A SMART GRID APPROACH TO DISTRIBUTION MANAGEMENT SYSTEMS (DMS) FOR ELECTRIC NETWORKS

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ABSTRACT

The aim of the paper is to describe possible requirements, objectives and development of automation systems for electrical distribution systems, such as flexibility, accessibility, reliability, economy, also highlighting possible novel types of operation of the grids.
These ambitious goals may be achieved by integrating functions and applications typical of EMS (Energy Management System) for transmission networks into developing DMS (Distribution Management System) for electric distribution networks. A research project under realization is presented.

INTRODUCTION

The paper is aimed at defining automation architectures for electric distribution network management and control in the new context of active distribution systems, i.e. electric distribution networks with significant percentages of distributed generation (DG).
DMS – Distribution Management System is the term used for indicating the distributed control centres that are required for managing electric grids at sub-transmission and medium voltage levels. DMSs are responsible for a large number of complex activities from off-line analysis including geographical information systems, personnel management, outage identification and restoration to advanced applications related to on-line control up to advanced auxiliary services provision. The paper presents the evolution from structures typically used for large Energy Management System (EMS) adopted in Transmission Networks to Distribution Management Systems [1] that manage and control electric distribution networks, see Fig. 1 [2].
Electric distribution networks are rapidly evolving from completely passive systems (i.e., systems with almost no local generation or with not-dispatchable generation) to system with significant percentages of generation mostly of the renewable type and with medium to small scale generation. This fact poses severe problems in distribution system management and requires a re-thinking of hardware and software structures for network automation [2].
Moreover the fact that most of distribution generation is of the renewable type requires that a coordinated control involving different resources such as generators, loads and storage systems is realized so that a unique entity is interfaced with the rest of the grid, [3]. Aggregations of both generators and costumers are expected to improve the participation of medium and small scale generators, as well as loads, to electricity markets.

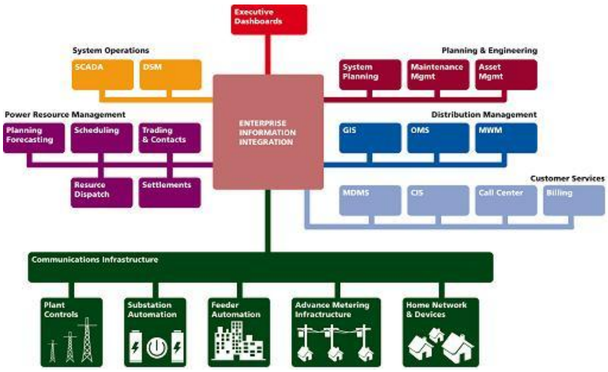

Fig. 1: Description of key elements in a modern DMS architecture [2]. MWM = Material World Modules; OMS = Outage Management System; GIS = Geographical Information System; MDMS = Maintenance Data Mgmt System; CIS = Customer Information System; DSM = Demand Side Management.

GENERAL REQUIREMENTS

An immediate challenge faced by operators of electricity distribution networks (DSO – Distribution System Operator) in the transition from passive to active networks is the integration and connection of distributed resources (DG – distributed generation) in the distribution networks [4].
In the "passive" approach the solution requires the creation of strong enhancements of existing facilities resulting in significant investment that, however, are not compatible with the resources of Distributors and may constitute economic barriers to the integration of DG.
On the contrary, the "active" management approach of distribution networks can maximize the utilization of the existing network by taking advantage of the dispatching of generators, the control of the voltage profiles through transformer ratio and voltage regulators, the control of reactive power and of the topologic reconfiguration of the power system.
The new vision for the electric distribution grid is that of a "smart" grid. The concept is synthetically expressed in documents elaborated by the Smartgrids European

Technologic Platform as: "*A SmartGrid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.*" [2]. The priorities identified by [2] are:

- Optimizing Grid Operation and Use
- Optimizing Grid Infrastructure
- Integrating Large Scale Intermittent Generation
- Information & Communication Technology
- Active Distribution Networks (New Market Places, Users & Energy Efficiency)

For the development of advanced electric power systems automation, it could be of interest to develop hybrid EMS/DMSs as pointed out by [6] some years ago in a timely vision. Such a system would require high-level analysis functions such as, for example, state estimation and contingency analysis, which are typical EMS functions, and the optimization of losses and voltage profiles. Security applications, state estimation and dynamic synoptic reporting should allow the safe real-time operation. These functions must be tailored so as to adapt existing systems and to integrate the functions of distribution systems with new managing and monitoring components.

Despite what currently happens at transmission level, distribution networks have only few measurements from the field and only a small number of controls are automated. Transmission networks usually have a number of measures of active and reactive power and voltage sufficient to satisfy the observability conditions. On the contrary, distribution networks have a limited number of power measurements (typical ones in a distribution network are current measurements at feeders and loads).

