PREVENTIVE ASSESSMENT FOR COMBINED CONTROL CENTRE AND SUBSTATION-CENTRIC SELF-HEALING STRATEGIES

Alberto BERNARDO	Nuno SILVA	António CARRAPATOSO	Gary OCKWELL
Efacec – Portugal	Efacec – Portugal	Efacec – Portugal	Efacec ACS – United States
abernardo@efacec.com	nuno.silva@efacec.com	amc@efacec.com	gary.ockwell@efacec.com

ABSTRACT

This paper describes the state of the art of self-healing strategies, proposing a combined approach for leveraging the characteristics of substation-centric Distribution Automation and Control Centre DMS self-healing, aiming at optimising operational management and improving network reliability.

The paper also presents field experience on Smart Grid and self-healing implementations.

INTRODUCTION

As utilities face increasing demand for availability, high security, cost reduction and improved quality of service, they need to cope with a pragmatic use of power assets, renewable DG and Smart Grid advanced applications.

A centralized dispatcher monitored Distribution Management System (DMS) plays an important role within this scope. Localized Distribution Automation (DA) is also valuable, where substation-centric solutions, based on micro-DMS running on substations with real time knowledge of their own downstream network topology, provide optimum fully automatic local switching plans [1].

This paper proposes a preventive assessment for combined control centre and substation-centric self-healing strategies, addressing several issues such as self-healing autonomy, the degree of automation of an unmanned substation-centric solution, or the role of the control centre complementing any substation-centric automatic restoration plan.

The advantages of substation-centric and control centre approaches do not conflict, on the contrary, together they offer improved Smart Grid operation, with positive impact on low latency improvement for fast self-healing decision making, as well as enabling islanding operations arising from the mix between DG, storage and demand response.

SELF-HEALING STRATEGIES

Many primary distribution systems are designed and constructed as meshed networks, but are operated as radial feeder systems with normally-open tie switches. These tie switches can help transferring unfaulted, but out-of-service load to neighbouring feeders to reduce the total load that has to be cut off over a prolonged period after a fault.

Whenever there is a fault in an electrical distribution system, in order to ensure minimal reduction of system reliability, the unfaulted de-energized areas should be supplied with power as soon as possible. Although repairing the fault may take a while, it is possible to quickly restore power to areas cut off by the fault or the consequent protections tripping if they can be temporarily connected to neighbouring feeders carrying the extra load.

Automatic feeder sectionalizing and restoration is a core application for DA. In their most basic form, these systems detect a fault, determine its location, and open the nearest available switches or fault interrupters during a tripped state of the fault-clearing recloser or breaker, isolating the faulted segment from the rest of the feeder. Automatic Fault Detection, Isolation and Restoration (FDIR) algorithms carry out complex network self-healing.

Self-healing main goals

- Supply maximum load affected by the fault
- Take the shortest time period to restore the load
- Minimize the number of switching operations
- Keep the network capacity within its operating limits

Constraints and issues

- Cables/lines loading and transformer capacity
- Voltage constraints
- Time-of-day loads (where the considered load could be the maximum load for a period after the fault occurs)
- Loads classification (priorities)
- Load shedding
- Number of switching operations
- Minimizing losses
- Sequence of switching operations
- Fault current sensitivity in the event of a subsequent fault to the extended feeder

Self-healing implementation types

There are different ways of implementing self-healing of electric power distribution networks:

- Centralized solutions, at the Control Centre (complete model) - The SCADA / DMS system concentrates all the modelling, maintenance and intelligence. The solution relies on telemetry and remote control for automatic network operation (FDIR also provides manual switching when applicable), besides power applications. It runs a complete overall network model and control options able to analyse multiple faults and solution scenarios across a wide area, suitable for a Smart Grid.
- Distributed solutions (static model) – Consists on a script-based approach using feeder distributed Remote Terminal Units (RTU). It is a cost effective solution when only few

switching devices are employed on a restricted area, using a dedicated communication infrastructure allowing fast response actuation with predefined automation schemes. However, it is not ready to operate under non-standard network topology and is unable to deal with multiple faults. It also lacks flexibility for DG, storage or electric mobility penetration, thus, not suitable for a Smart Grid.

