Paper accepted for presentation at 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania

New participants in SmartGrids and associated challenges in the transition towards the grid of the future

P. Favre-Perrod, *Member, IEEE*, R. Critchley, E. Catz & M. Bazargan

Abstract – **Different concepts for the long term evolution of electricity networks have been proposed. Visions of large scale, continent-wide interconnections, local scale independent distribution network cells and networks integrating other forms of energy have emerged. The inclusion of new classes of network participants, e.g. prosumers, services providers, transportation applications, regulators and the increase of the number of distributed generators is a common feature of all these frameworks. A series of challenges result from this evolution: the need to coordinate distributed participants, the need to harmonize standards and procedures, as well as the need to overcome a series of obstacles to change. This contribution reviews emerging network concepts and the associated challenges. Series compensation, reconfigurable power electronic systems and wide-scale use of phasor measurement units are early examples for these emerging solutions.**

Index terms – **Power transmission, Power transmission planning**

I. INTRODUCTION

QUITE a number of concepts for the layout and operation of future energy systems have been proposed in recent years. To respond to the shift towards renewable and stochastic energy sources, increased electricity consumption and the new market organization, a number of novel network concepts have been proposed: supergrids, microgrids, active networks and multi-energy networks.

An important factor is the appearance of additional participants in electricity networks: combined consumers/ producers (so-called prosumers: households with own generation, storage, etc.), providers of services (i.e. as opposed to “only” generators), transportation applications (electric vehicles) as well as other applications moving from fossil fuel sources to electricity and regulators.

This contribution reviews the major categories of approaches to future energy systems and discusses the issues related to the introduction of new participants into electricity networks, and the resulting necessity for adaptations in current electricity networks.

II. CONCEPTS FOR FUTURE ELECTRICITY NETWORKS

A. *Microgrids*

In a system comprising distributed electricity generation, consumers and producers may be located within the same distribution system, reducing the need for long distance transmission. Therefore, the concept of microgrids, i.e. small distribution networks with energy sources and sinks of similar magnitudes has been proposed [1].

These network cells can be operated independently from their superordinated networks. This means that energy balancing, voltage and frequency control can be performed locally and that comparatively sophisticated protection and control systems for the (de-) islanding of these cells become necessary.

B. *Active distribution networks*

The concept of active distribution networks has been proposed based on the need to adapt the passive distribution infrastructure to the myriad of novel distributed participants expected to appear in distribution systems. Rapid changes in demand and generation, provision of network services by distributed participants, bi-directional energy flows, increased information exchange and intelligent appliances (demand side participation) will require controllable and scalable architectures.

Concepts associated with active networks are virtual power plants, reattribution of control duties to network participants and solutions for dealing with information exchange among a very large number of participants (in comparison to the present situation).

C. *Supergrids*

Increased long-distance electric energy flows from large offshore wind farms, large scale solar-thermal or photovoltaic plants (e.g. in North Africa) to load centers are an unresolved problem. Several groups have therefore suggested the use of a combination of extra-high voltage or d.c. transmission, partly offshore. This overlaid network layer would provide the necessary interconnection capacity whereas the subordinated network layers would remain in place for (national) distribution.

Some authors have also proposed to combine such long

P. Favre-Perrod is with AREVA T&D, St. Leonards Ave, Stafford ST17 4LX, UK (e-mail: patrick.favre-perrod@areva-td.com)

R. Critchley is with AREVA T&D, St. Leonards Ave, Stafford ST17 4LX, UK (e-mail: roger.critchley@areva-td.com)

E. Catz is with AREVA T&D, Chemin de la côte, 69802 Saint-Priest, France (e-mail: emmanuelle.catz@areva-td.com)

M. Bazargan is with AREVA T&D, St. Leonards Ave, Stafford ST17 4LX, UK (e-mail: masoud.bazargan@areva-td.com)

978-1-4244-2235-7/09/$25.00 ©2009 IEEE

distance electricity transmission with hydrogen transmission, possibly as a coolant for a superconducting electrical conductor [2].

