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FEEDING THE GRID FROM REGENERATIVE SOURCES - THE WAY TO A SUSTAINABLE ENERGY SUPPLY?

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ABSTRACT:

Electricity produced from wind or sun is not matched to consumption by electrical loads and needs to be conditioned for general use. The strategy pursued in some industrial European countries of granting high priority to regenerative sources and subsidizing the infeed of raw natural energy into the electrical grid is ineffective when mainly thermal power stations are employed for grid control which should comprise the regenerative sources as well. Also, part of the expected fuel saving by the use of wind or solar energy is lost through the control of the thermal stations. When further expanding the use of renewable sources it is necessary to develop large energy storage facilities for decoupling generation from consumption; chemical storage could be promising for a flexible demand-driven reconversion to electricity with stationary or mobile fuel cells.

KEYWORDS : Renewable Energy, Supply / Demand-mismatch, Grid control

1. THE INTERCONNECTED AC GRID

Densely meshed AC grids, crossing entire continents and linking centers of industrial activity with isolated villages, are offering the possibility of instantly calling on practically unlimited electrical power; fed by thousands of generators from diverse primary energy sources and employing sophisticated protective measures, the power grid is providing a continuous and reliable supply. The availability of abundant electricity is a foundation of our lives in a technical world, making industrial production possible and offering mobility as well as countless services.

In view of the huge quantities (e.g. more than 500 TWh/a in Germany) the limits of energy consumption are coming within sight, due to finite fossil resources and detrimental effects on the environment, such as emissions and waste heat. Regenerative resources, in the end mostly based on energy from the sun, are said to provide a solution, but they too have adverse effects, such as the large required areas due to low energy density; also, electrical energy must be generated at the instant it is needed. Fig. 1 shows the chain of conversions from the sources to the final applications; drives are the largest group of consumers.

Rotating AC generators supplying sinusoidal voltages (there is no alternative because only trigonometric functions are invariant to the linear differential equations of electrodynamics in steady state) are driven by steam-, gas- or hydro-turbines, converting chemical (fossil), nuclear or mechanical-potential into kinetic energy.

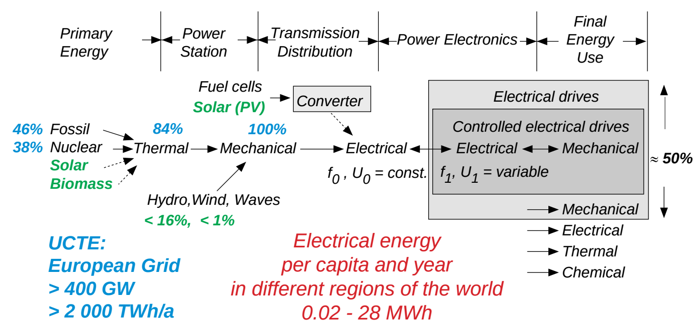

Fig. 1 Energy conversions from primary sources to end use

The varying load of the electrical grid is a result of arbitrary switching actions by millions of customers; while these are statistical events, there are systematic diurnal, weekly and seasonal rhythms as well as known dependencies on weather conditions, popular TV shows etc., permitting reliable forecasts for the next day; the load at night and on weekends may be only half that during peak hours. Detailed load models then allow cost- or emission-optimal scheduling of the generators under various constraints such as limited hydro storage, also considering the fact that the start-up of a thermal station may take several hours.

2. GENERATING ELECTRICITY ONTIME

Electricity cannot be stored to any substantial degree, hence the power fed to the grid must precisely match the varying load (similar to a just-in-time production line, where the required parts must be delivered when they are needed), otherwise frequency deviations and unscheduled power exchanges with neighbouring control areas result. In that respect the various primary sources exhibit marked differences:

