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Decentralized Operating Modes for Electrical Distribution Systems with Distributed Energy Resources

N. Hadjsaid, R. Caire, B. Raison

Abstract— **Electrical Distribution Systems (EDS) are undergoing some significant changes at various scales and levels. These changes are triggered by several factors such as the event of Distributed Energy Resources (DER) and the need to improve the quality of supply while achieving economical optima. Hence, several research initiatives, technological development and experiments have been launched worldwide to tackle this situation such as "SmartGrids".**

This panel deals with some new decentralized operating modes for EDS management with high penetration of DER. These decentralized modes are based on distributing the management system locally and intelligently using advanced Information and Communication Technology (ICT). These concepts are being demonstrated through an experimental platform: an analogical micro network (µGrid). Functions such fault management and high level of self adaptive architectures are developed for these new modes.

***Index Terms*- Active distribution networks, ICT and Agent Based Systems evaluation, Distribution Network, Distributed DMS, Restoration process, Distributed Generators, Protection devices.**

I. Introduction

Distribution grids are facing tremendous challenges due to several factors among them the most important is the increasing penetration of Distributed Energy Resources (DER) especially those based on renewable energies. These changes are expected at several levels and scales for both the generation business and the distribution grid operation. As such Electrical Distribution Systems will require new planning strategies and tools, new design methodologies, redefining operation and control of electrical networks for example. Indeed, these networks were not designed and built in the perspective of interconnecting large amount of DER especially when they are not observable neither dispatchable. Distribution Network Operators (DNO) consider that the integration of such resources into the grid may have significant consequences on system performance and security and hence on the know-how of the management systems and robustness.

Therefore, "business as usual" operating modes and regular devices in EDS are reaching their limits to ensure the centralized management of a large amount of information and high-level functionalities as those involved in ADA (Advanced Distribution Automation). Indeed, these functionalities require comprehensive information management support and coordination between EDS devices (circuit breakers, switches, fault indicators (FIs), on-load tap changers (OLTC), capacitor banks, sensors for instance), customers devices (controllable loads, Distributed Generators (DGs) with modulation abilities for instance) and also the information and communication systems for the control of operation tasks during the various operating states. Achieving such objective represents a challenge given the current EDS and the fact that transition steps should be considered taking into account the legacy system. On way to handle these difficulties consists in distributing the management system locally and intelligently using advanced ICT Systems.

Whilst validating next generation of ICT-based Decentralized Distribution Management System, two recent EU Projects, CRISP [1] and MICROGRID [2-3], had developed and tested various new control concepts for grid management and Distributed Energy Resource or Renewable Energy Source (DER/RES) coordination. They built the core algorithms and functionalities to integrate advanced ICT technologies (such as agents) into active distribution networks. Pursuing this ambitious research path, the EU INTEGRAL project (Integrated ICT- platform based Distributed Control (IIDC) in electricity grids with large share of Distributed Energy Resources and Renewable Energy Sources), will push the investigation target much further. The expected validations of INTEGRAL project rely on three field demonstrations which will cover a wide range of different operating conditions including:

- Normal operating conditions of DER/RES aggregations, showing their potential to reduce grid power imbalances, optimize local power and energy management, minimize cost and play a role in the energy market.
- Critical operating conditions of LV (Low Voltage) - DER/RES Microgrid, showing their ability to support the upstream network in case of large disturbances.
- Emergency operating conditions showing self-healing

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capabilities, i.e. fast reconfiguration for post fault treatment and quick restoration of power supply for customers.

All those demonstrations show the advantages and the robustness of agent based coordination for network devices and DER/RES sharing in a common framework a cost effective and reliable ICT architecture. This architecture is philosophically a bottom-up process and the sizing of such concept has to be assessed.

The setup of the analogical micro distribution network for the emergency operation investigation will be introduced first. Some self-healing concepts to overcome the post fault operations and fast up the restoration process are then presented. This panel presents thus the specific ICTs infrastructure which includes the measurement, collection and control of the automation devices as well the communication system between components and/or between each component with the cell level agent.

II. Functionalities of the Analogical µGrid

The analogical micro distribution network (figure 1 and table I) which makes possible to test real RTUs and distributed Distribution Management System (DMS) is presented in this section.

