The Way from Traditional to Smart Power Systems

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Abstract:

Power systems are underlying inevitable changes. Their transition phase from traditional into smart power systems is analysed by means of the three main components: power plants, grid and consumers; their management systems and the operators' role. Results show that power systems are undergoing a spiral evolution process with revolutionary elements only in the first transition phase of the integrated Energy Systems Era. The contemporary power systems are in the second transition phase. The storage is going to split-off from the power plant main component, and will create its own new main component. In frame of the further automation of the grid, the low voltage management systems will be promoted. A new actor, the low voltage grid operator will facilitate the prosumers participation on the grid operation.

Keywords: Smart grids, Smart power systems, Evolution process, Power management systems, Operators' role.

Introduction:

The "Energywende" is nowadays one of the most important political, economic and technical issues. It encloses the increase of the energy efficiency, the use of the renewable energy and the smart grid. Hence the electrical industry is going through a transformation process. The question of whether this transformation is subject to an evolution or revolution process is peculiar because it defines its development way. There will be a radical change of the order of things or a planned progression of events? The terms Evolution and Revolution are in a certain aspect one and the same thing, because they both represent a "Transformation" /1/. They differ to each other according to the time of their appearance. The word Evolution synonymous with gradual and continuous, natural or planned progression of events. While the word, Revolution, implies planned and deliberate changes more or less sudden in their action, taken to change the order of things.

The paper examined at the beginning the historical development of power systems. Further it focused on the analysis of the current period by investing in details the three main components of the power systems: power plants, grid and consumers; the development of the power system management systems; and the operator roles.

1 Power systems spiral evolution process

The historical development of power systems can be unfolded in three eras: the Legacy Distributed Power Era (1890–1910), the Central Station Power Era (1910–1990), and the int-

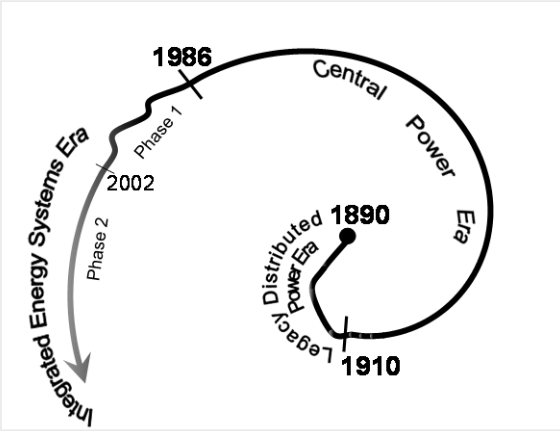


Figure 1: Three eras of power system development

grated Energy Systems Era (2000 –) /2/. The first era was characterised by small distributed power plants which provided electricity to local customers through DC power lines. The second was characterized by large power plants, which supplied power to the distant load centres through AC power lines. Conditioned by the technology level in this time the number of the small distributed power plants remained very limited. The rise of distributed power is transforming power networks around the globe into integrated energy systems. The third era, the current one, is characterised by the re rise of the small and very small distributed power plants. Furthermore the comeback of the DC power is already the scientific focus of many research units /3-5/.

The recurrent of the small distributed power plants and the consideration of the DC power on actual research works indicate a spiral development process of power systems. Figure 1 shows the three eras of power systems development as part of a spiral development process. Both first eras and their transition are characterized by a gradual, progressive technical evolution. Only the liberalization of the electricity industry marked a downright turbulent development of power systems. The transition to the third era is ongoing and can be unfolded in two phases:

- The first phase - the Electricity Industry Liberalization (1986-2002) implied planned changes, forced from political decisions. The liberalization put the old order completely in question; the market rules overcome the technical /6/. Several black outs and electricity crisis - e.g. electricity crisis in California (2000-2001), were the consequence. This phase can be categorised as a revolution process.
- The second transition phase: Smart Grid (2003 –). To determine its nature, a detailed analysis of the current power system development is following.

2 Power system development

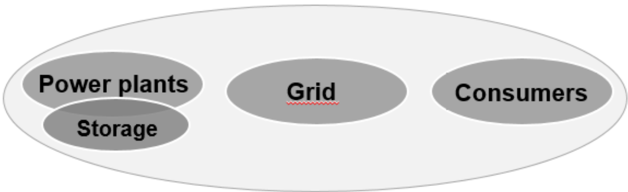
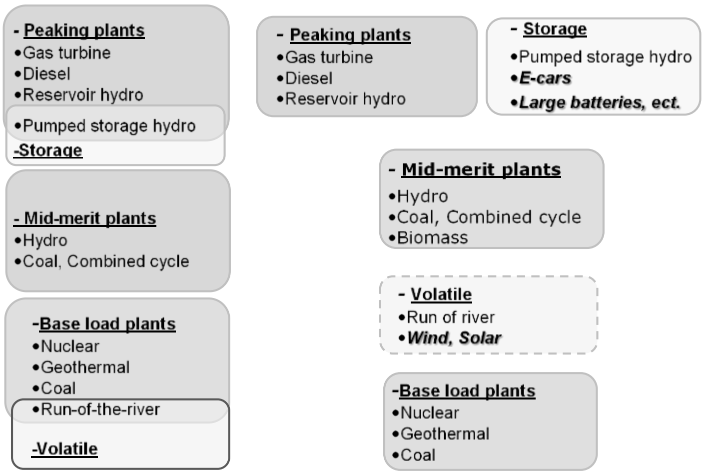