With power stations based on existing resources, be they fossil, nuclear, mechanical or biomass, electrical energy can be produced on demand and matched to the load. It is different with renewables such as wind or sun, where the incident natural energy is lost unless it is instantly converted to electricity; likewise, no power is available on

a calm day or when the sun is not shining. Therefore supplying a consumer from a regenerative source either calls for demand-side control, which (other than at the time of historic windmills) may not be practical with industrial loads, or for storing the excess energy generated during off-hours, making it available later.
The policies presently imposed in some European countries of assigning priority to highly subsidized electrical energy from renewable sources ignore these simple facts; by granting a large flat-rate compensation per kWh irrespective of the load, they encourage the feeding of raw wind- or solar- generated power directly into the grid, essentially using the grid as an easily accessible and seemingly cost-free energy dump. While this may have been tolerable on a minor scale, the power coming from wind farms is now assuming magnitudes where undesirable interactions with the grid control occur. The generating capacity from wind in Germany has reached 7 000 MW and is still rising, supplying more than 2% of yearly consumption; it is mostly concentrated in the coastal areas and the Northern low lands. Clearly, as seen in Fig. 2, there are limits to wind energy use in a densely populated industrial country.

Fig. 2 Windfarm at the German North Sea coast:
From a vacation area to an industrial district

3. EFFECTS OF GRID CONTROL

For operational reasons the European interconnected grid, extending from Spain to Poland and Sicily, is divided into control areas, six in Germany, where grid controllers are employed for maintaining frequency and scheduled power exchanges; this is done with control power stations, also covering the deviations of the actual load from the forecast. In addition, the incident and poorly predictable wind-generated power must now be compensated. Thus the wind energy is substituting power from conventional power stations with the aim of reducing fuel consumption and emissions there. When adequate hydro generation is available for grid control, as is the case in Scandinavian countries, the control problem can be efficiently solved by upgrading wind energy to storable and more valuable hydro energy. The situation is different when mainly thermal stations with fossil fuel are employed for control, because they have a restricted operating range and, due to the complex conversion processes, respond slower to demands; thermal stations exhibit at part-load also lower efficiency and increased emissions per kWh, so that the expected fuel saving is not fully realized.

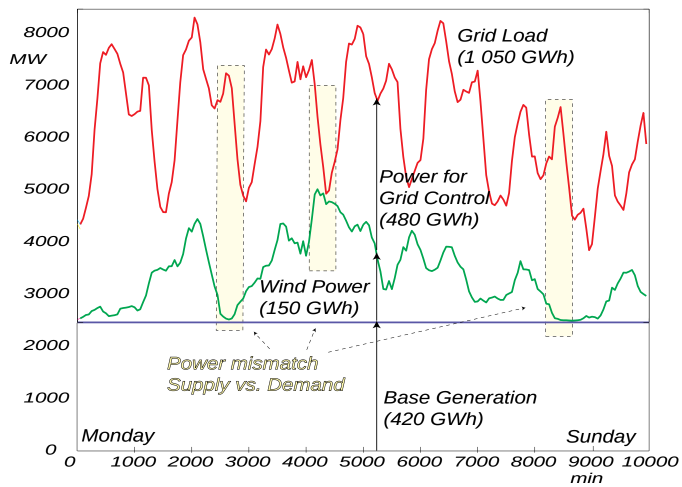

Fig. 3 Load in E-ON grid (North) and wind generated power during the week of April, 2 to 8, 2001

The situation in the North-German (E-ON) control area during a week in April 2001 is illustrated in Fig. 3, where the predictable load varies daily between ca. 4000 and 8000 MW; this power is fed to the grid via three channels:
- a constant infeed of about 2500 MW from base generation,
- fluctuating wind power up to 2500 MW and
- the power from control stations, mainly coal- and gas- fired plants; on a calm day, they supply the full difference between grid load and base generation.

Clearly, the wind-generated power is not even remotely matching the pattern of the load; intervals of major mismatch are indicated, for instance on Wednesday night, when peak wind power was supplied to the lightly loaded grid and inversely on Saturday evening. The control power stations have to compensate these incidental variations in the face of one-day-ahead uncertainties of up to 1400 MW for estimated wind power; of course, this is no concern to the wind farm operators who are interested in maximizing profit.
Another problem are large and unpredictable surges of the wind-generated power, as seen in Fig. 4; although the wind power is generated by thousands of converters spread throughout the Northern part of the country, Fig. 5, the total generation may exhibit surges of several hundred MW/15 min, caused by regional disturbances of the wind field. They cannot be compensated with thermal power stations and cause unscheduled power flows between control areas, increasing the grid noise.

