1. Introduction

FSM system is envisioned as a suite of tools specifically for grid operations, planning, and management. This software open platform, based on open-communication standards acceptance, should provide major enhancements by enabling key attributes of the Self-Healing Grid:

- Accurate real-time state estimation,
- Predictive analysis by faster than real-time simulation,
- Cost-effective and safe real-time optimization of the operations.

The target could be the emergence of a platform of help-decision tools that allows a grid operator to optimize the management of the grid in real time as well as predict the grid behavior up to 4 hours in the future based upon historical and real time data. The planning gets closer and closer to the operation.

The D-FSM objective is to design the requirements of distribution functions optimizing the real time operation of the grid and ensure compatibility with the transmission requirements.

2. Objectives of the project

The project has two objectives:

1. Identify the technologies to address the technological challenges of Self Healing Grid – (SHG).
2. Provide look ahead analysis of the system

2.1 Self Healing Grid

The concept of SHG requires enhancements in the level of automation of the Power System, which means an increase of remote control device featuring capabilities of communication with the rest of the system and able to have an action by itself.

The traditional local automation shall be controlled by distributed intelligent agents (IA), which are themselves connected to a superior and centralized unit.

Nowadays, the operation of distribution power system is based on local automation and manual switch. There are only a few remote control actions. Tomorrow, the operation of distribution power system shall be based on the right combination of local and global control of electrical devices.

This requires a new architecture where intelligent cells may control a local actuator or perform computations or ensure communication. The operation of the entire system requires accurate coordination between all of the cells. Considerable amount of information will flow within the information infrastructure. In order to minimize this flow and maximize this reliability of the system, D-FSM will identify for the DFSM functions, key parameters, key characteristics and key information and data between the components of such a distributed intelligence architecture.

2.2 Predictive Analysis

In the case of electrical power systems and particularly distribution power systems, the main function (after safety) is to ensure the security of power delivery, and D-FSM shall contribute to this enhancement of security. In this paper, security means reliability and availability of power delivery.

Now, advanced capability of anticipation aims at preparing to any kind of contingencies during real time operation and hereby, one objective of D-FSM tools is to provide predictive analysis of the electrical system by evaluating not only the existing conditions but also in advance the effects of any combination of contingencies that may occur.

Remarks:

- Fast means high level of performance in term of computation time
- This project is part of the Intelligrid project carried out by EPRI. [1].

3. Methodology

3.1 Approach

The approach of the first phase features 5 steps:

1. Evaluation of the possible futures (scenarios) to identify the technical context of the SHG.
2. Stakeholders engagement to capture the diversity and the common characteristics of distribution power systems
3. Description of the technical scope of the project
4. Focus on generic tools and selection of key function to prototype
5. Definition of High Level Requirement Document and recommendations
The current document is a synthesis of the first phase being carried out in year 2004 and preparation for the next phase, phase 2, to be carried out in year 2005.

### 3.2 Scenarios

FSM tools have to be flexible and reliable enough to suit all the possible future. To address this concern, the technological breakthroughs and future evolution of the distribution power system has been evaluated.

In order to simplify the approach based on all the possible breakthrough, three main scenarios have been identified that represent the main possibilities for the future development of the grid.

- **Scenario 1**: Higher penetration of DER,
- **Scenario 2**: Development of advanced markets (more elastic demand)
- **Scenario 3**: Higher Constraints on Distribution Grids

In such extreme but probable context, the operators will have a serious need for new real time tools to help them make the right decisions to operate grids closer to its limits, in a safe and cost-effective manner and that confirms the need for Fast Simulation and Modeling tools.

### 3.3 Engagement of stakeholders

D-FSM is an integral component of the self-healing grid envisioned in the Intelligrid Architecture. In order to ensure that the D-FSM suite of tools is practical for utility applications across the US and Europe, the D-FSM team solicited input from stakeholders. To capture the diversity and the common characteristics of the distribution power system, the stakeholders representation includes utilities with urban, suburban and rural power distribution infrastructure. Main results of the interview are as follows:

- Automatic reconfiguration of the network is the main real time function targeting self healing grid that is raised by stakeholders.
- Stakeholders are interested in better observability of their system through an advanced state estimator and in predictive analysis tools such as contingency analysis.

### 3.4 Technical scope

The following four main functions have been identified in D-FSM for realization of the SHG:

- **The Protection System** that includes relay tripping and coordination (Relay Protection Re-coordination : RPR)
- **The Automatic Fault Location and Isolation**: FLI
- **The Automatic Grid Reconfiguration**: GR
- **The Automatic Volt Var Control**: VVC

These 4 functions trigger specific local automation.

