DESCRIPTION AND BENEFITS OF A SITUATION AWARENESS TOOL BASED ON A DISTRIBUTION STATE ESTIMATOR AND ADAPTED TO SMART GRIDS

Maria SEBASTIAN
EDF R&D– France
Maria.Sebastian-Viana@edf.fr

Olivier DEVAUX
EDF R&D – France
Olivier.Devaux@edf.fr

Olivier HUET
EDF R&D – France
Olivier.Huet@edf.fr

ABSTRACT

Automation offers new margins to improve the performance of distribution operation and control. Additional distribution automation is particularly beneficial when it allows the network operators to use the dispersed generation and enhanced load control capabilities and in some case postpone new network upgrades. Such improved flexibility and control of the distribution network is only possible if the Control Centre operator has a more accurate real-time picture of the network. This paper explains how a Situation Awareness tool fed by a distribution state estimator would improve operators performance, facilitate grid operation and enhance network performance. Situation Awareness allows operators to anticipate and prepare for the next network operations in real time. This paper presents different scenarios of use of the situation awareness functions as well as a the architecture of these functions.

INTRODUCTION

Major evolutions are facing distribution utilities. Distribution automation and new control capabilities of loads and Dispersed Generators (DG) will allow to optimise the costs of network operation and to limit network upgrades. EDF R&D has been looking at these issues to find smart ways to improve the flexibility of tools and technologies for distribution operations.

This improved flexibility and control of the distribution network is only possible if the Control Centre tools and the Control Centre operators have a more accurate real-time picture of the network. Existing SCADA systems provide Control Centre operators with the view of the current flows and voltages at the HV/MV substation. Beyond the substation, very little is usually available. Current practices mainly consist in:

- Uploading at the Control Centre Boolean data coming from fault indicators, sectionalizers and remote switches.
- Using the MV/LV transformers rated power and the feeder current flow at the substation to roughly estimate the current flows along the feeders.

Existing estimations are rather insufficient when we consider the need to operate the network closer to its limits, to integrate an increasing number of DG. Existing data coming from the substation (measurements of voltage and feeder currents) is not enough to provide an accurate picture of the whole network. Several improvements would have to be implemented to enrich the data used at the Control Centre:

- additional measurements coming from new remote sensors,
- estimation of secondary substation transformer loads using typical load profiles of various customer types,
- integration of data coming from DG units (active, reactive and operational data).

The plurality of origin may lead to a new challenge for the Control Centre tools: there will be redundancy in the information provided by the data and the degree of trust we can have on each data will be different. Mathematical State Estimation tools can be used to filter "noise" and eliminate bad or incoherent data.

This Distribution State Estimator (DSE) will integrate various real-time measurement data and load profiles. By maximizing the value of the existing data, the DSE will enable the DSO to optimise the number of sensors and their location as well as observing operations closer to the physical limits.

The State Estimation is the first module that is needed to be developed. DSE results be used to the Situation Awareness tool to do, among others, the real-time and the next hour analysis, the reserve calculation,….

Next paragraphs describes:

- The Distribution State Estimator.
- The Situation Awareness tool.
- The scenarios on use of this tool.

VALUE CREATED WITH A DISTRIBUTION STATE ESTIMATOR

A state estimator designed for distribution operation will enable high value added applications for the tools in control centre. Four of the most important applications have been identified :

Release of Untapped Network Capacity and Congestions Management

Today, congestions were prevented :

- During the planning stage, by designing the adequate infrastructure using load growth scenario,

- During real-time operation in the Control Centre by monitoring the real-time value of the feeder currents in the primary substations.

However, the Control Centre operator does not get a very accurate picture of what is happening along the feeder and thus needs to take conservative actions in order to avoid overloads. A better understanding of where the active and reactive loads are located along the feeder would offer new margins, especially in the peak season for normal and emergency state operations.

Voltage and Power Flows management in the presence of DG

With a significant presence of DG on the distribution network, the power system becomes more complex. The "fit and forget approach" consists in adapting the design of the network in such a way that whatever the load level, the generation output level and the network configuration, voltage and power flows are always within limits.

This approach is rather costly in numerous cases and becomes complex if the issue is only dealt with at the planning level.

A real-time evaluation of the voltage levels and power flows across the distribution network combined with the possibility to adjust reactive and active injections can provide new margins and does not require network investments.

Provision of network services

DSOs usually contract their active and reactive power levels at the connection point with the TSO.

For active power, TSOs and DSOs usually contract limits for every interfacing bus. Penalties are paid by the DSO when the limits are exceeded. The challenge of the DSO is to balance in real time the flows in its network, in order to minimize penalties. This is particularly important in the case a substation transformer or a bus bar is lost and load has to be shared between backup feeders. The Control Centre operator therefore needs to assess where the load is located along the feeders: the total feeder active power value is not sufficient anymore.

For reactive power, contractual values can be set between the TSO and the DSO. The DSO can also become a player in a balancing mechanism. Reactive power flows can be adjusted by capacitor banks and DG. This requires the assessment of existing reactive power flows.

Validation of network reconfiguration

Network reconfiguration option is used in order to optimise power flows or prepare the network configuration to allow workers to access the sites and work off-line.