Figure 2: Main components of power systems in the present

For a better understanding, power systems are conceived in three main components: the power plants, the grid and the customer. Figure 2 shows the main components of power systems. Storage, almost in form of pumped hydro storage, is historically presented as part of the power plants component. Nevertheless the whole power system operates continuously and dynamically. None of these components can be treated separately; they are deeply interdependent. The generation-demand balance is the base process of the power system posturing. The fluctuation and uncertainty of the generation and demand have characterized power systems from the beginning. Therefore their design and operation is conceived to deal with the fluctuating demand and generation from hour to hour, day to day, and season to season.

2.1 Power plants

Large power plants are designed to balance different parts of the total system load. The 24 hour total system load profile is spitted into three parts: the base, mid-merit and the peak load. The base load part is more or less constant around the clock. The mid-merit part of the load, which changes are largely predictable – such as the morning rise and the evening fall. The peak part of the load is the variable, unexpected load demand. Depending on the supplying destination power plants are classified in base-load, mid-merit, and peaking plants. Figure 3a) shows the power plants classification in the near past. The base load plants (e.g. nuclear, some coal, Run-of-the-river, geothermal) tend to operate continually. Most of these plants are designed to operate at full power all the time, their output can be changed less quickly and to a lesser extent Specially the Run-of-the-river power plants have a volatile nature, because they are producing so much electricity as the current river flow. Run-of-the-river plants supply electricity is reliable and generally with predictable fluctuations. Therefore they are utilised in to cover the base load /7/. The mid-merit plants (e.g. combined–cycle gas, coal) ramp up or down to cover the rising or falling load during the day. While the peaking plants (e.g. open-cycle gas plants, reservoir or pumped hydro plants; storage facilities) are designed to operate only during short peak periods.



a) b)

Figure 3: Overview of power grid management systems: a) in the near past and b) in the future

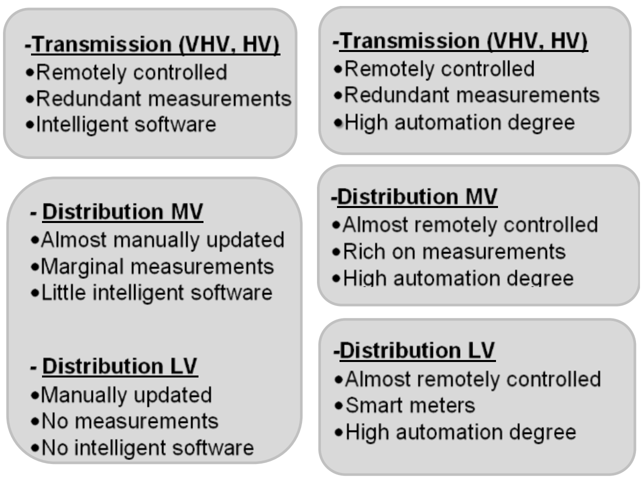
Figure 3b) shows the power plants classification in the future. Actually, the presence of the volatile energy is increasing by using more and more mostly the solar and wind energy. The idea to use the solar and wind technologies to generate electricity is as old as the power system history. Indeed the first small sized power plants (5 kW to 25 kW) were installed in Denmark during the first development era of power systems /8/. However, the development of the appropriate technologies stagnated because of the increasing availability of the combustible energy resources. From the beginning of the 21st century the solar and wind technologies are taking an unprecedented development. This is rising the presence of the high volatile renewable electricity in the systems, and with it also the increase of the fluctuation and uncertainty of the supply. In those conditions the generation-load balancing process is becoming harder. By high output of the volatile energy resources the mid-merit plants are forced much more than it would be expected to do otherwise, while even nuclear output must rump down in occasion /9/.

The presence of the storage capacities will increase the balancing capacity of the system. Different storage technologies (e.g. batteries, flywheels, compressed air energy storage, etc.) are in development process. With their consolidation and integration on large scale on the power systems, the storages may be spit-off from the power plant main component and create the own main components. The new storage technologies differ essentially from the power plant technologies.