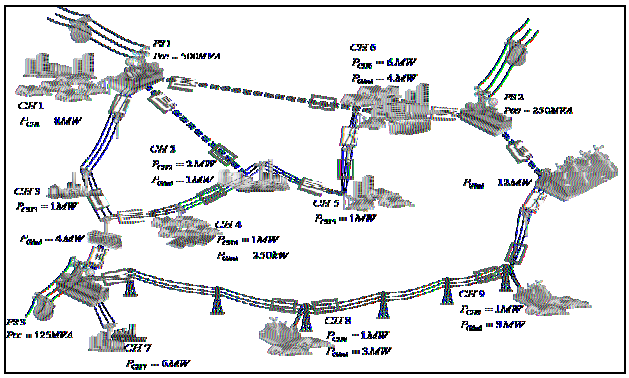

Fig 1. Topology of the analogical distribution µGrid

The scale reduction of the µGrid components is carried out through different ratios (power, inertia and voltage) to assure the identical of the internal static and dynamic behaviors of the network which includes aggregated loads and emulated DER/RES. Indeed, the performance of the control systems must be unchanged in comparison with the real system.

This network encompasses several zones representing different network characteristics. For instance, the electrical lines are generally underground cables in urban areas and overhead lines in rural. Otherwise, operation criteria differ in the various networks such as critical clearing time for the circuit breakers and the switches.

TABLE I. CHARACTERISTICS OF THE ANALOGICAL DISTRIBUTION µGRID

Characteristics	**Analogical µGrid**	**ERDF Grid**
Total load (kVA)	27	27.000
Total generation (kVA)	30	30.000
Voltage (V_{phph})	400	20.000
Number of nodes	14	300
Power's reduction ratio (λ)	1/1000	
Voltage's reduction ratio (µ)	1/50	
Remotely controlled switches	12 in the grid 16 on components (Load/DGs)	
Remotely controlled machines	Active/Reactive Power regulation	

III. Self Healing Functionalities

Real short circuit or overload currents that may occur in MV networks should be first cleared by protective devices and then the smallest faulty part should be quickly located and isolated by gathering, coordinating and processing the information resulted from communicating devices/sensors. Depending on the remotely controlled switch locations, the possible congestions on the lines and the dispatchability of DER/RES, the restoration process will be performed by an Intelligent Agent so that the faulty zones are limited as much as possible and as quickly as possible. The fault distance computation with the impedance based approach should indicate an estimated distance of the fault point from the substation. This estimation does not ensure a precise location of fault due to many bifurcations in the network. In order to locate exactly the faulty section, it is often necessary to cope with further information given by the remote Fault Indicators.

A method using combination of FIs states and fault distance computations from substation or other location was previously developed during CRISP Project. The advantages of this method consist in its high autonomous level for fault location with an associated ICT infrastructure. This method is very efficient for distribution networks with many branches and ramifications (figure 2).

From the fault position, the network may be divided into two parts: downstream fault part and upstream fault part. In order to reenergize the downstream fault part, the system operator must close the feeder circuit breaker to establish the power flow from substation. Whereas, the upstream fault sane portion of network can be supplied by closing the tie switches to connect it to another feeder (figure 3).

Another definition has been introduced in the CRISP project: the level 1 cell. It is the group of feeder linked by tie switches. This structure is the core place of the self healing capabilities.

To carry out the self-healing functionalities within the analogical µGrid, it is mandatory to link (in a form of a network) all of the automation devices within the demonstration site. Local Area Networks (LANs) provide a solution to this requirement.