D. *Multi-Energy networks*

Since many consumers and producers handle several forms of energy (and not only electricity) and networks of the future are expected to see a higher integration of different energy services including storage, so-called multi-energy networks have been proposed [3]. The underlying intention is to consider all forms of energy when developing an optimal network structure.

Fig. 1 shows a possible arrangement of consuming and producing participants connected to the multi-energy network by adapted interfaces called energy hubs. This network encloses several forms of energy, e.g. electric, thermal and chemical.

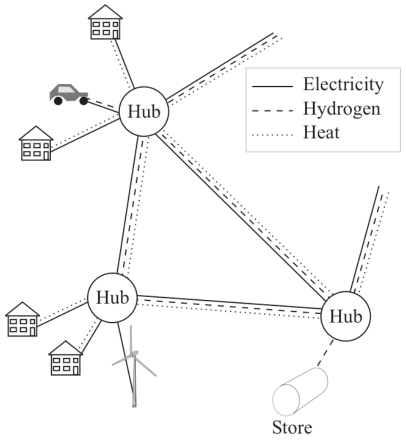

Fig. 1. Illustration of the structure of a multi-energy network. Energy consumers and producers (electrical, chemical and thermal energy) are interfaced by energy hubs which convert, condition and store energy.

III. NOVEL PARTICIPANTS IN FUTURE ELECTRICITY NETWORKS

Fig. 2 shows some possible characteristics of the organization of an electric system of the future: new participants (prosumers, service providers, etc.) will use networks to exchange active power, services and information in "multi-lateral" transactions. A sharper distinction between the roles of each participant can be expected (nowadays, active and reactive power are often provided by the same participant, e.g.). This contrasts with the present mainly unidirectional flow of active power:

- Since more player (discussed below) will appear in the system, the number of transactions (or exchanges) will increase.
- More different types of transactions will occur in the system. Today essentially active power is traded whereas in the future, services markets will emerge.
- These transactions will be multi-lateral: from a utility-consumer relationship the system will evolve towards a marketplace involving a broad range of participants.

A. *Prosumers*

Opportunities for businesses and households to cover parts of their needs with own generation will increase in the future. In combination with the introduction of intelligent appliances (demand side participation) this implies that the traditional energy consumer can become a producer at certain times of the day, hence the emergence of the word "prosumer".

B. *Services providers*

Participants might emerge who do no produce or consume energy, but participate to the optimization of network operations by providing services. Such services include energy storage, provision of balancing power (reserve), power quality and possibly reactive power (in sub-transmission networks).

C. *Transportation applications*

The public and technical debate on the solutions to make road transportation independent on fossil resources shows that electric cars are a very strong option for the future. Plug-in cars are therefore a potential new network participant.

The high amount of energy involved, the storage capacity represented by the cars and the specific spatial "behavior" of these new participants makes them hugely different from other grid participants.

D. *Regulators*

As governments' interests are often no longer represented in the boards of monopolistic state utilities, regulators have been put in place to accompany the re-regulation process. The focus of their interest is security and compliance to legislation. In order to increase the effectiveness of regulation, these new actors are likely to be more actively involved in aspects related to network operations in the future.

E. *Distributed generators*

Distributed generators connected to distribution networks are not fundamentally new. Their rising number will however contribute to the factors affecting changes in future networks.