The strengthening of the grid is also another possibility to increase the balancing capacity of the system. However the extension of the high voltage grid is a longsome process and sometimes impossible. As results the grid is oftener overloaded. Another factor that is challenging the grid is the increasing of the distributed generation share. The advance of the small power plants technologies have combined to alter the economic appeal of distributed power vis-à-vis central station power plants.

2.2 The grid development

The grid is the binding link between the electricity production and consumption. Actually it is divided into two parts: transmission, which includes the very high and high voltage grid (HVG); and the distribution, which includes the medium and low voltage grid (MVG and LVG). Figure 4a) shows an overview of power grid parts in the near past. Within the power system, only the HVG is fully monitored by using redundant real time measurements and intelligent software like state estimator. Almost all switch devices are remotely controlled. Power plants and reactive devices are usually primary controlled. Secondary (e.g. load frequency control) and sometimes also tertiary control are implemented based on economical or scheduling purposes. In distribution the switch devices are predominantly manually updated. They have marginal real time measurements and almost no intelligent software. The number of the distributed power plants, which inject directly on distribution is very limited. However, the presence of the volatile energy and the increasing share of distributed generation is challenging the grid. The technology advances and the requirements for the highest energy efficiency, dynamic optimization, and market participation are embossing it. The transformation of the grid is an ongoing process. Figure 4b) shows an overview of the power grid at the end of the transformation process (in the future). The distribution grid will be decentralised in MVG and LVG /10/. All three parts of the grid be HVG, MVG or LVG will be high automated by the implementation of the secondary control based on technical issues. The number of the real time measurements in MVG will increase. Using of the intelligent software will enable the full monitoring of the MVG and LVG. Smart meters will substitute the traditional meters in large scale.

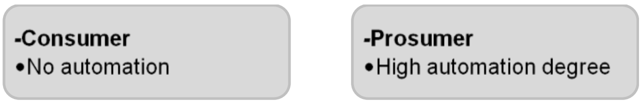


a) b)

Figure 4: Overview of power grid parts: a) in the near past and b) in the future

2.3 Consumers

Consumers are the third main component of power systems. In reality it is the integral effect of millions of customers, who are used to electricity being available when needed, which



a) b)

Figure 5: Costumer overview: a) in the near past and b) in the future

define the power system dynamic in the most routine of the day. Figure 5a) shows an overview of the costumers in the near past. Customers were purely consumers and no any home automation were available. However, recently the behaviour of many costumers is changed. The installation of the small PV plants on the house roofs transformed them during the day in electricity producers. A new category of customers appeared: the prosumers. The increasing number of the prosumers connected on the grid is challenging its operation. Consequently, the house automation and their integration on the grid is the focus of many research projects. Figure 5b) shows an overview of the costumers in the future. Smart home automation and their integration on the grid will increase clearly the number of prosumers.

Summarising the volatileness and the presence of the distributed generation are not new phenomena in power system history. The large scale integration of the renewable electricity and of the distributed generation is rather an additional than a new challenge in the power system operation. The advanced technologies and the requirements of the "Energywende" are evaluating power systems. Storages are undergoing an intensive development process. After have been consolidated and integrated in large scale they may split-off from the power plant main component and create their own main component. Figure 6 shows the main components of power systems in the future. The consumer main component may evaluate to the prosumer one.

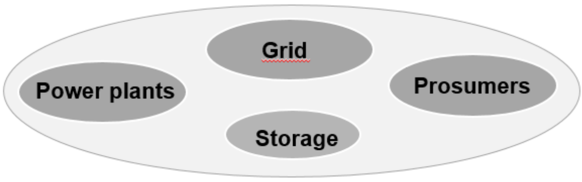


Figure 6: Main components of power systems in the future

3 Power system management systems

A Management System is a system of computer-added tools that provides management and control services. They are used by operators of electric utility to monitor, control and optimize the performance of the power grid. Figure 7 shows an overview of power grid management systems in the present and in the future.

Energy Management Systems (EMS) are the first management system in the power systems history and provide advanced management and control services specialized for HVG. Meanwhile Distribution Management Systems (DMS) are developed recently due to the increasing requirements on real-time network monitoring and dynamic decisions and provide advanced management and control services specialized for MVG, Figure 7a).

