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DISTRIBUTION GRIDS OF THE FUTURE – THE TECHNOLOGICAL CHALLENGS WE ARE GOING TO FACE

INTRODUCTION

The sustainable availability of electrical energy is one the most important factors in order to guarantee economic growth, social welfare but also protection of the environment. The European Union recognized the increasing dependency on the import of fossil energies like natural gas, oil and hard coal. Additionally, the European Union also identified an increasing threat of climate change caused by the increasing use of fossil energy sources. Therefore, the so-called 20-20-20 targets were agreed on as a substantial element of the “2008 EU Climate Action and Renewable Energy Package” [1]. By 2020 the member states of the European Union shall reduce their CO_2 Emissions by 20%, increase their energy efficiency by 20% and finally increase the use of renewable energies in the overall energy sector to 20% of the total energy used. The baseline is given by the year 1990. These targets will show a substantial impact on the role of electricity in the modern society. The world of tomorrow will be more green, more energy efficient, more sustainable but also more electric. In other words electricity is a part of the solution. The 20-20-20 targets have a substantial impact on distribution grids and their operation. Therefore, the analysis of the 20-20-20 targets allows the development of a scenario concerning the structure and the operation of the electrical grids of tomorrow.

ADJUSTMENT OF EUROPEAN ENERGY POLICY THROUGH THE 20-20-20 TARGETS

Electricity is a highly efficient and environmentally friendly energy. E.g. even the today’s energy mix in the European Union shows thanks to CO_2 free generation units like nuclear and renewable power plants as well as low CO_2 generation units like gas fired power plants a low overall CO_2 exposure. The planned implementation of carbon capture and storage technologies (CCS) for coal fired power plants and the planned increase of electricity generation by renewable energy sources will reduce the CO_2 emissions even more. In addition the efficiency of fossil fired power plants has been increased substantially during the last years. Coal fired power plants exceed 40% efficiency and gas fired power plants even achieve about 50% efficiency.

On the demand side heat pumps create more than three units of thermal energy out of one unit of electrical energy. The well to wheel efficiency of electrical cars achieves about 33% while the efficiency of combustion engines amounts from 20% to 23%. Driving all cars in the European Union with electricity would increase the electricity consumption by some 10% to 15% and increase the efficiency by about 50%. The increase in consumption is rather limited from a technical point of view and it should be possible to handle it with the available network technology.

This potential of electricity clearly shows that electricity is a part of the solution. However, one question has to be answered: what does it mean for the electrical grids when the electricity consumption as well as generation by renewable energy sources of different size are increased?

SUBSTANTIAL CHANGES IN THE ELECTRICITY SECTOR

The increase of electrical applications in the transport (electrical vehicle) and heating sector (heat pumps, electrical direct heating in low energy houses) will increase the electricity demand in comparison to a business as usual scenario. Contrary to this, the efficiency in the use of electricity, e.g. in the field of street lighting systems with LEDs, will be more efficient compared to today. However, in total the electricity demand will increase to a limited amount. As already stated this increase should not lead to any bigger technical challenges, nevertheless, it will create the need for investments.

With respect to the variations of load flow on the consumer side the volatility will stay in the range where we see it today. However, concerning generation a completely changed situation has to be expected. In the past and in most cases even today the generation is characterized by the following elements:

- The produced electrical power shows a deterministic character, as thermal power plants – coal and gas fired as well as nuclear power plants – are in most countries dominating the generation portfolio
- Power plants are concentrated at consumption centers which allows short distance transportation
- The tie-lines between countries as a rule had and mostly still have a mutual back-up character in order to support each other in case of power plant outages
- Big power plant units – above 400 MW of installed capacity – are dominating the generation portfolio. As a consequence the units are connected to the transmission grid which makes this grid to become a power plant dominated grid
- Due to this, the balance between the deterministic generation and the volatile – however, not fully probabilistic – consumption is the task of the transmission system. The generation follows the consumption
- Finally, the load flow that we observe today has a clear direction. It comes from the higher voltage level and goes the lower levels.

The 20-20-20 targets are aiming to have 20% share of renewable energies included in the energy sector. This mainly includes heating,

ISSN 1337-6756

transport and electricity. There are means like the electrical car and the heat pump but also biofuel and wood which are increasing the percentage of renewables used in the first two sectors. However, both will stay below the 20% threshold. This means that the electricity sector has to contribute more in order to achieve this target as a whole. Estimations on a European level amount up to 35%.

