Renewable Energy System management processes in Smart Grids operation

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Abstract

Many regulations, with EU energy package as one of the most important, contribute to the growing role of RES in the general energy-fuel balance. Numerous advantages from the implementation of RES are also an important issue in the process of its development. Nevertheless, connecting numerous RES into the electrical grid causes its instability. Due to Renewables 2011 Global Status Report, RES have grown to supply an estimated 20% of global final energy consumption in 2010 and total global investment in renewable energy (RE) broke a new record in that year. The process of implementing RES into a grid is complex and demands fine management strategy. Local smart grids tend to be a solution for managing an increasing number of dispersed RES. The aim of this paper is to present management processes during implementiation of RES into a smart grid.

Keywords: Renewable Energy Resources, smart grids, electric vehicles

Introduction

In 2010 RES accounted for approximately half of the estimated of new electric capacity added globally. The most significant RES was a wind energy that increased its' capacity by 39 GW. Other popular types of RES were hydropower (30 GW) and solar power (almost 17 GW).

The leaders among countries around the world in RES' investments in 2010 were the United States, China, Canada, Brazil, and India tied with Germany. During that year, in the USA RES accounted for 11,6% of national total electric capacity. China made the best results in installing wind turbines, solar thermal systems and was the best hydropower producer in the world. A share of RES in China's energy-fuel balance was 26%. In the EU's countries RES accounted for nearly

41% of total investment in electric capacity in 2010 that gives 22,6 GW with total installations up 31% over the previous year [1].

This significant, world-wide growth illustrates a popularity of RE. It is assumed that dispersed RES have an important potential to mitigate climate change thanks to a reduction of greenhouse emissions. It can also lead to local energy independence. However, increasing share in a energy-fuel balance requires changes in energy policies and grids. Locating a RES development at a local level demands local strategies of management. The development of RES is a very complex process that demands making various considerations and taking a lot of actions. The uncontrollable growth of RES', based on wind energy, share in the electrical grid is a potential cause of its volatility. That is the reason of including social, economical, grid, legal and environmental issues into RES' development strategy for communes and investors.

Large amounts of dispersed RES generate a need for a new approach in a modelling, analysing, forecasting, managing and simulations in a grid. That is an opportunity for smart grids that are seen as a solution for enhance reliability and stability of a grid. It is outlined in a definition of a smart grid by the Smart Grid Task Force: "the integration and application of real-time monitoring, advanced sensing, communications, analytics, and control, enabling the dynamic flow of both energy and information to accommodate existing and new forms of supply, delivery, and use in a secure, reliable, and efficient electric power system, from generation source to end-user".[2]

RES technologies can be variable and unpredictable over differing time scales, variable but predictable, controllable or constant.[3] These RES' characteristics makes a management process in a grid more difficult and smart grids tend to be a solution for this instability.

1. RES' characteristics

Growing popularity of RES entails changes in RE policies around the world. In a consequence there has been an escalated growth of RES technologies in a recent time. During five years, the amount of countries that defined their RES policy

[1] *Renewables 2011, Global Status Report*. REN21, Paris, 07/2011, p. 17-18.
[2] *Reliability Considerations from the Integration of Smart Grid*. NERC North American Electric Reliability Corporation, Princeton, December 2010, p. I.
[3] *Report Renewable Energy Sources (SRREN), Summary for Policymakers*. IPCC Intergovermental Panel on Climate Change, Abu Dhabi, May 2011, p. 3.

doubled from an estimated 55 in early 2005 to 119 by early 2011[4]. RES policies: national, provincial or local are crucial in RES development. In developing countries the reach of a grid is very limited, that is why a core of RES policy is to wider energy access to improve social and economic development. In industrializing economies the reach of a grid is better but due to rapidly growing electricity demand there is a deficit in an energy capacity. In these countries the crucial part of RES policy is to ensure an access to electricity in areas so far not reached by a grid and to cover an increasing demand. In developed economics, the grid is national commonly available but grid's infrastructures are usually old. In these there are two important factors in RES policies: modernization of a grid and environmental issues. RES policies have also helped in overcoming barriers in RES deployment such as: social, institutional and policy barriers, market failures, lack of data significant for RES development. A well processed RES policy depends on numerous local factors i.e.: affordable capital, a level of technical maturity, ease of RES integration into a grid, a local / national RES base.[5]

There are numerous types of RES: wind, ocean, geothermal and solar energy, biomass, hydropower and – generally – these sources can be integrated into all types of grid from national to small, local ones. Nevertheless, some RES integration as i.e. wind or solar energy may be more difficult without storing devices due to their variability.

