energy sources for the generation of electricity, that are alternative to wind power and that provide less randomness on power availability:

- Solar energy (photovoltaic and thermal);
- Biomass;
- Waves;

- Small hydro.

After the characterization of the alternative technologies available for the generation of electricity using renewable energy sources the idea was to make a comparative assessment of those technologies based on technical and economical parameters. With such process we intended to establish a relative merit order that enable us to create a scenario for sustainable evolution of renewable generation technologies, regarding the performance at economic, environmental and security of supply levels.

Each technology was assessed through 0-100% scales in accordance with the following criteria:

- Levelized Generating Cost;
- Renewable Proportion (fraction of generated electricity considered as renewable);
- Credit of capacity during Winter peak periods;
- Credit of capacity during Summer peak periods;
- Dispatchability (ability to enable the optimized power delivery);
- Randomness (level of predictability of the power delivery from each technology);
- Complementarities (level of complementarities of each technology regarding the remaining renewable energy sources).

In order to define the weights, which characterize the importance of each criterion, it was considered that an identical partition between economic (levelized generating cost) and, environmental and technical criteria (the remaining ones) was appropriate.

2.2. Solar - photovoltaic

The direct conversion of solar energy into electricity is obtained through the absorption of radiation photons, to the peripheral electrons of the atomic structure of that material, creating a free/hole electron couple. To explore this phenomenon photovoltaic cells, which enable the generation of electricity from the solar radiation, are used.

Currently, for the production of photovoltaic cells that are used to assemble photovoltaic panels, the following materials are presented:

- Crystalline Silicon (c-Si);
- Amorphous Silicon (a-Si);

- Cadmium Telluride (CdTe);
- Copper Indium Diselenide (CIS).

Improvements on efficiency rates are expected for the different technologies in the future. However, levelized generating costs are not foreseen to be under 77 €/MWh, through 2020.

Table 1. Evolution of levelized generating cost for photovoltaic technology

Year of commercial application	2005	2010	2020
Capacity (MWp)	10	20	20
Investment Cost (k€)	38500	46400	27600
Annual Generation (GWh)	15	29	29
Lifetime (years)	25	25	25
Interest rate (%)	6,22	6,22	6,22
O&M Cost (€/MWh)	3,07	1,97	1,31
Levelized Generating Cost (€/MWh)	208	130	77

2.3. Solar –Thermal

Concentrated Solar Power (CSP) systems generate electricity by converting solar energy in high temperature heat using different layouts of mirrored surfaces. These systems focus direct solar radiation through optical devices to the area where the receptor is located, transforming radiation into high temperature heat and then into steam.

CSP systems need direct solar radiation to be concentrated. There are four main systems for this purpose:

- Parabolic trough;
- Parabolic dish;
- Power tower;
- Solar chimney.

The parabolic trough technology is the most advantageous one and considered as the best choice for when the construction of new solar thermal power plants is concerned. Besides the fact of being commercially available in large scale units (largest unit built: 80 MW), these systems are very modular and allow the integration of hybrid units, as well as storage systems. The highest efficiency ratio demonstrated by this technology was 21%, in terms of conversion of direct solar radiation into delivered electricity.

Table 2. Evolution of levelized generating cost for parabolic through technology including storage system

Year of commercial application	2005	2010	2020
Capacity (MWp)	100	150	400
Investment Cost (k€)	481 600	534 300	1 288 000
Annual Generation (GWh)	473	736	1 997
Lifetime (years)	30	30	30
Interest rate (%)	6,22	6,22	6,22
O&M Cost (€/MWh)	28,00	18,00	13,90
Levelized Generating Cost (€/MWh)	104	72	62

2.4. Biomass

Energy contained in biomass can be used in different ways. The most common method uses the heat from biomass combustion for producing steam, which can be delivered to industrial processes, or used to distribute hot water through district heating pipeline or to generate electricity. Three main technologies are used to generate electricity from biomass:

- Direct combustion;
- Gasification;
- Joint combustion.

Having in mind the construction of new power plants, optimized for the use of biomass as primary fuel, the best technologies are the direct combustion and the biomass gasification. Given its maturity in development process, the direct combustion technology is a commercially available option. In the medium term, the biomass gasification is foreseen to be more competitive in relation to the conventional technology.