Remarks: both function VVC and GR are linked together since any grid reconfiguration involves a new voltage scheme (VVC function is required) and emergency or severe alarm within VVC may lead to switch operation in the grid (GR).

Relay protection Re-coordination (RPR) is a function that follows both previous function (GR and VVC). Indeed, any change in the topology of the grid is likely to affect the protection scheme.

### 4. Description of the functions

#### 4.1 VVC

The VVC function is a generic function that is required by all kinds of distribution power systems.

The security of power system as well as the availability of power delivery is based on the static and dynamic stability of the Generation/Load balance. This is achieved by controlling the frequency and the voltage.

Basically, frequency control ensures the synchronism and voltage control ensures proper conditions for frequency control and power flows. The voltage at each node has to remain in a certain range of value, otherwise the system becomes fragile since there can be a cascade of events that leads straight to a voltage collapse and ultimately a blackout.

Voltage stability issue is particularly related to the management of the Reactive Power that is why voltage stability concerns need a specific function that is named Voltage and Var Control. This function assigns a set point value for the voltage of specific node and determines the amount of reactive power supplied by certain capacitor bank or generation unit.

There will be different ways to implement the VVC function with respect to local use and constraints but the operational function remains generic and can be applied everywhere in the context of the three scenarios defined in section 3.2.

The VVC function includes:

- Reduction of voltage and current stress on the grid (optimization of power flow to suit scenario 3)
- Contingencies analysis modules (fault, maintenance work, cost effective consideration, DER plug and play possibilities, ... to suit scenario 1 and 2)
- Use of results by operators (Visualization, Analysis and Control Actions)
- Reconfiguration of local automation (Voltage regulation, protection system, ...)

The pre condition or pre-arming of such a function embraces the following events:

- Grid reconfiguration
- Optimization of the losses
- Load variation
- Generation variation (for instance due to wind condition)
- Markets demand, risk analysis, …
4.2 GR

The Grid Reconfiguration is equivalent to any function that would lead to any switch status change (where switch can be circuit breaker, sectionalizer, …) that addresses feeder, transformer, half substation, DER Unit, capacitor, D-FACTS, Load, … except reflex automation initiated by the protection system further to a fault, (see section 4.3).

The pre-condition or pre-arming of GR function embraces following events:
- Service restoration
- Optimization of the losses
- Load variation
- Generation variation (for instance due to wind condition)
- Many others (markets, voltage quality, …)

In case of fault occurrence, after the protective relays have tripped, fault has to be located and isolated, see section 4.4. Then power delivery is restored by reconfiguring the grid. Finally, service restoration function requires the VVC function and also includes the same features as VVC: Reduction of voltage and current stress on the grid, contingencies analysis module, use of results by operators, reconfiguration of local automation (switch opening and closing).

As a conclusion, Grid Reconfiguration is mainly used in the purpose of optimizing the Grid Operation

Remarks
- GR does not include fault detection and protective relays tripping (achieved by the protection system), nor Fault location, and isolation (FLI)
- But GR includes Service Restoration function

4.3 Protection System and Relay Protection Recoordination

Fault occurrence generates local reflex automation (safety issue). It is the detection of the fault and the selectivity of the right protection that is involved. The response time is defined by the function of protection of the system. In the SHG concept and operating the system “close to its limits”, local reflex will be coordinated through a global control that will set right parameters. The update of the protection system is not in the scope of D-FSM for now as it is a special section about various protection schemes. RPR function is also used to pre arm trigger or inhibit trigger of specific protective relays. This function is part of the protection system that is implemented in the utility and its evolution also depends on the protection system and on the type of protective relays that is used in each utility.

4.4 Fault Location and Isolation

This function is related to the system of fault management. Once a fault has been detected but not eliminated by the protection system, (permanent fault), a certain part of the power system is no longer supplied. The fault has to be located and isolated as quick as possible so that the maximum of customers can recover the power delivery.
cost of energy or both. There are different ways to design it and this is a key point for the distribution system.

5.3 Aggregators

The aggregator is a very complex modeling tool that gives electrical equivalent of a part of the network. The aggregator may address the load, the generation, both, the topology, etc. For instance, it is possible to aggregate the whole power system in the secondary of the HV/MV transformer in a model including RLC load, rotating load, generation and an average length of feeder. It is like a static or dynamic equivalent of the network. The aim is to simplify the system for the upper hierarchy level and to reduce the information flow.

5.4 Load Forecasting Module, LFM

For the purpose of contingency analysis, the knowledge of the load in look ahead mode is required. The load forecasting module is a predictive analysis tool based on load metering data, load shape and load profile, that makes the load predictable. It is used particularly as an input to Contingency Analysis. Indeed, in this way, the prediction of the future electrical state of the power system is based on a reasonable assumption of the value of the loads.