- Substation-centric DA solutions (dynamic model) – Based on a model driven intelligence sited at the primary substation, coordinating feeders and neighbouring substations, the decision process being made at substation or Control Centre level (pending approval). It grants interoperability supporting different switches, reclosers and RTU vendors, assuring adaptability to any real-time network configuration, including any protection or automation plans. Though the operation area is restricted to the neighbouring of the substation where the substation-centric solution performs, covering a specific Distribution Grid Area (DGA), it is able to dynamically derive complex restoration solutions involving multiple feeders, using where necessary, automatic load transfer schemes to achieve optimal restoration, besides offering flexibility for DG, storage and Electric Mobility (EM) penetration.

SELF-HEALING PREVENTIVE ASSESSMENT

This section describes a method for leveraging the advantages depicted in the previous section, by combining a centralized dispatcher monitored DMS (SCADA/DMS) with substation-centric self-healing strategies for radial operation of open-meshed distribution networks.

Self-healing is more than simply providing the maximum extent of reliability indicators (IEEE 1366) improvement as a result of faulty conditions, since it will also need to address new emerging power assets: DG, EM and storage.

Only at SCADA/DMS level there is a global awareness of the full network conditions, namely where possible constraints may apply, the supervision of line segments capacity, which substation feeders have full flexibility to secure adjacent sections of the network, for instance, while knowing any other relevant data (operational, maintenance status, meteorological, customer details, load forecast).

With the increasing penetration of DG, EM and storage, also only at a higher level it will be possible to have a complete picture of their impact over the network.

The nature of upstream and downstream recovery of a faulty section deals with the topologically connected remote controlled switches and reclosers and the ability of adjacent areas to participate in this process. If we add the complexity of DG injecting intermittent power into the network, as well as of temporary stored power, or demand side management, the role of the adjacent areas may be strongly enlarged.

Latency is a key aspect of self-healing: the higher the decision level for remedial actions, the slowest the action, not to mention the growing volume of data.

"Think Global, Act Local" expresses the main concept behind the Preventive Assessment for Self-healing. Indeed, the role of getting a global awareness of the network operating conditions is represented here by SCADA/DMS. The industry offers some distribution network self-healing solutions, with constrained time performance. Also, some inaccuracy may occur when a large data volume needs to be synchronized and available for the operational management processes, difficulting the decision making process.

Substation-centric self-healing solutions respond faster to any faulty conditions, with a local awareness of the network model. Yet, their scope of intervention is strictly local, even coping with a large number (limited to a certain extent) of substation feeders, tie-points, switches, reclosers and protection schemes or any other vendor rich mixture of RTU, IED and automation controllers participating in the network, besides DG, EM and storage.

A DGA is an operational area defined by one or more substations and their feeders, with possibility of automatic reconfiguration in the event of a fault. Within this area, it is possible to restore non-supplied loads executing few switching manoeuvres to perform load transfer between feeders. The entire distribution network is, therefore, the sum of all DGA. The utility will always play the role of defining the granularity level and type of DGA.

Adjacent DGA may share data belonging to any common border. Each DGA may comprise several substations and their interconnected branches and equipment, where the role of master is assigned to one substation. This master is provided with a Substation Automation System (SAS), as well as another system running the local network model, implementing local power network application and topology features, using real time data acquisition within its own DGA, for implementing self-healing and any kind of DA features. This master substation's SAS complementary system is called the Smart Substation Controller (SSC).

The big issue that concerns utility decision makers, network architects and operators is the level of trust that a substation-centric or even any other local self-healing autonomous process can be granted, when carrying out an automatic fault detection, isolation and subsequent restoration plan, triggered by one or multiple faults.

This anxiety can be relaxed if a combined approach is used. Basically, besides performing the expected function set, the SCADA/DMS should perform preventive actions on a regular basis, tagging each DGA with a dynamic status, as a result of having met a certain customized criteria. The utility must define what a criterion is, which conditions apply, as well as their weight in the tagging process.

A What-if scenario can then be used, combining real time data from every DGA, comprising switching state and status data, node voltage and branch current measurements, the capacity of network branches, feeders or transformers, besides fault data, power quality, stability and security, potential contingency risks, demand response, adjacent DGA capacity for self-healing support, atmospheric conditions with possible impact on fault occurrence or intermittent DG, or even any other relevant data resulting from system, human or statistical awareness.