Managing RES growth demands compiling a local RES range and working out new, flexible methods of short term load and demand forecasting, planning and operation tools, demand response programmes (DR), implementing new RES and storage technologies, etc. What is more, long-term development of RES will demand grave investments in a grid infrastructure, modification of institutional and governance frameworks, concentration on social aspects, advance in markets and planning and capacity building in anticipation of future RES growth[6].

Development of RES contributes to sustainable development and offers the chance to supply social and economic progress especially in poor rural areas without access to national grid. These areas may be supported by small smart grids - microgrids, that can work in a islanded mode with local RES and have a possible impact on local power supply. These concept can be also implemented in developing countries where decentralized microgrids and dispersed RES may expand and improve energy access. But also in urban or metropolitan areas a conjunction of

[4] *Renewables 2011, Global Status Report*. REN21, Paris, 07/2011, p. 49.
[5] *Special Report Renewable Energy Sources (SRREN), Summary for Policymakers.* IPCC Intergovermental Panel on Climate Change, Abu Dhabi, May 2011, p. 23-24.
[6] *Special Report Renewable Energy Sources (SRREN), Summary for Policymakers.* IPCC Intergovermental Panel on Climate Change, Abu Dhabi, May 2011, p. 15.

microgrids and RES may have a serious impact on power quality and service, energy supply stability, demand optimization and reduction of atmospheric pollution.

Implementing of RES gains an ecological benefit that is a reduce in a greenhouse gas emission. The ecological factors embrace advantages gained from a substitution of coal-based energy with green-energy. Producing energy from coal results in increasing an atmospheric pollution. 1 MWh got from a combustion of coal emits the following amounts of noxious substances: 850 kg of carbon dioxide (CO2), 11 kg of carbon monoxide (CO), 10 kg of sulphur dioxide (SO2) and 4 kg of nitrous oxides (NOx). A wind plant energy capability is estimated for 2 000 – 2 400 MWh/1MW per year. It means that from 1 MW of installed power it is possible to gain from 2 000 up to 2 400 MWh of electric energy every year. This value can change under numerous circumstances like weather conditions or turbine's working time. Taking two presented above values under considerations it is possible to reduce the emission of noxious substances in a result of replacing conventional power plants with wind power plants as shown in a table below.

Table 1. reduction of the emission of noxious substances in a result of replacing conventional power plants with wind power plants

	Unit	2 000 MWh	2 400 MWh
CO2	kg	1 700 000	2 040 000
CO	kg	22 000	26 400
SO2	kg	20 000	24 000
NOx	kg	8 000	9 600

Source: Own elaboration.

Greenhouse emission reduction is not an only environmental impact of RES development. RES technologies can offer benefits also in reducing deforestation and forest degradation and lowering associated health impacts. RES have also low fatality rates thanks to their decentralized structure.[7]

An important factor of RES development is their economical competitiveness in comparison with cost of coal-based energy. Currently, the price of green-energy is higher but it depends on technology characteristics, regional variations in cost and performance, differing discount rates.[8] A RES investment's profitability depends on numerous factors like: location, financing methods, installed power, cus-

[7] *Special Report Renewable Energy Sources (SRREN), Summary for Policymakers.* IPCC Intergovermental Panel on Climate Change, Abu Dhabi, May 2011, p. 18.

[8] *Special Report Renewable Energy Sources (SRREN), Summary for Policymakers,* IPCC Intergovermental Panel on Climate Change, Abu Dhabi, May 2011, p. 9

tomary manner of depreciation, price of a land, etc. Several RES technologies are already competitive and other may become due to popularization of these resources and microgrids. Though, it is important to notice, that profitability of RES depends not only on economic factors but environmental and social as well.

2. Smart Grids operation

Existing grids tend to be centralized with radial topology and one-way communication. They are prone to failures and blackouts and require manual restoration. Customers have only few possibilities of making choices and limited price information. By contrast, smart grids accommodates distributed generation (DG) and network topology. Two-way communication, monitors and numerous sensors takes effect in self-monitoring, self-healing, remote monitoring and pervasive control system. For customers, implementation of a smart grid denotes a full price information and many possibilities of making choices[9].

It is looked forward that local microgrids will progress reliability of a bulk power and distribution system and perk up energy efficiency and quality. Due to the interconnection of RES, it will reduce greenhouse emissions. What is more, demand response programmes will enable consumers to manage and control their energy usage and costs in a more aware and responsible manner.