Given that 35% of the electricity should be generated by renewable energy sources the installed capacity has to go far beyond this level as renewable energy sources have a much lower annual time of utilization in comparison with the conventional power plants. Assuming a 50% utilization time for renewable energy sources the installed capacity has to be about 70% of the existing available capacity of conventional power plants.

From an economic point of view this means a huge investment program in new generation units and a huge effort concerning supporting schemes. Renewable energy sources as a rule will be "must-run" power plants with specifically high generation costs.

From a technical point of view we will see huge new capacities e.g. off-shore wind generators to be connected to the transmission grid at places where there is no consumption. This leads to the challenge of long distance transportation. In case that some member states, above all Germany, is executing the planned phasing-out of nuclear power plants by around 2020 the technical challenge of long distance transportation will further increase.

As an example the German Free State of Bavaria which is – even in a stand alone comparison – one of the strongest economies of the European Union with a population of about 12 million people depends to about 80% on electricity produced by nuclear power plants. Together with some 20% generation of electricity in hydro power plants the energy mix even today is nearly CO_2 free. This very positive situation will change substantially after switching off the nuclear power plants and in addition a severe electricity import problem will occur as Bavaria for sure is not a preferred region for wind energy and the potential of hydro power is already used.

In addition to the long distance transportation the non-controllable electricity generation profile of renewable energy sources leads to additional technical challenges. The electricity production is based on climate conditions (wind, rain, sun) but also on day and night cycles with limited links to the electricity demand.

With respect to distribution we will see a huge number of smaller hydro, solar, geothermal and biomass power plants but also CHP units using various technologies. These generation units will be very close to the consumers and even will change the pure consumer of today into a producing consumer, a so-called "prosumer". However, most of the generation will not follow the electricity demand but rather the climate conditions or the heat demand in case of CHP units. This again makes the electricity production not controllable.

As a consequence the load flow will change within distribution grids from a pure "top-down" load flow to a mixed "top-down" and "bottom-up" load flow. In combination with the expected increase of electricity consumption the necessary networks capacities have to be provided. In addition, the higher variability and volatility of the load flow also leads to a higher variation of the voltage. We will not only see the today's decrease of voltage when the distance to the MV or LV feed in transformer increases but also to an increase of voltage when the dispersed energy production is high in times of low consumption.

Today the voltage is kept close to the rated voltage. Deviations are only allowed within a narrow band. If this overall voltage quality standard should be kept in the future measures have to be taken. They either can be of a passive nature which means an increase of the short circuit power by installing more transformer and line capacity or they also can be of an active nature. In this case new devices like voltage controlled MV/LV transformers, voltage control units in the mains or flexible reactive power sources have to be integrated into the system. In principle this technology is available, however, further research and development are requested.

At this stage it has to be mentioned that there is another approach as well. However, it is only a theoretical one at the moment. It should be possible to lower the overall voltage standards and to widen the band for deviations. In order to maintain a certain voltage quality for the consumer an individual voltage controller – e.g. implemented as a self-commutated inverter with AC output – has to be added to the individual connection point of a customer to the public grid. Again, it has to be mentioned that this approach would be quite revolutionary and the idea is more on the level of an academic character at the moment. An even more revolutionary approach would be to change from AC to DC in the household and thus to avoid the high number of converters used today.

In order to summarize, the implementation of the 20-20-20 targets will lead to three challenges for the electrical network:

- Solving the transportation challenge which is caused by the locations of the big renewable generation sites. This item is assigned mainly to the transmission grid
- Solving the voltage quality challenge which is caused by the dispersed generation and which leads to changing load flow direction in the distribution grid
- Solving the power balance problem which is caused by the fact that not only the load is volatile but also the generation. Renewable energy source are not controllable with respect to production. This item is a system issue.

CONECTION OF NEW POWER PLANTS AND TRANPORTATION OF THE ELECTRICAL ENERGY

The connection of the immense renewable generation capacities includes several challenges. To begin with, the power plants have to be connected to the existing grid. As far as the transmission grid is concerned long distance transportation becomes an issue as already mentioned above. As a consequence congestions within the national systems have to be reduced by building additional transmission lines. As an example within Germany it is crucial to reinforce the North – South capacities. In addition, the cross border bottlenecks have to be removed as well by increasing the cross border capacities. As an example the projects of cross border lines between Belgium, France, Germany, Luxembourg and The Netherlands can be mentioned.