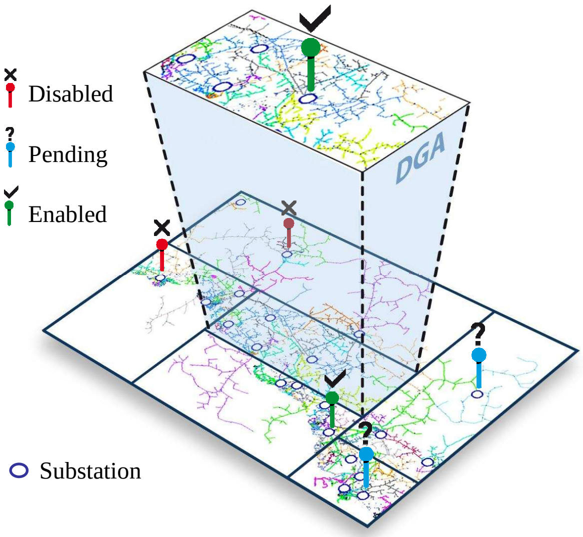

Figure 1 – Representation of several DGA and their status

At another level, it would also be possible to model and include data related to emergency situations or to the lack of maintenance teams for prompt corrective maintenance, as well as available storage or EM demand.

Besides tagging each DGA at SCADA/DMS level, a token with the same kind of status data will be sent to the concerning DGA, precisely to its SSC (Figure 1). Upon reception of the token, each DGA's SSC knows its status and modus operandi about the self-healing behaviour mode:

- Disabled – the SSC will only perform SCADA tasks, by collecting data from any downstream RTU or fault locator, and will share it with the corresponding SAS, if applicable. In no circumstances it will have switching impact on its DGA. The SSC will only report the corresponding DGA telemetry to the SCADA/DMS.
- Pending – besides performing SCADA tasks, the SSC will use its network model to perform self-healing plans that, before being performed, will be submitted to the approval of the SCADA/DMS. At this level, the skills and experience of the operator will dictate the adequacy of the switching plans proposed by the SSC, or even correct those plans (advisory/approval mode). Therefore, the SSC may impact positively its DGA by performing the recovery plan, as a result of an approval from the operator. It will not automatically execute any orders in case the operator does not issue an approval. It will react accordingly to any changing plan arising from upstream, besides reporting its DGA telemetry to the SCADA/DMS.
- Enabled – the SSC is granted full autonomy by the SCADA/DMS to perform any automatic isolation and subsequent restoration plans whenever a fault is detected. It will report its DGA telemetry, network values and topology changes to the SCADA/DMS, reducing the data volume to be fed upstream related to any restoration plan.

PRACTICAL IMPLEMENTATIONS

The increasing penetration level of renewable DG and microgeneration units could drive distribution networks to operate near the voltage limits [2]. The Smart Grid paradigm undertakes these and other challenges through the deployment of communication infrastructures, smart meters (SM), RTU, IED and new functions never employed so extensively until now, all over the network.

To tackle these challenges in an adequate way, EDPD (the Portuguese DSO) has implemented a technical architecture (Figure 2), where main components and services were developed for a fully active distribution network [5]. The INOVGRID project implements a nation-wide Smart Grid. The new infrastructure is meant to manage commercial and technical issues, as well as providing advanced services, integrating growing micro and distributed generation facilities, with all related control features, and, at the same time, increasing information availability and intelligence over all layers of the network grid [2, 3].

In order to develop this project a consortium was created, headed by EDPD and incorporating companies from metering (Janz), power systems management, automation and communications (Efacec), IT systems (Logica) and a scientific research institute (INESC Porto).

The adopted technical architecture is capable of dealing both separately and in an integrated way with commercial and technical information. It is based on a 4-level hierarchy:

1. Producer / consumer level, with Energy Boxes (EB) providing SM functions, home energy appliances management and micro-generation control;
2. MV/LV substation level, with Distribution Transformer Controllers (DTC) responsible for managing a set of EB from the level below, concentrating their data, while monitoring the substation, transformer, local sensors and public lighting, enabling automatic operation;
3. HV/MV substation level, with intelligent devices capable to process downstream network topology and monitor operational parameters. The Smart Substation Controller (SSC) is responsible to aggregate and manage the operational data from SM and DTC and to apply DSM, self-healing and DG management strategies, with the capability to supervise adjacent substation feeders.
4. Central management and control level, comprising commercial and energy management, while controlling overall network operation and quality of service.