Table 3. Evolution of levelized generating cost for biomass power plants

Year of commercial application	2005 (1)	2010 (1)	2020 (2)
Capacity (MWp)	100	150	110
Investment Cost (k€)	151 000	201 900	138 380
Annual Generation (GWh)	700	1050	771
Lifetime (years)	20	20	20
Interest rate (%)	6,22	6,22	6,22
O&M Cost (€/MWh)	47,40	47,40	32,90
Levelized Generating Cost (€/MWh)	67	64	49

1) Direct combustion technology
2) Biomass gasification technology

2.5. Waves

Energy from waves results from the concentration of wind energy on ocean's surface. Differences of temperature within terrestrial surface produce wind, which in its way through the oceans transmit part of its energy through the waves.

Basically the wave technologies used for the generation of electricity are divided in two main groups:

- On-shore and near-shore;
- Off-shore.

There are several non-technical barriers to the development of exploitation of waves energy. In spite of waves energy being close to the final phase of I&D there is still much uncertainty concerning the cost and efficiency rate that should be overtaken by demonstration schemes before undertaking large scale commercial investments.

Table 4. Evolution of levelized generating cost for waves energy power plants

Year of commercial application	2010	2020
Capacity (MWp)	2	3,5
Investment Cost (k€)	3200	4900
Annual Generation (GWh)	4,12	7,44
Lifetime (years)	30	30
Interest rate (%)	6,22	6,22
O&M Cost (€/MWh)	15,55	15,05
Levelized Generating Cost (€/MWh)	73	64

2.6. Small Hydro

The technology that supports small hydro systems is very mature. There is great diversity concerning the conceptions that have been adopted in small hydro power plants that, associated to a very large portfolio of sizes, makes it very difficult to characterize this type of power plants.

In accordance to some available data, about actual small hydro plants that were constructed in Portugal, the average value of the investment in this technology falls in to range between 1600 €/kW and 1750 €/kW. If we consider a capacity factor of 32.5 % and O&M costs of 5 €/MWh, we get a levelized generating cost inferior to 45 €/MWh.

2.7. Technology comparative assessment

In order to assess the intermittence/complementarity existing between the different renewable energy sources alternative to wind power, it was necessary to collect data regarding solar radiation, inflows and wind speed. Compiled data enabled the analysis of 40 years of historical data (1956-1995).

Results showed that wind speed and inflows distribution shapes along the year are pretty similar, and therefore there is a high positive correlation (0.98) between these two sources of energy. This high correlation could mean that there is some dependence between the two phenomena. Compared to solar radiation, wind speed and inflows vary almost inversely (correlation of -0.7 and -0.66 respectively), which means that these forms of energy can be considered as complementary.

The intermittence level of wave energy, as well as its complementarity to wind power is more difficult to obtain, because wave formation doesn't rely only on on-shore wind, but also on some other wind of off-shore origins. Given the lack of elements that would allow a more detailed analysis it was assumed that wave energy has a pattern similar to wind power.

Looking at the obtained classification, shown in the graphic bellow, for all considered technologies it is possible to distinguish two main blocks. The upper block, with higher relative merit in the long term, includes biomass, small hydro and solar-thermal. Another one appears to be less attractive and it comprises wind, solar-photovoltaic and waves technologies.

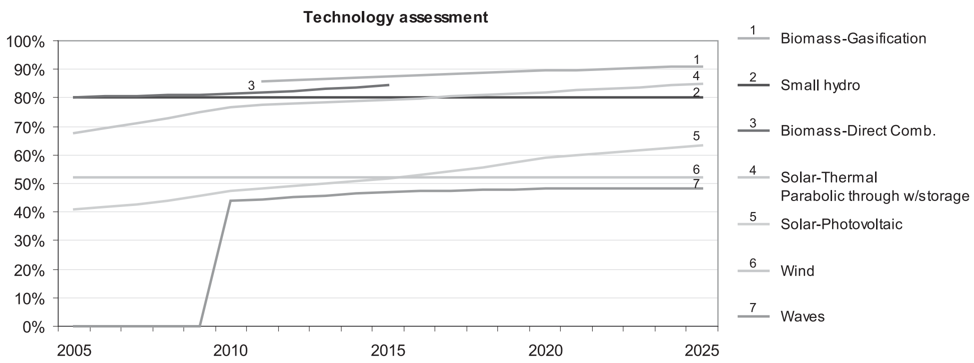

Figure 1. Assessment of the different renewable energy technologies

Based on these results it's foreseen that the primary renewable energy technologies to be integrated in the long-term should be biomass (first through direct combustion and then gasification), solar-thermal (using parabolic through with storage system) and small hydro. These choices are justified by the overall relative merit demonstrated.