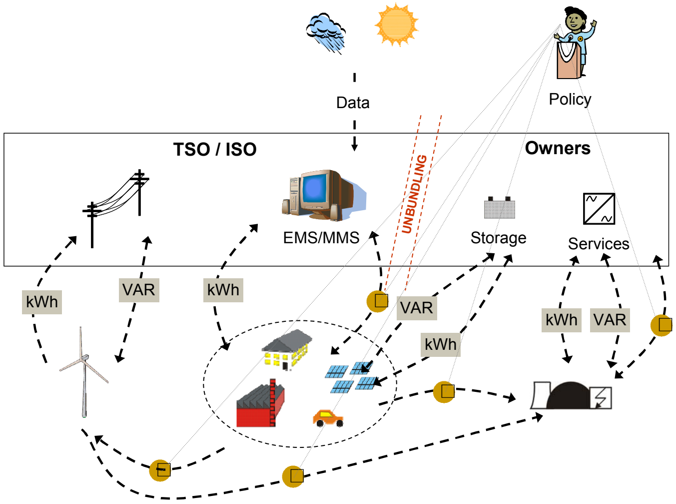

Fig. 2. Participants and transactions in the future electricity transmission and distribution system.

IV. CHALLENGES

A. *Coordination of distributed services*

The appearance of large numbers of distributed participants raises the question of the aggregated action of dispersed network participants (plug-in cars, generators, smart appliances, etc.). From a system operator's perspective, these participants have the potential to substitute central plants' functions by means of their collective and coordinated action. As a consequence, new ways of making the information regarding large numbers of distributed participants available to network operators will need to be developed and integrated into network management systems. These systems will also need to make better use of forecast tools for both stochastic generation and load. Establishing a DSO (distribution system operator) function appears to be key to reach this.

B. *Harmonization of regulations and operational procedures*

The inclusion of new participants and network duties will impact on network operation. The following changes can be anticipated:

- Mechanisms to make use of demand response need to be established: currently system flexibility is manly provided by centralized power plants; their replacement by renewable and stochastic generators will require the participation of the loads to system balancing.
- Islanding, synchronization and reconfiguration of distribution sub-networks needs to be facilitated, since local generation is likely to be sufficient to feed a significant share of local loads in may future distribution networks. This will permit to ensure higher reliability and a faster recovery from outage situations.
- Operation of storage and other new small-scale network participants providing services needs to be integrated into grid management tools. The computational challenge of managing this rising number of resources shall not be underestimated.
- Integration of a large number of distributed and renewable generators will require plug and play style network connection (thus lowering the associated engineering efforts). A number of pre-standardization efforts have been started into this direction.

Microgrids solutions have been successfully implemented in the past, e.g. using AREVA T&D's Pacis substation control system. The technical viability and the added value for sensitive users could thus be established. However, such systems remain the exception in current systems, and more effort will be necessary to encourage utilities to use MicroGrids at a larger scale.

A second early example of a modular system permitting the integration of a larger number of distributed participants are D-STATCOM systems. E.g. an SVC MaxSine dynamic shunt compensation device has been delivered by AREVA T&D to a steel processing plant near Abu Dhabi. The 72MVAr AREVA T&D SVC MaxSine provides high customer benefits: thanks to the improved power quality, the steel processing plant could increase the power it receives from the network, thus reducing the typical tap to tap time (equivalent to one cycle of the arc furnace) from 53 minutes to 49 minutes. This implies a high productivity gain for the customer and more revenues for the local utitily. This example shows that D-STATCOM permit to increase the usage of distribution network. Other application cases, independent of an industrial process are likely to appear in the future, e.g. in the context of integrating large amounts of generation into rural networks, or increasing the amount of electrical energy delivered to urban areas due to the increasing "electrification" of our energy consumption

C. *Technical standards*

The following areas of standardization will require adaptations, which include the following:

- Information systems, especially new components such as meters; data transmission formats and protocols as well as "physical" interfaces, plugs and space requirements.
- Quality of service (especially at the lower voltage levels).
- Ancillary services provided by participants: responsive demand, storage, reactive power, filtering, etc.
- Type testing and certification of interfacing equipment (distributed generation, energy storage), including proof of "plug & play capability".