Thus an important requirement for the state estimation algorithms is the ability to combine different types of data such as, for example, measurements coming from the field and statistical data on load curves. Customization of such algorithms for the state estimation from the current developments in advanced transmission networks to applications for distribution networks is strongly needed. It might be helpful for achieving a better and more complete observability of the power system to use tools coming from ICT (Information and Communication Technology) such as PMUs - Phasor Measurement Units, WAMSs - Wide Area Monitoring Systems, etc. [5].

One major focus for DMSs is to support the operators with reliable tools to track information not measured: it is important for a DMS to be equipped with functions that are able to detect, report, suggest solutions and to inform consumers of the nature of the disturbance and the estimated time of outage duration. Even more complex functions, such as system recovery after a power failure, could be extremely useful for distribution systems.

Moreover it is useful to consider that the distribution network is more sensitive to topological changes. Additional cables, switches and disconnectors or even distribution substations may frequently modify the pre-existing distribution network configuration. Such changes in topology are much more frequent and likely to occur in the distribution networks rather than in the transmission system.

Since distribution networks are strongly influenced by the terrain it is important for the operator to be able to be aware of the geographical features of the regions in which the distribution network operates. For the effective use of a DMS is therefore necessary that the system can import maps from GIS (Geographical Information System).

In summary, DMSs help operators and engineers in evaluating the electrical behaviour of the network providing fast and efficient tools. These tools usually work "off line" on snapshots of the system, although some of them may switch to "on-line" operation, thus providing the results of the performed calculations directly on the operator synoptic and updating monitored diagrams when changes occur in the measurements coming from the field.

In particular, the main DMS functions are [4], [5], [6]:

- real-time measurements
- state estimation
- power flow calculation
- performance indexes calculation
- short circuit calculation
- voltage control
- losses optimization
- configuration switching optimization
- control of local Distributed Generation
- control of dispatchable loads
- energy storage devices control

POSSIBLE DISTRIBUTION MANAGEMENT SYSTEM ARCHITECTURES

The automation of a power system is placed within a control hierarchy structured to meet the needs of different levels of delivery of energy within the electricity network. This requires that one can manage the network from a "single place" (the control centre) and/or a set of centres distributed on the territory. This control mode exploits a data acquisition system called SCADA–Supervisory Control and Data Acquisition–and is based on communication between the control centre and those devices that can be controlled (generators, switches, tap changers, etc.). These devices need to be equipped with actuators to enable them to perform the operations required by the control centre. The communication between the control centre and the actuators is achieved–in the latest and more innovative configuration–by using the so-called Intelligent Electronic Device (IED).

With the development and the increasing penetration of medium and small size generation in MV and LV

networks (such as small hydro power plants, cogeneration plants, photovoltaic panels or wind farms) distribution networks have ceased to be purely passive loads. A power system with a high percentage of such generation units substantially differs from the traditional power systems viewpoint for which all the distribution networks were passive with uncontrollable loads and few distributed generation.
These reasons show the importance of modern distribution systems that, in recent years, have evolved from an initial supervision-and-control philosophy to an integrated approach.
The complexity of IEDs depends on the configuration of the control system and the hierarchical levels which the system is made of. SCADA is formed by the control centre, communication systems and IEDs. SCADA systems are distributed so as to control the different layers of the network, either as an integrated system that controls a number of underlying layers or as separate systems that pass information (possibly synthesized) to higher levels of control. In fact the choice of how the central system should be arranged directly dependent on the properties of the various layers of the network.

The term DMS, to date, is used to indicate a different number of complex solutions, from traditional energy management, even including advanced features for off-line studies, to the complete real-time distribution networks management that include SCADA systems.
The distribution companies have always maintained their networks according to four main aims of interest (operation, maintenance, engineering, marketing), which influenced all DMS application functions and have often generated independent application software.
The new trend of DMS is to realize single platforms that integrate all functions and applications. However, according to primary and predominant objective of the distribution company the path that leads to a complete integration of functions in the DMS can be different.

DMS systems make extensive use of data to develop strategies for managing and controlling power systems and need to send command signals to the controlled systems. Therefore, it is essential to have a strong interaction of DMS with ICT world [3].
Proper integration between power and communication systems will allow to obtain greater operational flexibility for both generation units and loads [5], [6].
A possible important aspect is the provision of ancillary services to transmission and distribution networks by the local distributed generation. Along with the primary energy supply service, the market provides the supply of a number of services that are considered ancillary to the transmission of electricity from producer to customer, even though many of these services are not necessarily tied to transmission and can be supplied by third parties, different from network operator. These services include, in general, dispatching and control services such as, for example, frequency and voltage regulation, reactive power supply and reserve provisioning [5], [6], [7]. The services can be separated and, therefore, provided by more than one operator in a competitive manner. The final user must carefully determine what specific services are needed and then determine which suppliers can ensure that service at lower cost.
In order to illustrate the potential flexibility of Distributed Generation, the possible fields of action can be:

- assist in the distribution network management through voltage support and coordinated control of power flows;
- use of GD for a better management of the zonal imbalances associated with daily trading of energy;
- use of interruptible and/or controllable loads, such as air conditioning systems as a potential "virtual energy accumulator", with potential benefits in both fuel consumption reduction and elasticity of demand.