System complexity increases due to DG and micro-generation diffusion, to loads becoming more responsive, implying their correct control and automation, by increasing the number and sophistication of devices and RTU.

All utility central systems act as one over the whole network. Control and automation functions are no longer limited to them and appear all over the network.

The large scale deployment of communications and automation is changing the passive distribution network into an active Smart Grid where all switching can be remotely

monitored and automatically operated. DTC, SSC and RTU are required to enable local network optimal operation based on constantly updated distribution system settings [4]. At consumer/producer level, the SM enable accurate recording of load/generation profiles, reducing billing costs, detecting fraud and providing energy balancing.
At the MV/LV Distribution Substation the DTC also optimizes energy flows and network topology, while providing data for self-healing strategies in collaboration with primary substation SSC. The SSC is able to optimize energy flows, providing self-healing features.
The central system level provides commercial and energy management, while accurately processes billing and load profiles, offering a global view and optimal operation control of the network, assuring outage management, DG management and planning, aiming at granting system stability. Its deployment allows implementing preventive assessment for combined self-healing.
Self-healing can be executed by the SCADA/DMS or by the SSC itself, depending on the preventive assessment results.

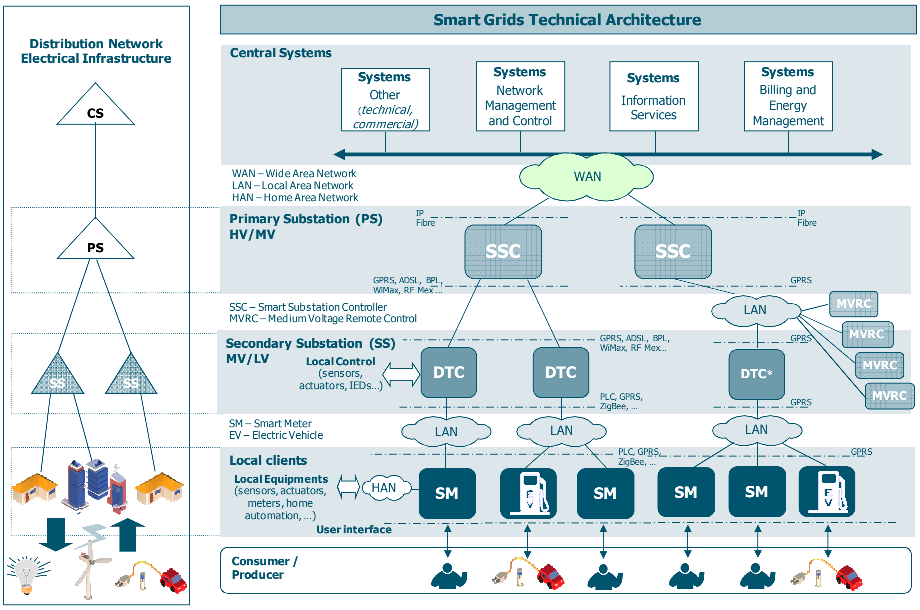

Figure 2 - Technical Architecture of the INOVGRID Project

CONCLUSIONS

The Smart Grid endeavour is to integrate promising technologies that include SM, demand response, DG and storage, outage management and several DA solutions.
Future distribution networks require new planning for novel decentralized architectures able to include those technologies and new design and planning tools relying on heuristics, probabilistic approach and multi-scenario analysis, among others. In addition, it is necessary to develop new active network technologies enabling a massive deployment and control of DG in combination with demand side participation, comprising the energy market while managing and optimizing a secure network.
This paper described the objective of self-healing, aiming at proposing the combination of a SCADA/DMS centralised solution with a distributed substation-centric model based solution. This would add the needed intelligence for autonomous, reliable and fast self-healing strategies coping with Smart Grid needs. This hybrid solution does not require extended changes on the network infrastructure or applications, thus deferring DSO investment.
The SCADA/DMS performs a preventive assessment of all DGA, tagging and assigning them to a specific self-healing response mode. This, results from the evaluation of data each utility finds as the most relevant, meeting a certain criteria, according to the utility's operation rules and inter-operable assets. So, concerning the self-healing decision-making criteria, besides "Think Global, Act Local", one can also say: "Render to the Utility what is due to the Utility".

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