Once standards will permit this, the use of multi-functional and interoperable power electronic converters is likely to become more widespread. The HVDC*ice*^{TM} system developed by AREVA T&D is an early illustration of this. This system is a combination of a static VAR compensator and an HV transmission line de-icing system: in normal operation the system acts like a standard FACTS device and it takes only minutes to automatically reconfigure it to a de-icing system (DC current source). This scheme has been successfully implemented in Hydro Quebec's transmission network. It has the advantage of reducing the required space and costs for providing each of its services. In this example, the SVC consists of a TCR, an SVC and additional filters. As shown in figure 3, the TCR is the reconfigurable part of the converter, which can be used as a DC current source for the de-icer.

D. *General barriers for SmartGrids*

Finally some more general barriers to the transition towards SmartGrids exist:

- Conservatism of network operators (e.g. reluctance to adopt decentralized operation or reduce operational margins). This can be explained partly by the failure of solution providers to clearly establish the benefits of novel solutions. On the other hand the downstream consequences of power interruptions cause a high risk aversion of utilities and operators

- Diverging views of different user groups or equipment suppliers
- Difficulty to establish the clear advantage of Smart-Grids technologies in “classical” systems (e.g. to compete with existing systems reliability and losses)
- Failure to identify a strategy for continuous and gradual changes. This is currently being addressed by European policies.
- Long equipment lifetime. This means that old technology cannot be replaced with new as it becomes available and that all new components need to be compatible with potentially 40 years old existing technology.

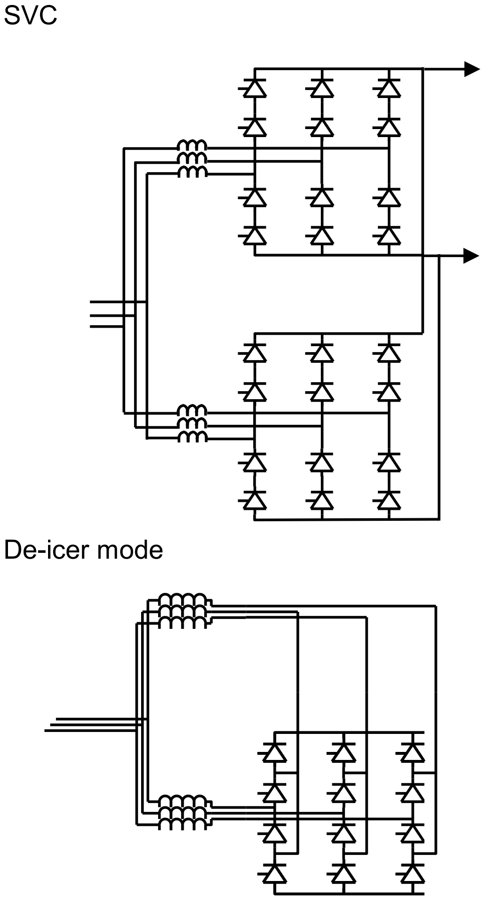

Fig. 3. Reconfigurable HVDC*ice*™ TCR. The same power electronic building blocks can be automatically reconfigured to obtain two distinct functions: a TCR (thyristor controlled reactor) or a DC current source for the de-icing of overhead lines.

Phasor measurement units (PMUs) represent a forward-looking means of insuring system stability and realibiltiy depite increased stress. E.g. Hydro Québec has installed 10 units into its network. The PMU system records the harmonics distrortion, phase angle difference, frequency, voltage variation and system status every 5 seconds. These measurements are a cornerstone of the TSO’s defense plan and are used for power rejection and remote load shedding, automatic switching of shunt reactors, underfrequency load shedding, undervoltage remote load shedding and protection against system separation. Operators are furthermore supported in their task by advanced visualization systems like AREVA T&D e-terra Vision.

Series compensation is another means to increase the transmissible power: it is currently used where the transmission distances are very long (e.g. Brazil, Finland, Canada and China). Series capacitors are used in the HV (High Voltage) and EHV (Extra High Voltage) transmission lines to compensate the inductive reactance of the transmission lines. The advantage of a series capacitor is that it automatically compensates the line i.e. the compensation power can be adapted according to the line current. This reactive power increases the power transmission capability and stabilizes the system.