In order to enable DG to supply ancillary services for the electric grid it will be necessary to use advanced communication systems. It is worth mentioning here the significant work performed within the IEC 61850 standard framework. Fig. 3 present an overview of possible system services comparing the possible role of both transmission and distribution systems.

Frequency stability:	FP - primary regulation (< 30 s) FS - secondary regulation (< 5 min) FM - minute reserve supply (7 - 15 min)
Power balancing:	PD - scheduling and dispatch
Voltage stability:	VT - Tap-changer control VQ - reactive power regulation
Restoration of supply:	RB - black start capability RI - island operation
Further system management:	SQ - power quality assurance SO - operationsl and asset management

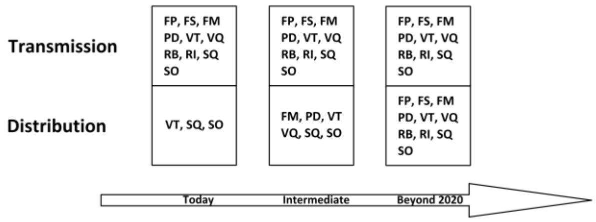

Fig. 3: Ancillary system services. Possible roles for electric distribution systems. (adapted from [8]).

AN APPLICATION EXAMPLE

In order to properly develop and implement methodologies and control and communication architectures in the presence of electrical distributed generation experimental sites also intended to establish innovative solutions are required. In the following we refer to Smart Grid Project, funded and directed from the ENEL Technical Research in Pisa in the years 2007–2008 [7].

This Project had as objective the study and development of innovative solutions for the connection to the network of significant amounts of distributed generation resources. The focal themes of the Project were planning, control and management of a distribution system within the framework of the liberalized electricity market for developing new local markets for energy and ancillary services provision.

The project included design aspects of a test site for:

- different medium voltage (MV) network configurations (radial, meshed, islanded)
- new technologies and strategies for distribution network control, protection, communication and management
- development of an active management system able to operate the network in islanded conditions, to manage the connection with other networks and to maintain the load/generation balance
- control architectures specifically designed for controlling the flow of active and reactive powers through the coordinated management of generators and storage facilities.

The scheme of the MV experimental site within the Smart Grid Project used for supporting the theoretical analysis the following facilities:

- conventional generation (1 MW) including an internal combustion engine in CHP configuration;
- a gas turbine (600 kW) in regenerative configuration, coupled with a boiler and an absorber;
- two fuel cells (250 and 500 kW) based on different technologies (SOFC and MCFC);
- an heat load emulation system;
- a static compensator (1 MW) with a battery storage system additional load provision;
- load and generation emulators up to 6 MW.

This scheme, therefore, included the installation of various types of generators (internal combustion engine, gas turbine, fuel cell and wind turbine) in order to study and test strategies for voltage control of active MV networks and the integrated management of distributed resources in normal or islanded network operation.
For this purpose it was essential to precisely define the Distribution Management System (DMS) and the SCADA characteristics. They should abandon the traditional design and operation of distribution network and get closer to the specific characteristics of monitoring and control systems used at transmission level. The proposed architecture is shown in Fig. 4.

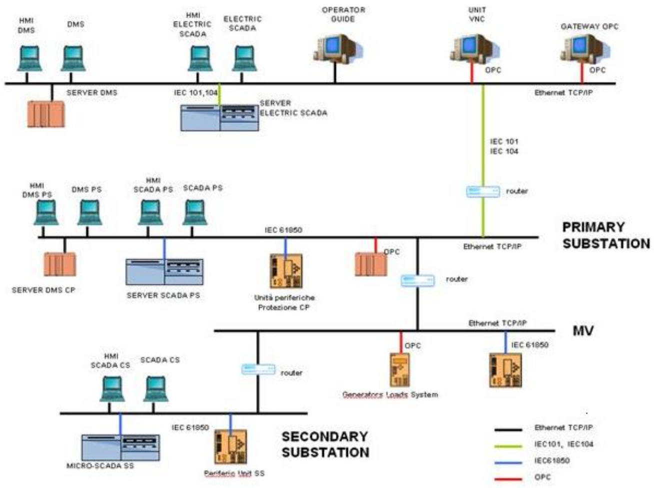

Fig. 4: SCADA/DMS architecture for application on test network.

CONCLUSIONS

The paper presented and discussed in the context of modern architectures for electrical distribution system automation the emerging role of advanced DMS capable of integrating management and control functions. Technological aspects related to communication systems including problems of protection and communication, the role of distributed generation in providing ancillary services have been addressed.

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