All those projects are feasible from a technical point of view. Nevertheless, with respect to the approval procedure there are quite some challenges as there are many restrictions in order to get the official building permission. The procedure is not only time consuming but the rules also differ from member state to member state. In many cases it is easier to get the building permission for a wind park and to build it than to connect the wind park to the existing grid. However, without grid there is now transport of electricity. The NYMBY (not in my backyard) effect is quite widespread in the European Union.

Another issue is the request to use underground cables. It has to be reiterated that on a transmission level the cable technology is much more expensive compared to an overhead line and the electrical parameters – above all the specific capacity – are by far less favorable. In addition extra high voltage cables are from a technical point of view not as mature as high voltage or medium voltage cables.

Finally, it has to be mentioned that the North Sea off-shore wind parks will be connected through DC-lines to the electrical system on the mainland. By connecting the wind parks with additional DC-lines – which is not technically fully solved at the moment – a big energy exchange platform between the UK, the Nordic market, Germany and The Netherlands will be created. The hydro power plants in Norway even can be used as storage systems for the wind energy produced in the North Sea. Arguing more future oriented this North Sea DC grid can be considered as the core of a potential European DC super grid which connects solar thermal energy generation in the south of Europe or in Africa with the wind energy produced in Northern Europe. In any case DC technology can substantially increase the North – South transportation capacities.

BALANCING OF THE SYSTEM

As electricity still cannot be stored to a lager extend the balance of generated and consumed power has to be granted at any time. Today the load is considered to be volatile and the deterministic generation follows the load. Only unplanned outages on the generation side create some volatility. The metrics for describing the power balance is the constancy of the frequency.

In general, there are three steps on the generation side in order to achieve the power balance in the system. These steps are differing with respect to time duration:

- Power plants contributing to the primary reserve:
  The reaction time is in the range of 30 sec, the time duration of the service has to be as short as possible in order to gain back the availability for other incidents and the whole UCTE area is contributing
- Power plants contributing to the secondary reserve:
  The reaction time is in the range of some minutes, the time duration of the service is about 15 minutes and has to be replaced by the minute reserve in order to become available for other incidents and only the frequency control area concerned is contributing
- Power plants contributing to the minute reserve:
  The reaction time is in the range of 15 minutes, the time duration can be some periods of 15 minutes and concerning time duration there are more economic than technical constraints.

The substantial increase of volatile renewable generation capacities increases the need for back-up power plants but also increases the requirements towards primary and secondary control as the generated power might change (i.e. drop down) very fast and to a large extent. Above all, wind generation is quite challenging when it comes to a storm and the turbines are quickly taken out of work for safety reasons.

In order to provide enough back-up power – i.e. power which corresponds with the minute reserve criteria – there are several options:

- Market coupling in order to optimize the use of the existing tie lines and to increase the area where consumption and generation has to be balanced
- Building new tie lines in order to improve the coupling of markets and to give more options for energy exchange
- Building new lines in order to allow long distance transportation of energy and to further increase the area where consumption and generation has to be balanced (the establishment of a European DC super grid is the far end of this idea)
- Building new peak power plants (those power plants will be mainly gas fired which leads to the question of a sustainable and reliable supply with natural gas)
- Building additional storage options (next to the existing hydro storage power plants pressurized air storage systems are an interesting option; with respect to decentralized systems electrical vehicles should be considered as well)
- Introducing and fostering demand side management by including the private households

From a political economy point of view the options should be used according to the merit order.

In order to make the situation more transparent an example shall be discussed. We assume a country where there is a consumption of 30 TWh of electricity per year. In case the utilization time of the conventional generation park amounts to 4 000 h in total a power plant capacity of 7 500 MW has to be installed. Thereof e.g. 4 000 MW might be base load and e.g. 3 500 MW might be peak load.

In case that 35% of the energy consumption should be supplied from renewable energy sources roughly 10 TWh have to come from those sources. Assuming a utilization time of renewable power plants in the range of 2 000 h per year a capacity of 5 000 MW of renewable energy sources has to be installed.