Increased power transmission requirements from north to south and increased power export from Canada to the United States have lead to insufficient transmission line capacity in a part of B.C. Hydro’s network. B.C. Hydro decided to increase the compensation level of the existing power transmission line by building a new series capacitor bank. Nokian Capacitor Ltd, and B.C. Hydro signed the supply contract of the Guichon Project in May 2002. The Series Capacitor bank 500kV, 420Mvar, 2400A, 60Hz was put into commercial use in November 2003. The Guichon project increased the current currying capabilities from 1600 to 2400 amperes, improved system stability and reduced losses. It also ensured sufficient power supply in the case of faults in parallel lines.

V. CONCLUDING REMARKS

A number of visions for the long term development of energy systems co-exist and confirm that the addition of new players changes the requirements for the development of future energy systems. This will require a larger agreement among sector participants to respond to the challenges related to the long term evolution of network architectures and operations, as it was initiated e.g. by the European technology platform SmartGrids [4].

Some flagship projects show that advanced features can be added to current electricity system using state-of-the-art technology, but they are still only a few examples. Indeed the SmartGrids technology platform has indentified this and released a deployment plan for the envisioned innovative feature of the future electricity grid [5]. The action of all involved stakeholders is now required.

VI. REFERENCES

[1] R.H. Lasseter, “MicroGrids”, *Proceedings of the 2002 IEEE Power Engineering Society Winter Meeting*, vol. 1, p. 305, 2002.

[2] P. M. Grant, “The supercable: dual delivery of chemical and electric power”, *IEEE Transactions on Applied Superconductivity*, vol. 15(2), p. 1810, 2005.

[3] M. Geidl, G. Koeppel, P. Favre-Perrod, B. Klöckl, G. Andersson, and K. Fröhlich, “Energy hubs for the future”, *IEEE Power and Energy Magazine*, vol. 5, p. 24, 2007.

[4] European SmartGrids Technology Platform, “Vision and Strategy for Europe’s Electricity networks of the future”, 2006.

[5] European SmartGrids Technology Platform, “Strategic deployment document for Europe’s Electricity Networks of the Future”, 2008.

VII. BIOGRAPHIES

Patrick Favre-Perrod was born in Vevey, Switzerland, in 1979. He graduated in electrical engineering and information technology from ETH Zurich, Switzerland.

He has written his thesis in the area of future power systems at the high voltage laboratory of ETH Zurich. He is currently a research techologist at the AREVA T&D Technology Centre in Stafford, United Kingdom. His fields of interest include multi-energy systems, active electricity networks and novel building blocks for T&D networks.

Dr Patrick Favre-Perrod is a member of CIGRE, IEEE and Eletrosuisse.

Roger Critchley was born in Stoke-on-Trent, UK in 1947. He joined AREVA T&D (then English Electric) in 1966 as a sponsored student and studied Electrical/Electronic Engineering at Staffordshire University, UK from 1966 to 1970. Since then he has worked extensively in the field of power electronics, mainly in R&D of power electronics based solutions for both industrial and HVDC/FACTS applications. His current role is in AREVA T&D’s Technology Centre where he is responsible for all Power Electronics based research and innovation projects. He is a Member of the Institution of Engineering and Technology (IET).

Emmanuelle Catz was born in Paris, France, in 1975. She graduated in Electrical Engineering from Supélec (Gif Sur Yvette, France) in 1999. Since then, she has been working in AREVA T&D, in the fields of High Voltage Substations and Power Electronics applications.

Masoud Bazargan is the General Manager of AREVA T&D Technology Centre in Stafford where he heads a multi-disciplinary team of engineers and scientists working on a wide range of research topics including SmartGrids technologies. Dr Masoud Bazargan is a Chartered Electrical Engineering and since joining the industry, he has been mainly working in the area of Power Systems modeling and analysis. During his career, he has worked for manufacturing as well as utility and consultancy industries.