LV network is the part of the distribution networks which has traditionally been characterized as the most unglamorous one. No any attention was devoted to it and its elements, and as result no any appropriate management system is designed yet. Different manufactures are trying to solve the increasing requirements to model and observe LVG with the existing DMS, which are designed almost for medium voltage grid. However the ongoing smart meter roll out process and the photovoltaic penetration with their specific technical characteristics are bringing masses of data into play, which cannot be managed meaningful with the traditional

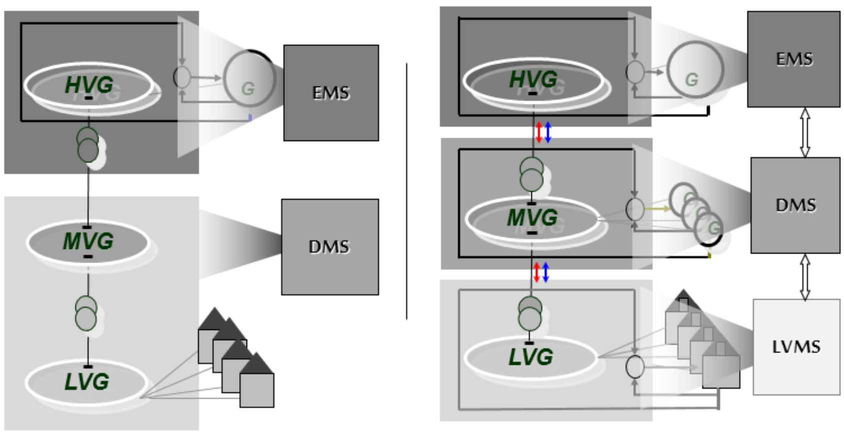


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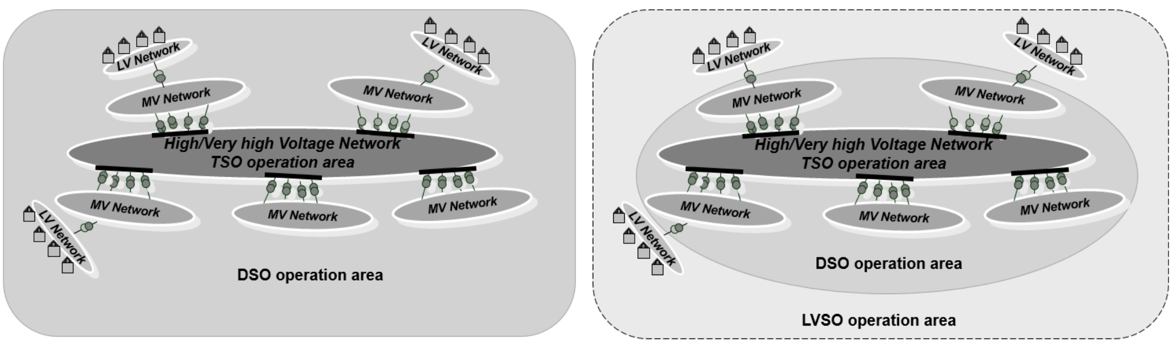
Figure 7: Overview of power grid management systems: a) in the present and b) in the future

DMS. Those data management and their use for the on line control and the dynamic optimization of LVGs is one of the challenges nowadays. Consequently, the establishment of a Low Voltage Management System (LVMS) is necessary /10, 11/, Figure 6 b). A LVMS is a system of computer-added tools used by operators of electric utility grids to measure, monitor, control and optimize the performance of the injections, loads, storing devices and the low voltage grid.

4 Operators role

The deregulation of the electricity industry in the last decade of the 20th century required the introduction of two new actors: the transmission and the distribution system operator (TSO and DSO). TSO is actually operating and managing the high and very high grid, while the DSO the medium and low voltage grid. Figure 8a) shows the power grid operation areas in the present. As described above LVG has recently gained significantly more attention. Smart meters installation and the requirements to include the prosumers to the demand response process complicates their operation and management. Costumers are the most conservative part of the power systems. Their integration in the demand response process is very longsome and related with social issues /12/. Therefore a new actor, the low voltage grid operator, is proposed to be introduced /10/. The need to introduce this actor has already been stressed in various research projects such as the Beywatch /13/, Address /14/, Fenix



a) b)

Figure 8: Power grid operation areas: a) in the present; b) in the future

/15/, etc., which have called for the necessity of this actor, sometimes named Supervisor or Aggregator, to be in charge of the interface between the electricity company and the prosumer portfolio. Figure 8b) shows the power grid operation area in the future. The DSO operation are will restricted than only to the MVG.

5 Conclusions

In the second transition phase of the third era the power plants component is enriching with volatile energy resources and small distributed power plants. A fourth main component is rising: the storage. The grid is upgrading with more measurements and automation, and the consumers are transforming to prosumers. Numerous research projects are ongoing to realise a smooth transition process into the third era. The existing Energy and Distribution Management Systems are in upgrading process with new appropriate applications. A new operator, Low Voltage System Operator, may appear together with the corresponding Low Voltage Management System.

All this shows that modern power systems are in the middle of an evolutionary process.

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