3. COMPLEMENTARY ENERGY STORAGE SYSTEMS

The energy storage is one of the most appropriated solutions to support the integration of intermittent generation of electricity. Reversible hydro power plants can be used for this purpose due to their high capacity for dynamic quick response, which is a characteristic of this technology.

Systems alternative to hydro power (some yet in I&D process) can be based on the following technologies:

- Electrochemical batteries;
- Super capacitors;
- Superconductive coil;
- Electromechanical batteries;
- Compressed air storage;
- Hydrogen production and storage;
- Regenerative fuel cells.

Among these technologies only electrochemical batteries can be considered as commercially available and ready to install. All other mentioned technologies are still in demonstration phase of development and some, as super capacitors, superconductive coils and electromechanical batteries, seem to be more appropriated for short duration energy storage.

The production and storage of hydrogen, in spite of constituting an attractive solution from the environmental point of view, especially for end-use purposes will only be viable as far as substantial increase in conversion efficiency from hydrogen into electricity is achieved and if the cost of fuel cell is considerably decreased.

The technology which presents the higher technical-economical potential is the regenerative fuel cells.

Working principle of regenerative fuel cells is very similar to electrochemical batteries since they store energy chemically. When necessary, they can generate electricity by inverting the process.

The first generation of regenerative fuel cells used to produce hydrogen and water from the electrolysis of water. Recently technology improvements introduced special electrolytes that are regenerated. The first tested solution produced a reversible reaction to saline solutions (electrolytes): sodium bromide and sodium polysulfide. This technology is referred to in international literature as PSB – Polysulfide Bromide Battery.

The first PSB system to be implemented in large scale projects was Regenesys ™. This technology can be installed very close to, or even within, city limits, because it doesn't produce any noise or atmospheric emissions. It consists of a modular solution providing systems with installed capacities between 5 and 500 MW, and allowing for energy storage from a few seconds up to 12 hours. Projected lifetime is nearly 20 years without the need of replacing any component.

The first PSB system started its construction in Little Barford, UK, next to a combined cycle power plant. Its commissioning was projected for 2003, but some delays hindered this objective. Some other projects have been then suspended until this prototype reaches the expected performance.

More recently, a new type of regenerative fuel cells has been developed which uses other electrolytes, based on vanadium bromide. This new technology is referred to as VBR – Vanadium Bromide Redox Fuel Cell.

This technology comprises two main parameters: capacity and amount of stored energy. Capacity is related to the amount and area of the electrodes used for inciting reaction between the electrolyte and the power electronic associated. The amount of stored energy is directly proportional to the volume of available electrolyte.

This solution, yet in the initial phase of commercialization, promises to be very competitive in terms of costs, when compared to electrochemical batteries. Namely, involving the same costs, this technology has several advantages: a longer lifetime and lower environmental impacts than conventional batteries.

The first VBR large system took place in South Africa as a result of cooperation of VBR Power Systems (manufacturer) and ESKOM power utility. There is also a Japanese company – Sumitomo Electric Industries – which can produce around 10 MW/year of this technology. This manufacturer has several systems in demonstration phase for energy stabilization purposes and storage in wind farms.

Table 5 presents the main characteristics of the two types of regenerative fuel cells with more implementing potential, assuming costs for energy storage corresponding to 5 hours.