5.5 Contingency Analysis module, CA

In layman's terms, Contingency Analysis (CA) is a "what if" scenario simulator that evaluates, provides and prioritizes the impacts on an electric power system when problems occur. A contingency is the loss or failure of a small part of the power system (e.g. a transmission line), or the loss/failure of individual equipment such as a generator or transformer. This is also called an unplanned "outage". Contingency Analysis is essentially a "preview" analysis tool. It simulates and quantifies the results of problems that could occur in the power system in the immediate future such as overloads, voltage violation at buses or stability issues. It is also an evaluation tool of the existing contingencies state, and the current situation of the power system. This allows operators to be better prepared to react to outages by using pre-planned recovery scenarios.

5.6 Dynamic Security Analysis , DSA

The DSA makes dynamic stability calculation by taking into account the electro mechanic transients in the system that are generated by the dynamic of the rotating machine and their regulation, the evolution of the load, the dynamic of the local automation such as the tap changer, etc. It is based on the integration of differential equations using specific algorithm featuring sometimes a variable simulation time step. The dynamic Security Analysis is not a priority as long as the penetration of DER remains low and that is the case for now.

6. Framework of FSM suite of Tools

Based on networks model that always keep on being checked and updated, figure 1 represents the high level requirements of Fast Simulation and Modeling Tools.

The Automated Actions targeting SHG (right box in figure 1) represents the local automation such as tap changer in the substation or update of the protection scheme within any digital protective relay. There are four main local automations:

- The reconfiguration of the grid (GR) that may be caused by fault, maintenance work, power flow optimization (cost effectiveness), frequency or under-voltage load shedding, DER or energy storage device plug and play, etc.
- The Volt Var Control (VVC) that can be located in the substation, in the DER Unit or along the network
- The relay tripping and Relay Protection and Re-coordination that can be located in the substation, in the DER Unit or along the network
- The Fault Location and Fault Isolation

The Data acquisition and synchronization suite of tools (left box in figure 1) represents the DATA coming from the whole distribution Power system (SCADA, Metering, etc.) and from other adjacent system such as transmission Power System, etc. The issue here is the observability of the system. These data coming from field in real time update the Network models. Real Time Data become information and feed the information system.

The set of network models (central box in figure 1) is the main part of the information system. It includes all the modeling object required in the representation of the Distribution Power System. Consistency and reliability of this part is challenging topic. The requirements of the network models (modeling tools) will be based on the Specific profile of the Common Information Model CIM.

The key functions and sub-functions (bottom box in figure 1) include the simulation tools that are required for information processing, (check consistency, update models, define new limits, etc.) and for improving the accuracy of the network models. For instance the function VVC update the voltage scheme using Load model, topology model, and the state estimator may update some instantaneous values of static load and generation. But the main function of these tools is to help the operator when he has to take a decision related to the control of the local automation (actuators in the right box in figure 1).

Major functions identified for this project are actually Grid Reconfiguration and Volt Var Control. Both function include the same sub function such as Contingency Analysis, Load Forecasting and Power Flow optimization.

7. Selection of a focus function

Fault Location and Isolation and the Coordination of the Protection System cover wide aspect that depends a lot on specific designs of power systems, and specific characteristics of distribution utilities. Therefore these function require many specific utilities use cases since they...
depend on network topology and equipment in use.

VVC (Voltage and reactive power control) function integrates:

- Information model update
- Functional requirements that embrace the main part of the distribution power system operation
- Innovative simulation and modeling tools
- Local action (regulation in the substation, in DER level, …)

VVC function requires the complete suite of modeling and simulation generic tools that have been identified and VVC is even more generic than grid Reconfiguration function. Therefore, the project will focus on VVC.

8. Conclusion

Figure 1 represent the High Level Requirement of the Fast Simulation and Modeling Tools targeting the Self Healing Grid. Now. The next phase of the project in year 2005 will get into details of this figure 1 and write the functional specification for VVC and for the key sub functions.

The issue of the data is crucial, that is why particular attention is paid to the network models. The definition of the network modeling tools will be based on the CIM using UML tools, and derivation or specialization rules will be explained in detail.

The objective of predictive analysis enhances the role of the fast simulation tools such as the contingency analysis module.

REFERENCES


AUTORS

Arnaud Valenti has been working for EDF for 8 years in the field of fault location applied to distribution system, and in the development of power system simulation software.

Serena Lee is project manager in ConEdison, New York.

Ivan Bel is project manager in EPRI, branch E2I.