Assuming also that e.g. 10% of the renewable power installed is available on a reliable base 500 MW of the installed 7 500 MW can be replaced. This means that the new generation portfolio amounts to 12 000 MW of installed capacity – which is an increase of 60% – compared to the initial situation. Out of this 4 500 MW are volatile i.e. non controllable.

As a consequence the demand for peak power is increasing from 3 500 MW (load defined) to 4 500 MW (generation defined). Of course there might be a coincidence between peak demand and peak offer. However, as the availability of the 4 500 MW renewable generation can not be guaranteed an equivalent back-up power has to be available. As a consequence, in our example the existing peak power plant capacity has to be increased by 1 000 MW or demand side management options in the same amount have to be made available. This corresponds with a reduction potential of 13.5% for the load.

SMART METERING

In order to add demand side management to the portfolio of options for balancing the system several preconditions have to be fulfilled:

- There must be sufficient load available that can be influenced
- The information on the current and actual consumption of the customer must be made available
- There must be a bidirectional communication channel to the customer in order to get the information on consumption and to send orders to the consuming devices of the customer
- The coordination of millions of small load changes must be done successfully. The logistics behind this cannot be compared with ripple control applications or the load management on the transmission side.

As a consequence, it is obvious that without the implementation of smart metering demand side management with respect to private households is not possible. In addition, it becomes clear that smart metering can not be only defined by bringing customer data to a data center. Smart metering also includes orders to be sent from this data center to the consuming devices. It is more than just data collection with a higher sample rate combined with automated meter reading and visualization to the customer. This often seems not to be fully clear when smart metering is discussed.

In case there is a high specific electricity consumption per customer, like e.g. in the US with about 15 000 kWh/yr because of air condition systems or in Norway with about
20 000 kWh/yr because of electrical heating, it is evident that there is a high potential for demand side management. Above all, in these examples the thermal inertia of the buildings is used as energy storage.

In Germany with about 3 000 kWh/yr average consumption per household the potential for demand side management is much more limited. However, the necessary investments on the metering side are the same. In this case it seems to be necessary to get more electricity applications to the households. The 20-20-20 targets will support this as already discussed above. Potential fields for increasing the electricity applications are:

- Electrical vehicles
- Electrical direct heating in combination with low energy houses
- Electrical heat pumps
- Air-conditioning.

In any case demand side management on a customer level will shift system responsibilities to a certain extent from the transmission level to the distribution level. This means of course a more intensive cooperation between the transmission and distribution systems.

Concerning the use of demand side management several options are possible:

- Load leveling, which means to shift consumption from peak to off-peak times and which only needs a limited data exchange frequency
- Contributing to the minute reserve, which means a reaction time for load reduction of about 15 minutes. This approach is a rather physical one
- Load curve shaping, which means to minimize the deviations between the purchased energy and the actual consumption with respect to a balancing group. In case the balancing period amounts to 15 minutes the reaction time must be shorter. This approach is focusing on the trading side of the business.

One interesting question is how to get the data from the customer to the data centre. Just to show the order of magnitude, in the case of Germany we are talking about 40 million metering places. The use of PLC technologies (from 0.6 to 2.5 kbit/s) to bring the metering data from the meter to a data nod (e.g. situated in a MV/LV transformer station) and then through GPRS (from 9.6 to 20.0 kbit/s) or other technologies to the data centre is a quite promising and economic approach. However, there will be limits for the data transmission and it does not seem to be very likely that e.g. every minute all data of all of the customers are transmitted. New technologies like IT broad band cables which shall be made available to all households allow baud rates of 50.0 Mbit/s and thus open new options.

It should not be an exaggeration to state that the data management described will be a kind of revolution within the distribution business.

In order to come to a technically feasible demand side management some customers have to be used as samples in order to create a consumption pattern. The individual customer will be controlled through an overall data centre.

With respect to the contribution of demand side management to the system stability also a more regional approach is possible. Each distribution unit – e.g. HV/MV transformer together with the equivalent MV and LV grid – has to define certain load flexibility as a function of the frequency. The consumers and producers within this distribution unit are acting in such a way that the load is reduced when the frequency is reduced as well and the other way round. The data centre in this case is linked to the transformer station.

In any case, the individual contribution of a customer to demand side management has to be evaluated on a monetary base.