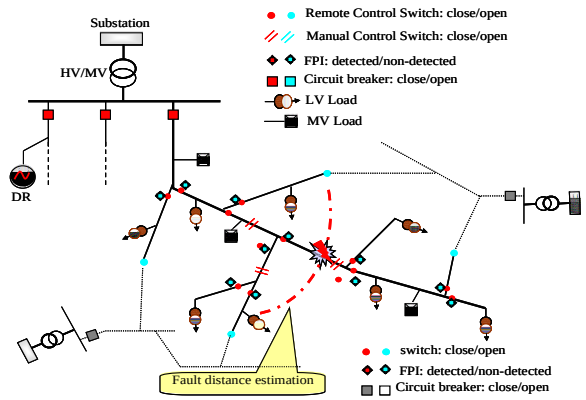

Fig 2. Computation of fault distance in distribution feeders in presence of DERs

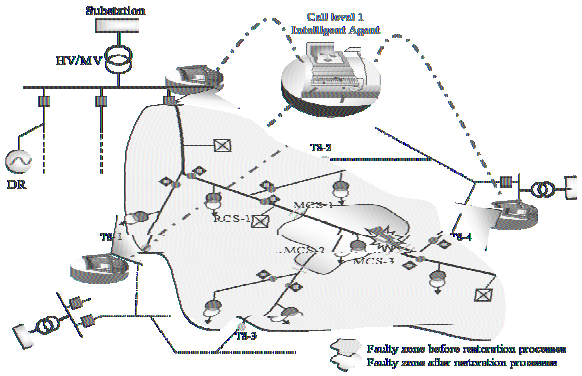

Fig 3. Restoration processes within the level 1 cell intelligent agent

The data communication among the agents in a level 1 cell has then to be specified to assure the reliability of all the functionalities. This is why an emulated communication network was built within CRISP project, allowing the choice of data speed between each communication node [7]. For exchange with other cells or other demonstration sites, the most adapted technical solution is using Wide Area Networks (WANs).

IV. Testing and Evaluation

The test bench is an industrial demonstrator dedicated to distributed generation and control. It is developed within the Grenoble Institute of Technology, in France through Grenoble Electrical Engineering laboratory (G2Elab).

It is included in a wider research platform called PREDIS which aims to demonstrate, among others subjects, the energy management of DER/RES. Some analogical micro networks are installed.

The RDPREDIS (PREDIS Distribution network) was replicated from a real French distribution network. It will be used, among other things, to prove the self-healing functionalities and restoration process. This investigation relies on the outcomes of the CRISP demo B project [8]. The difference is that all of the concepts and algorithms developed within CRISP project such as Cell Level concept and Help Tool Fault Diagnosis (HTFD) software will not be applied on the power system behavior resulting from the real-time simulation but on the data measured directly on the analogical micro grid.

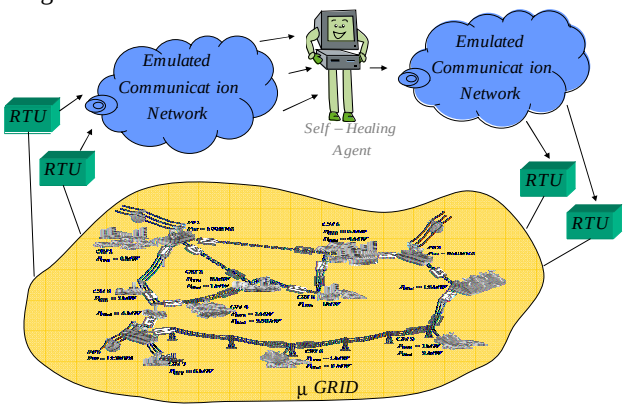

Fig 4. Illustration of RTUs and agent in the Loop concept

This concept allows conducting "RTUs and ICT Hardware In the Loop" simulation and validating agent based automated scheme with real ICT components (sensors, communication and control).

The emulated communication network is included in a controlled communication router with special software able to control the bandwidth of each communication channel between RTUs and the agent [7].

V. Conclusions

The transition from current to future EDS while accommodating large amount of DER and keeping the desired level of quality and reliability will require investigations on decentralized operation as well as on adaptive architectures. This panel is dedicated to some of the concepts under development at Grenoble Institute of Technology and IDEA dealing with these decentralized operating modes including emergency management functions. These concepts are being developed jointly with an experimental platform (the µGrid) setup in Grenoble Institute of Technology. This process is intended to validate the above concepts and to size correctly the needs in term of communication and computerization performances.

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VII. BIOGRAPHIES

Nouredine HADJSAID received his Ph.D. degree in Electrical Engineering and "Habilitation à Diriger des Recherches" degree from the Institut National Polytechnique de Grenoble (INPG) in 1992 and 1998, respectively. From 1988 to 1993, he served as a research and teaching assistant at the Ecole Nationale Supérieure d'Ingénieurs Electriciens de Grenoble (ENSIEG) and at the Laboratory d'Electrotechnique de Grenoble (LEG). He is a full professor at Grenoble Instutute of Technology and a General Director of a common research center on future electrical distribution system between EDF, Grenoble Institute of Technology and Schneider Electric.

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Bertrand Raison (M'03) was born in Béthune, France in 1972. He received his M.S. and Ph.D. degrees in electrical engineering from the INPG, France, in 1996 and 2000. He has joined since 2001 the "Laboratoire d'Electrotechnique de Grenoble (INPG)" as associate professor. His general research interests are fault detection and localization in electrical systems.