Table 5. Characteristics of Regenerative Fuel Cells

Regenerative Fuel Cell	PSB	VBR
Power ranges (MW)	5 to 500	5 to 500
Storage capacity (h)	up to 12	up to 12
Initial cost - 5h of storage (€/kW)	500	750
Annual Maint. Costs (€/kW)	9	9
Chage/discharge Efficiency (%)	65	75-80
Lifetime (years)	15 to 20	15 to 20
(cycles)	12000	12000

Comparatively to reversible hydro power plants, these new emergent technologies provide some advantages, namely quicker response, higher modularity (enabling joint systems with wind farms) and reduced environmental impacts during their lifetime. Main disadvantages are still early phase of development and unknown impact during decommissioning process (due to used electrolytes).

4. SUSTAINABLE EVOLUTION OF DEMAND

From demand side perspective, the future Directive of the European Parliament and of the Council on energy end-use efficiency and energy services is currently under proposal assessment and its enforcement is expected in 2008. Targets regarding energy saving of each country shall then be defined based on 2002-2007 reference period. During this period the average demand in Portugal is expected to be 46400 GWh (based on central growth forecast of national economy). This means that in the 6 following years total accumulated annual energy savings, corresponding to 6% of that value, will have to reach 2800 GWh.

The process of identifying the best (and affordable) strategy in order to comply with referred Directive focused on energy efficiency and fuel-switching (replacing energy sources in end-use). Selection of alternative solutions was based on studying relative competitiveness, assessed through CSE – Cost of Saved Energy parameter.

In Portugal there is a great potential for demand side management (DSM) in public services sector, by increasing energy efficiency in lightning and acclimatization. Replacing incandescent light bulbs by fluorescent lamps and electromagnetic ballasts by electronic ones, as well as using heat pumps in substitution of resistive heaters, would generate energy savings of nearly 450 GWh, after 6 years of implementation.

In residential sector, energy efficiency measures and/or fuel-switching could support a decrease in the rate of resistive heaters ownership, which should be replaced by heat pumps or by central heating using natural gas furnaces. The same decrease could be achieved in utilization of electrical thermal accumulators that shall be replaced by gas water-heater or by solar water heating (using natural gas as backup).

In industry, electric motors have been used to drive a great range of loads, including pumps, compressors, ventilators, mixers, mills, transponders, etc., representing around 75% of total industry power consumption in Portugal. High efficiency motors are characterized for having 30 to 50% less losses than standard motors. This type of motor must me applied to loads with high number of working hours, namely in the following situations:

- New applications or modified lines of production;
- Replacing over-dimensioned standard motors;
- Replacing malfunctioning motors.

Moreover, by controlling flows in pumps, ventilators and compressors, by using electronic speed variators, up to 25% of energy savings could be achieved compared to regulable valves.

The impacts of these measures in the shape of Portuguese load diagrams could result in benefits at power system requirements level estimated in a total higher than 600 MW.

Table 6. Strategy to achieve demand side goals for Portugal

Sector	**Capacity Savings (MW)**	**Energy Savings (GWh)**
Services	215	450
Residential	175	280
Industry	250	2070
Total	640	2800

Additionally, promoting solutions based on demand response strategies (active control of loads) in every sector could modulate annual peak load of electricity in critical situations. In Portugal it is estimated that 1.5% of annual peak loads could be controlled, in the first year of implementation, up to 3% (after the sixth year of implementation).

5. CONCLUSIONS

The studies that have been developed and promoted by REN and that were here briefly exposed opened the way to the construction of the long-term sustainable scenarios, regarding the evolution of renewable generation. This should be based on the block of technologies that present the greatest relative technical-economical merit (including increased worth from security of supply perspective), which includes biomass, small hydro and solar-thermal.

Complementarily, it was possible to identify mechanisms that enable the necessary electricity savings, as well as the possible energy storage systems, which are crucial tools for making intermittent energy sources compatible with system requirements.

Among the newly technologies for large scale application in energy storage systems, VBR and PSB technologies present the best results in terms of technical and economical assessment. Several VBR systems are currently in the testing phase. PSB system is in a rather early phase of conception, although in a long term it can be foreseen as the best available solution.

From demand side management perspective, a group of (feasible) measures to be implemented was identified. They include promotion of energy efficiency, fuel-switching and demand response.

The developed study has demonstrated to be an essential tool to the definition of strategies that enable the sustainable integration of renewable energy sources, in line with the Renewable Energy Sources Directive.

6. REFERENCES

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