The most sophisticated version of smart metering requires bidirectional communication and frequent measurement of the load. However, there are also reduced levels of “smartness” which need less technological efforts and also might bring some benefits to the utility involved:

- Visualization of consumption in order to increase the information for the customer and to allow him to get better control about his energy consumption. The benefit for the utility is in the field of image and potentially customer loyalty. The local availability of information is sufficient
- Increase of consumption flexibility with respect to tariffs. This allows the utility to get influence on the peak load. Again, the local availability of data is sufficient
- Improvement of the customer switching process. The real and not the estimated consumption is made available very timely. However, at least automated meter reading is necessary
- Enabling more frequent billing. In case the regulator asks for a more frequent billing based on the actual consumption automated meter reading becomes indispensable
- From an operational point of view outage localization through automated read meters becomes possible even in the LV grid
- Frequently read meters also can contribute to reduce black take offs
- In case of an increased importance of dispersed generation a better control of the load flow – e.g. in order to avoid overload of lines – becomes necessary. Again, automated meter reading is sufficient
- Finally, there is demand side management with a focus on peak load reduction, provision of minute reserve or the management of a balancing group. Only in this case a bidirectional communication is indispensable.

As a consequence of this analysis only the last point allows a sound business case for the full deployment of smart metering. The other features are just “add-ons”.

From a political economy point of view the question how to get the additional flexibility into the electricity system in order to balance load and generation at any time in an economic and sustainable way has to be answered. This means it has to be analyzed whether the implementation of smart meters, the establishment of pressurized air storage systems or the commissioning of an additional gas fired peak power plant is best solution concerning the merit order.

In order to get a clear decision at this point it is important to remember the different electricity consumptions per household in the European Union. This means that the merit order can differ from member state to member state. The more electricity applications we see in one household the more efficient demand side management will be.

With respect to the statement that only demand side management allows a business case there should be a clear distinction between the electronic meter including in-house options as well as automated reading and the bidirectional communication when it comes to regulation. Only elements which allow a business case can be subject to the market. All the other issues which are requested by policy – e.g. improvement of customer information or more frequent billing with actual data – have to be recognized by the regulator as costs of the system operator. Of course, any cost reductions by efficiency increase have to be deducted from the cost base.

Finally, the customer protection has to be mentioned. Providing consumption data with a high frequency allows a quite detailed analysis of the behavior of the customer. In any case his privacy has to be respected. This issue has to be taken very seriously.

SMART GRIDS

Based on the analysis done so far a definition of a smart grid is possible. The smartness of a grid is given by its ability to manage the challenges caused by the 20-20-20 targets in a smart, i.e. cost efficient, sustainable and future oriented way. This includes distribution grids as well as transmission grids.

With respect to the transmission grid the connection of the large size renewable generation plants has to be managed as well as the long distance transportation of the electricity generated. Therefore new technologies like DC transmission lines – not only as point to point connections – combined with AC lines, the use of the thermal reserves of transmission lines by implementing temperature monitoring, and so on have to be implemented.

With respect to distribution grids the changing load flow has to be mastered as well as the increased changes in voltage. This means in detail to increase the installed grid capacity but also using more flexible elements like voltage controlled MV/LV transformers or others. Dynamic reserves in the infrastructure have to be made available.

The investments into transmission and distribution grids must be secured within the regulatory regime, however, from a technical point of view the development of grids is more an evolution than a revolution. Specifically, smart grids are able to manage the future increased generation by renewable energy sources and the future increased use of electricity in an optimized way. Gird automation which can be achieved by more remote control in MV and LV grids but also through stand alone switching logics – sometimes referred to as a self-healing grid – are additional, potential elements of smart grids.

The enabling of demand side management by implantation of smart meters with a bidirectional communication together with controllable consumers and producers forms a different feature. It contributes as well to achieve the 20-20-20 targets but stands besides smart grids. As already discussed, demand side management supports system stability through balancing the gap between the volatile generation and the volatile consumption. Elements like electrical vehicles or heat pumps which increase the controllable power together with the necessary communication infrastructure are part of the demand side management feature. In general demand side management has to be done in a way that doesn't reduce the comfort of the customer.

SMART GRIDS, SMART METERS AND THE MARKET

In order to implement the 20-20-20 targets there are two basic subjects. To begin with, there is the adjustment of the transmission and distribution grids to the new requirements which is a regulated issue. Secondly, there is the implementation of smart meters. The basic requirements – i.e. the customer information about his current and actual consumption, the more frequent billing based on the actual energy consumption as well as the timely customer switching – are regulated issues. Demand side management features which compete with other options like energy storage options or peak power plants are market based. This means the customer who is participating in a demand side management regime has to have benefits for this participation.