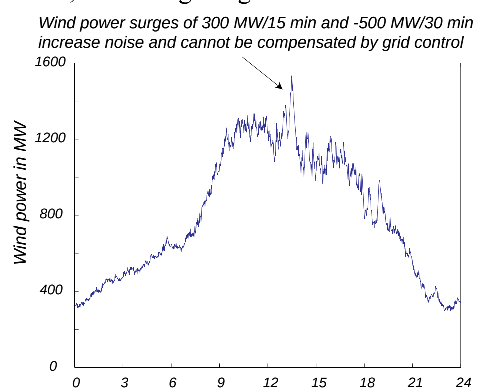

Fig. 4 Wind power surge in E-ON grid on June, 23, 00

Fig. 5 Distribution of wind farms in Germany

Furthermore the priority of wind-generated power has the long- term effect that conventional control power stations are pushed into a stop-gap role, being allowed to supply control power only when there is not enough wind, whereas their capacity must remain adequate for calm periods. This can render investments unprofitable, endangering future reliability of service.

In the short term the problem of feeding large blocks of incidental wind-generated power into a lightly loaded grid can only be resolved by extending grid control also to wind power generation, as is done with all other generators, i.e. relax the priority position of wind energy. Also, the occurrence of positive wind-generated power surges could be mitigated by including rate-of-change-limiting provisions in the rules for connecting new wind power plants. Such restrictions would be, of course, highly unpopular with the wind power industry but they are unavoidable if the use of regenerative energy is to be further enlarged. The difficulties will considerably increase, when plans are realized to construct gigantic Off-shore wind power plants in the North and Baltic Seas, amounting to 25 000 MW by the year 2030, that would have to be connected to the European grid. While the wind-generated power would multiply, its variations with time could be similar to those in Fig. 3; in fact, the wind field on the open sea may be spatially even more coherent since there are no obstacles causing turbulences. Including the Off-shore wind power in the grid control may be implemented with controllable DC-links.

4. ENERGY STORAGE FOR MATCHING GENERATION TO CONSUMPTION

When expanding the use of renewable energy sources on such a massive scale, the problem of energy storage needs to be tackled, conserving surplus incidental wind energy for calm periods with insufficient generation. The required total storage capacity would exceed anything in use today, even large pumped hydro storage plants with thousands of MW. Of particular interest could be chemical storage media, such as hydrogen or other energy carrying substances produced with Off-shore wind power, stored underground and used later for generating electricity on demand with stationary or mobile fuel cells. While the technology of electrolysis is well advanced and efficient converters ($\eta > 0.80$) are available, it would have to be extended to much high power ratings. However, considering the widespread enthusiasm with the more complex and less advanced fuel cells, it should be practical to develop electrolysis in parallel with the primary energy acquisition, thus removing a major obstacle for the use of renewable sources. Just feeding raw wind-generated power into the grid, regardless of the need, is clearly not a promising strategy for the future.

5. STORAGE ALSO FOR SOLAR ENERGY

Similar problems of matching generation to demand exist with photovoltaic converters, another important future field of power electronics. Conditioning this energy source for grid supply is not a pressing problem now in view of the negligible volume; still some large installations have been built in Germany in recent years, for instance the 1 MWp photovoltaic converter shown in Fig. 6, where the solar cells are integrated into the roof and facades of an educational building; about 7000 generators of this size would be needed to generate just 1% of the electricity used in the country, indicating that this is only a demonstration of the basic possibilities. Another large photovoltaic converter is shown in Fig. 7.

