Smart grid power system control in distributed generation environment

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Abstract: This paper discusses on general aspects of smart grids and focuses on some smart grid features at distribution level like interconnection of distributed generation and active distribution management, using automated meter reading (AMR) systems in network management and power quality monitoring, application of power electronics in electricity distribution, plug-in vehicles as part of smart grids, and frequency based load control as examples of interactive customer gateway.

Keywords: smart grid, electricity distribution, distributed generation, active distribution management, automated meter reading, plug-in vehicles, frequency based load control

1. INTRODUCTION

The energy markets are in transition and there are many drivers for creating a new kind of power delivery system for the future. There are many drives and needs as follows:

- The penetration of distributed generation (DG), especially based on Renewable Energy Sources (RES), will continue due to environmental reasons.
- The European and North American vision is to have common electricity market areas with a high penetration of distributed power generation.
- Efficient use of energy at customer level and intelligent demand response has become an essential issue.
- Power quality (supply reliability and voltage quality) requirements will increase due to public and regulatory actions and at the same time failure rates are expected increase due to the climate change.
- There is a need, due to economical reasons, to increase the utilization rate of existing network. The traditional way of developing a distribution network would be the investment on passive wires which would lead to decrement of utilization rate.
- Many components of existing networks are becoming into end of their lifetime. They need replacement or continuation of their lifetime in safe and controlled way.
- Regulation of network companies will tighten up while companies want to ensure profitability of their business. This will mean rationalization of network management both in short- and in long-term perspective.
- The risk of major disturbances is increasing, both the probability and consequences. The reason for increased probability is the complexity of power network and the increased failure rate due to climate change. The consequences are increasing due to society's higher dependency on the power supply.

There are much research, and many visions and concepts for future power delivery system, like super grid, smart grid, micro grid, intelligent grid, active network, power cell etc. Some of them focus on transmission level functions (e.g. integration of large-scale wind power or utilization of FACTS -devices) as some cover low voltage level and customer interface (e.g. large-scale advanced AMR). The concepts have many common features but also some differences, but they are not analysed more deeply here. The main aims to fulfil the above needs are still same. A shared vision of smart grid, or corresponding concept, is an important issue in order to develop commercially successful and useful products for future power delivery system. This vision should be shared by network companies, product vendors and network customers**.**

This paper focuses mainly on general aspects of smart grids at distribution level and gives some examples on studied and developed smart grid features.

2. CHALLENGES FOR DISTRIBUTION SYSTEM

Electricity distribution networks create a market place for small-scale power producers (i.e distributed generation) and for customers (i.e users of electricity). Here, the role of distribution networks is of great significance. For example in Finland, about a half of the total price of electricity for small customers and over 90 % of all interruptions come from the distribution process. There are many challenges for distribution system to enhance it's functionality as the real market place, as follows:

- improving the capability to serve the increasing amount of distributed generation,
- enabling the electricity market development at the customer level e.g. for enhancing market-based demand response and customer-oriented services,

- safe and cost-efficient operation of distribution networks in all circumstances.

Traditionally power generation, distribution network management and loads have been considered as quite independent processes. Along with increasing amount of distributed generation the traditional approach is being gradually changing. Considerable amount of renewable energy resources represents distributed generation, but also active energy resources like loads, storages and plug-in hybrid vehicles will be increased. One of the main barriers for the penetration of active resources at distribution network level is the complexity of the interconnection process. From network management point of view the increasing amount of DG is often considered with reluctance as it brings the complexity of transmission network to distribution network level. The main reason for the complexity is caused by the present methods for managing the distribution networks as well as the features of different active resource components themselves, which are not sufficiently developed to enable easy interconnection. So far loads and customers have been passive from network point of view. By making the customer connection point more flexible and interactive the demand response functions (e.g. by real-time pricing, elastic load control) are more achievable and the efficient use of existing network and energy resources by market mechanisms can be improved.

3. GENERAL FEATURES OF SMART GRIDS

Smart grid concept has different aspects as shown in Fig. 1. It includes novel solutions of infrastructure for future power distribution, e.g. use of power electronics and DC. Active resources (i.e. distributed generation, loads, storages and electricity vehicles) actually change the traditional passive distribution network to be an active one. New network solutions and active resources call for novel ICT solutions for network operation and asset management providing intelligence to active networks. Smart grids enable active market participation of customers and also have effect on changes in business environment. Smart grids are customer-driven marketplaces for DG and consumers.

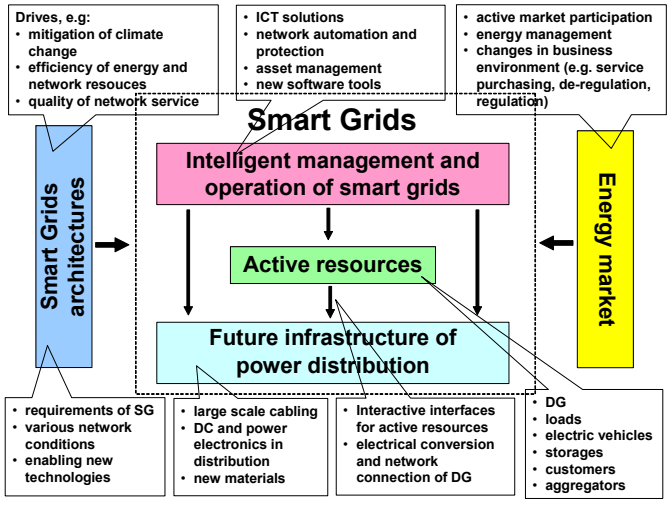

Fig. 1. Aspects of smart grids

Smart grids can be characterized as follows (partly based on Chuang 2008):

- interactive with consumers and markets
- adaptive and scalable to changing situations
- optimized to make the best use of resources and equipment
- proactive rather than reactive, to prevent emergencies
- self-healing grids with high level of automation
- integrated, merging monitoring, control, protection, maintenance, EMS, DMS, AMI, etc.
- having plug-and-play –features for network equipment and ICT solutions
- secure and reliable

Traditional grid includes centralized power generation, and at distribution level one-directional power flow and weak market integration. Smart grids include centralized and distributed power generation produced substantially by renewable energy sources. They integrate distributed and active resources (i.e. generation, loads, storages and electricity vehicles) into energy markets and power systems. Smart grids can be characterized by controllable multi-directional power flow.

Smart metering has been seen as an essential part of the vision of smart grids. Remote readable energy meter is being developed to be an intelligent equipment (i.e. interactive customer gateway) including in addition to traditional energy metering also different kind of new advanced functions based on local intelligence. This gateway opens possibilities for network companies, energy traders and service providers to offer new kind of added-value services to end-customers.

The concept of smart grids may be characterized by words like flexible, intelligent, integration and co-operation. gGrids are flexible because they utilize controllable resources throughout the network. Respectively the passive network has flexibility by network capacity i.e. network itself may handle all probable loading conditions. Intelligence is simply investments on protection, controllability and information and telecommunication technologies instead of pure passive lines, cables, transformers and switchgears.

DG and existing controllable resources like direct load control, reactive power compensation and demand side integration provide a good potential as a controllable resources for the smart grids. The integration of DG and flexible loads in distribution network will benefit the network when managed appropriately. The traditional passive network management or "fit & forget" principle in DG connection needs to be changed into active network management. The integration of DG and other active resources into a distribution system is a requirement in order to fully exploit the benefits of active resources in network management. With proper management of active resources the overall system performance may be improved from presently used practices.

One important control task in power systems is to maintain balance between power production and consumption which means keeping power system's frequency at an appropriate level. This process is becoming more and more challenging