In addition, there are new market roles. A data exchange agent has to deal with the data provided form the smart meter. He has to give the data to all parties who are allowed to deal with these data. However, he also has to send the consumption or generation orders to the customers and producers. The data exchange agent has to act in a transparent, objective and non-discriminatory way. The function can be regulated or not. It also has to be decided which structure has to be given to the data exchange agent. Finally, it has to be decided how to organize the data exchange agent (country wise, regional, hierarchy, a.s.o.):

Three more market related issues shall be mentioned as examples. To begin with, the price for renewable energy is subject to support schemes which exclude this energy from the market. For the future it can be estimated that the installed capacity of renewable energy sources will amount more or less to the same power that we have today in the conventional power plant portfolio. The liquidity of the power market will be reduced substantially in case there is no integration of renewables into the market. This questions the current market model.

Secondly, the current systematic of grid tariffs doesn't charge generators at the moment ($G = 0$) in order to avoid market distortions. All costs are assigned to the customer side ($L > 0$). There is also no transmission component ($T = 0$). In future the customer will become a "prosumer" which e.g. means he is a generator for 50 % of the time and a consumer for the remaining 50 % of the time. With respect to the example this means that he pays grid tariffs only for 50% of his energy consumed (while his overall energy balance with the public network amounts to zero). In order to get the grid costs reimbursed there are two basic options. Either the grid tariffs L have to be doubled or the generation G has to take some part of the costs as well. In order to avoid market distortion a European harmonization is indispensable when it comes to $G > 0$. An alternative is to install independent meters for generation and consumption in one household. In this case the current grid tariffs can be kept.

Finally, it seems that electrical vehicles play an important role with respect to the market model. The deployment of electrical vehicles and the necessary charging equipment is much more advanced than the deployment of smart meters. Charging posts can be considered as private households where the inhabitant – represented by the electrical vehicle – is changing frequently. Also in this case the customer has to have a choice concerning the supplier delivering the electricity. This means that the function of the data exchange agent has to be established as well. As a consequence, the market model used for electrical vehicles has a pilot function for the market model which is connected to smart meters.

PERSPECTIVES FOR DEVELOPMENT

Wide area connections of grids like the connection of the UCTE grid and the Russian grid – either with AC or DC links – as well as the Mediterranean extra high voltage ring also have to be considered as elements of smart transmission grids [3]. Different generation and consumption patterns are connected and thus contribute to a better balance between production and demand. Even different time zones would be connected through such projects.

Also the already mentioned idea of a European super grid based on DC which integrates Northern wind power with Mediterranean solar thermal power generators combines different generation patterns and thus contributes to a balance between production and demand as well [4]. Even if those ideas sound quite visionary the first elements of a European DC super grid can be built quite timely in combination with the planned huge off-shore wind parks in the North Sea.

CONCLUSIONS

The 20-20-20 targets will contribute to a sustainable development of the energy supply of the future. Transmission and distribution grids will have different, however, increased transportation tasks. Stabilization of voltage will play a more important role in the distribution grid. In the future not only the load but also the generation will be volatile. This will increase the challenges with respect to keep the power balance. All available options for a solution have to be taken into consideration. This brings demand side management back on the agenda. Smart meters with a bidirectional communication will play an important role. In addition more electrical applications which will occur as a consequence of the 20-20-20 targets will contribute in a positive way in order to make demand side management feasible. The regulatory framework has to take the new situation into account and in order to keep the markets liquid renewable energy sources have to become a part of the market.

REFERENCES AND REMARKS

[1] European Commission; “EU Climate Package”; 2008
Remark: It is interesting to note that CO_2 reduction targets are referring only to the energy sector which together with the transportation sector is responsible for about 35% of the CO_2 emissions. The meat production sector with an overall CO_2 emission share of 18% is not touched at all
[2] European Commission; European Smart Grids Technology Platform; “Vision and Strategy for Europe’s Electricity Networks of the Future”; 2006
[3] UCTE-IPS/UPS; “Feasibility Study: Synchronous Interconnection of the IPS/UPS with the UCTE”; 2009
[4] Desertec Foundation, “Concept Studies”; 2009

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