Solar radiation contains a dominant diurnal component like the grid load, but the instantaneously generated power depends also on many other factors, mainly unpredictable weather conditions; since every cloud whose shadow moves across the solar panels is leaving its traces, rapid power fluctuations may result that cannot be compensated by the thermal control stations. The power produced by the 1 MW solar converter in Fig. 7 during the day of the 1999 solar eclipse is seen in Fig. 8, showing, apart from the "black out" at noon, large variations within short time intervals, when the rapidly changing power increases the noise in the neighbouring grid by varying power flows on the lines.

It is sometimes claimed that this would level out when enough converters are connected to the grid at different locations, but this is only true from a global perspective, since the spatial averaging is achieved through the uncorrelated transient currents produced by the converters.

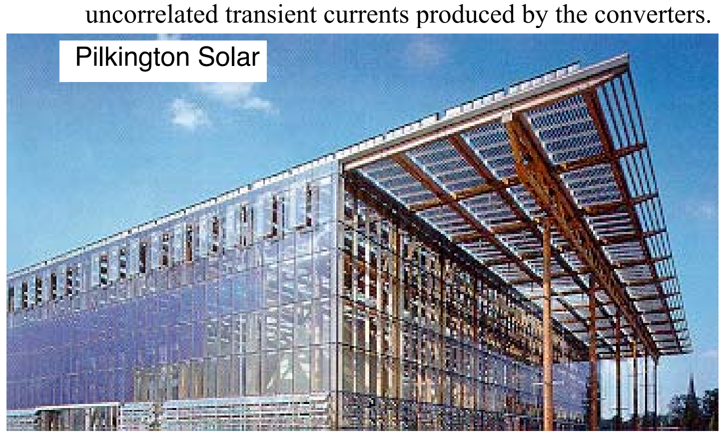

Fig. 6 Photovoltaic converter integrated into an educational building at Herne, Germany 1 MWp, 750 MWh/a, 10 000 m^2 solar cells

Fig. 7 Photovoltaic generator at the Munich Trade Fair 1 MWp, 1000 MWh/a, 7800 m^2 solar cells

Hence, a precondition for expanding photovoltaic generation to utility levels is again the availability of decentralized storage; in thinly populated arid regions without an electrical grid and at low power this can be done with batteries or by water pumping (little use is made of it because of the cost); on a large scale, desalination of sea water might be a suitable application where large installations requiring hundreds of MW each exist at the Persian Gulf. However, such global approaches to the energy problem are presently of no great concern in industrial countries. Instead a strategy without long-term perspective is pursued by granting subsidies for solar-generated electricity of 0.45 \$/kWh, in some towns even up to 0.90 \$/kWh, thus encouraging the construction of converters for feeding raw solar energy to the grid.

6. CONCLUSIONS

Electricity produced from wind or sun is not matching the pattern of consumption and needs to be conditioned for extended general use. While the strategy in some industrial countries of subsidizing the infeed of raw natural energy into the electrical grid can create a "wind boom" leading to staggering figures for the generating capacity, the interactions with the grid control need to be examined more closely. When mainly thermal control power stations are employed, part of the gain at the site of the wind- or solar-power plant will be lost by the control at remote generating stations. It is therefore indispensable to accompany the desired transition towards a sustainable decentralized energy system based on renewable resources by developing large energy storage facilities; chemical storage could be promising in view of the energy density and the flexible end-use with stationary or mobile fuel cells.

7. ACKNOWLEDGMENT

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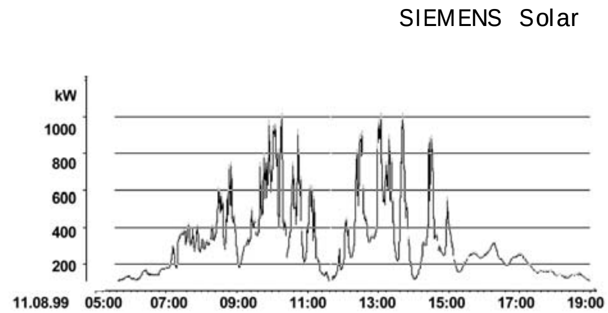

Fig. 8 Output power of photovoltaic generator Munich during the solar eclipse on August, 11, 1999

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