Smart grids characteristics embrace interoperable tools enabled by expansion of ICT tools to improve monitoring, management and way of electricity usage. ICT for microgrids should support following core areas: real-time management, process interoperability, data exchange, Web-based consumer engagement, design reflecting service-oriented architecture standards (SOA), inclusion of tools to manage deployment, operation and maintenance of advance metering infrastructure (AMI), home area network (HAN) and other systems.[10]

Microgrids are scalable what means that its range can fluctuate from a large-scale utility level to commercial or industrial level or small, remote microgrids for a single community. Utility microgrids are able to facilitate large-scale deployment of RES and CHP generation, DS and offer ancillary services i.e. local supply of reactive power and premium power quality as long as DR programmes. Commercial or industrial microgrids are designed for users with a demand for a high degree

[9] Feasel M., 2009. *The Smart Grid: Getting smart about possibilities, challenges*. (in:) Plant Engineering, October, p. 52-53.

[10] Johnson L., 2010. *Design Considerations for Smart Grid Management Systems*. (in:) Power Grid International, p. 36-41.

of power quality and reliability. Even short power outages may be critical and not tolerated. These grids are usually smaller that utilities ones and includes areas like big shopping centres, universities and their campuses, factories or other industrial installations. Remote microgrids consists of small DER for electrification of small, often isolated, communities or single premises. In a case when a remote microgrid works in an independent, isolated mode (i.e. on geographical islands or in developing areas) it is crucial to install RES that have to be sized to serve all users with an adequate level of reserve capacity for contingency management.

The wide subset of functions that microgrid's management ICT system must ensure can depend on a reach of particular smart grid. In a case where there is an area in which more than one microgrid exists, emerge new functions i.e. communications between two grids, cooperation with a national grid or energy market. That demands additional supervisory control like distribution network operator (DNO) and market operator (MO). When a microgrid works in an islanded mode and do not cooperate with national grid these objects are not necessary.

Control and operational strategies of microgrid can vary according to local accessibility of RES, load characteristics, market participation strategies or power quality and stability constraints. Dynamic, variable, unpredictable characteristics of RES differ from traditional, conventional ones and thanks to distributed RES and single-phase loads, microgrid is inherently subject to a major degree of imbalance. Economic factors often state that RES in microgrid should be readily connected and disconnected while maintaining its operation. What is more, microgrid might be obligated to deliver prespecified power quality levels or other preferential services to some loads. Also strategies for operating microgrid should include storage systems[11]. Distributed storage (DS) technologies are necessary when the supply and demand can't be precisely matched. DS can improve the whole performance of a microgrid, because it stabilizes and permits dispersed RES to work at a constant and stable output, in spite of possible fluctuations, provides the ride-through capability during dynamic variations of primary energy and permits RES to flawlessly operate as a dispatchable unit.[12]

[11] Katiraei F., Iravani R., Hatziargyriou N., Dimeas A., 2008. *Microgrids Management.* (in:) IEEE Power & Energy magazine, May/June, p. 54- 64.

[12] Kroposki B., Lasseter R., Ise T., Morozumi S., Papathanassiou S., Hatziargyriou N., 2008. *A look at Microgrid Technologies and Testing Projects from Around the World.* (in:) IEEE Power & Energy magazine, May/June, p. 41- 53.

3. Smart buildings intrusion into microgrids

Smart, green buildings may complement microgrids and support a development of prosumers' society. According to the European Union Directive on the Energy Performance of Buildings (EPBD 2002/91/EC), more than 40% of Energy consumption in Europe is due to heating and lighting operations in buildings. That is a reason for searching for a new ideas in construction to gain more energy savings.

A smart, passive building has to be designed with a usage of special building materials, architecture and installation but, as it is written in a European Commission Report "ICT for a Low Carbon Economy. Smart Buildings", Information and Communication Technologies (ICT) are the engine for making this possible.

A concept of a zero-energy, smart building arises in a House2020 project performing within the scope of Bioenergy for the Region - Programme for PhD Students development. The project consists of two major parts: a concept of a single smart, passive house and a passive estate project that consist of 20 terraced houses with perfect southern exposure and 1 technical plant.

The main features of designed passive house are: superinsulation, compact shape, exposure towards the equator, right fenestration, air tightness and a Building Management System (BMS). Reduced energy demand for heating is achieved by: smart design, increased thermal insulation, air tightening the building envelope, installing high performance windows, incorporating an HRV system and BMS system that helps to optimize an energy usage.

Thanks to a superinsulation a passive house acts like a thermos. The risk deriving from thermal insulation is an excessive moisture of building partitions that causes: deterioration of the interior microclimate, a good environment for microbial growth, decrease in thermal insulation of materials plus corrosion and destruction of partitions. For that reason a good ventilation installation should be designed.

The main installation in a building are: solar hybrid system, micro-power station scheme and a recuperator. Micro CHP installation consists of: steam turbine, multifuel, evaporator, capacitor, power generator, electric pump and low boiling medium. Solar hybrid system has a photovoltaic module as a top layer and solar thermal collector as a bottom one. Photovoltaic module produces electric energy and solar thermal collector is responsible for photovoltaic module cooling and heat production. The efficiency of the integrated solar system is higher than a sum of its components as a result of providing optimal work temperature of photovoltaic module. A recuperator is responsible for a ventilation and disposal of used air. In winter warms the air from a central heating installation and in summer chills air with the usage of a absorption cooling unit.

As mentioned above, Due to the European Commission Report it is clear that if smart, green buildings are to become commonplace, that this can only be facilitated by ICT. ICTs role is crucial due to the facts that: new ICT based systems would allow peer-to-peer sharing of energy produced through renewable schemes, smart meters would allow households buy and also sell energy and ICT will allow information on energy consumption of every energy-consuming appliance in a building to be provided in real-time, in a user friendly way, thereby empowering citizens to take decisions that lead to energy savings.

BMS is a solution that is already present in some buildings. Nevertheless, the is inability to centralize and manage data found within building equipment. Existing buildings are full of technology and communication devices that have been installed ad hold over time. These devices, eg.: household devices, computer and Internet connections, security devices, HVAC systems, lighting, tend to operate on different protocol standards. That is why, usually these solutions are non-integrated and managing or monitoring energy usage is difficult.

The concept of a new BMS system designed for a House 2020 project will include new challenges for BMS systems: usage of smart meters, prosumers, smart household appliances, management of energy consumption. The concept will also include the idea of microgrids, making communication among the set of buildings possible. The energy consumption user profile will be analysed and optimized in a way that maximizes the use of RES installed in a building or a set of buildings.

4. Management of energy storage processes – Vehicle to grid

The intermittent output characteristics of RES makes integration of these sources into a grid more difficult and bound their optimal performance. One of solution for this disadvantage is usage of electric vehicle's (EV) batteries to store energy when supply exceeds demand and use this energy when demand is higher than actual RES capacity. The flexible load of EV's can accumulate electric energy and give it away during peak times. It will prop up a penetration of dispersed RES.

It is possible to distinguish three main types EV technologies: hybrid electric vehicles (HEVs), pure electric vehicles (Pure-EVs) and plug-in parallel hybrid electric vehicles (Plug-in PHEVs).[13] HEVs' motor use gasoline and batteries and don't

[13] Dickerman L., Harrison J., 2010. *A New Car a New Grid.* (in:) IEEE Power & Energy Magazine, March/April, p. 55-61.

need to use electricity from external sources. Pure-EVs run on electric motor powered by batteries recharged by plugging in the vehicle. Plug-in PHEVs can be charged with electricity like EVs and run under engine power like hybrid electric vehicles.

A proper management can make a grid supply the additional energy demand for EVs and manage with intermittent energy production from RES. EVs charged throughout the time off-peak period can store it and send to the grid during the time of peak or more likely – could function as reserve or other ancillary services. This idea is called Vehicle-to-Grid (V2G). It means that the grid has to be updated to become two-way system making possible to collect electricity from remote storages, like PHEVs car batteries. V2G is expected to be one of the core technologies for smart grids integrating renewable sources[14].

V2G revenue in optimization of the load throughout a day. That will make a capacity of a grid improved and more efficient. Charging EVs when an energy demand is low, implicates storing available additional energy and will improve supplying energy demand when it will increase without a necessity of further investments in grid capacity. It will also support a development of dispersed RES and microgrids.

Summary

Both, RES and microgrids are tend to be solutions for improving existing grids in a future. Smart grids are able to transform the quality of whole distribution system thanks to dispersed RES. Variable character of these sources implicates a necessity to manage the load. Local microgrids will gain a better quality of energy, a stability of supply and an energy independence. That is why a development of RES should be perceived at a local, commune level.

RES can enhance power quality and reliability and potentially reduce the need for traditional grid expansion. The difficult RES' management process can be improved with an implementation of smart, local microgrids and – in a next phase – popularisation of electric vehicles and their storage possibilities V2G.

[14] Ota Y., Taniguchi H., Nakajima T., Liyanage K. M., Baba J., Yokoyama A., 2010. *Autonomous Distributed V2G (Vehicle-to-Grid)*. (in:) IEEE PES Conference on Innovative Smart Grid Technologies Europe, October 11-13, Gothenburg.

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