Before closing down a switch on a radial medium voltage network and obtaining a temporary closed loop (for a few seconds, before opening another switch), the Control Centre operator needs to make sure the phase shift and voltage amplitudes of the feeders are compatible. This requires an estimation of the voltage along the feeders which is only available using a State Estimator. The difficulty of this estimation is that it requires a model of the upper network which is not necessarily available.

SITUATION AWARENESS TOOL

A new tool is required to show the end-user a usable and accurate real-time view of the network calculated by the DSE and provide him with the information required in order to anticipate issues or prepare the next operations .This tool is called Situation Awareness.

Situation Awareness will improve the work of Control Centre operators, facilitate the operation of the grid and enhance the performance of the network. The architecture of the new tool (see Figure 1) will embed the following modules:

- Distribution System Estimator,
- Situation Awareness Core,
- Contingency Analysis,
- Alarm Log,
- Load Profiles,
- Day Ahead Operation Planning,
- Solution Module (see Figure 4),
- Solicitation of Reserves or Reconfiguration.

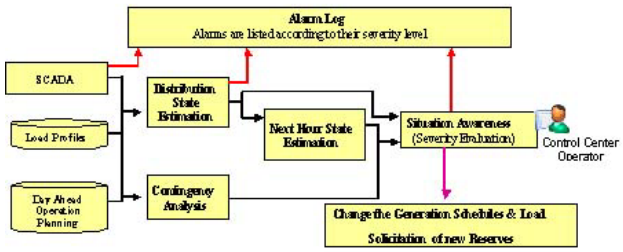

Figure 1: Situation Awareness Architecture

The DSE is at the very core of the Situation Awareness tool, as it provides the estimated values of voltages, currents, active and reactive flows in the network. Its results are compared to reference values and showed, to the end-user, by the Situation Awareness Core module in a synthetic representation : only the critical parameters and values are highlighted, alarms are raised when needed, and solutions are proposed in order to help the operator cope with difficult situations and manage priorities (during severe storms for instance).

The Alarm Log can receive alarms from the SCADA, the DSE and finally from the Situation Awareness tool. It lists them according to their severity.
Four classes of alarms related to the type of value produced, have been identified, :

- Security of assets,
- Security of supply,

- Optimisation of operation expenditure (OPEX),
- Quality of the network observation.

Moreover, more advanced functions of the Situation Awareness tool, such as Short Term Contingency Analysis and Day Ahead Operation Planning (see scenarios described bellow), enable to anticipate critical situations that could threaten the quality and reliability of the supply.

SCENARIOS OF USE OF THE SITUATION AWARENESS FUNCTION

Different scenarios of applications of the Situation Awareness functions have been developed to illustrate what a Situation Awareness tool could offer to a Control Centre operator by providing anticipation capabilities and reliable information.

Real-Time Situation

The objective is to show the location of high loads, overloads and the over/under voltage at each line and node. It is possible to illustrate by zones of similar voltage on the network. The inputs and process script of Situation Awareness are the results of the DSE. Different limits are extracted from the network databases supplying the SCADA.

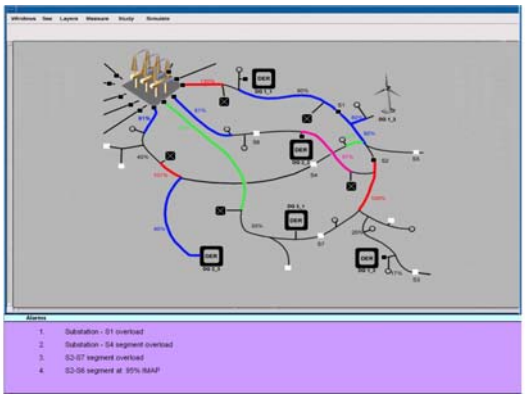

Figure 2: Line overload in real-time

For each alarm, a different colour code represents their severity. This colour code can be selected by the Control Centre operator. It can be changed or adapted to any particular situation.

Figure 2 illustrates the real time results during normal operation. It is possible to use it also for Contingency Analysis. DSE generates the real time situation of the network. There after, Situation Awareness tool runs Contingency Analysis (N-1 network device or generator) in this situation. The objective is to test automatically the loss of all the networks devices and generators. Contingency Analysis is used in order to detect and signal the possible problems (see Figure 3) and to anticipate possible solutions (see Figure 4).

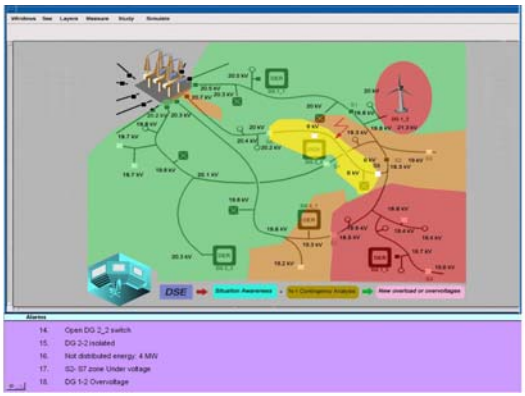

Figure 3: Voltage excess limit. N-1 Contingency Analysis

For each problem, Situation Awareness allows the Control Centre operator to run an application (the Solution Module) to solve the potential problems. This application recommends different possibilities (see Figure 4).

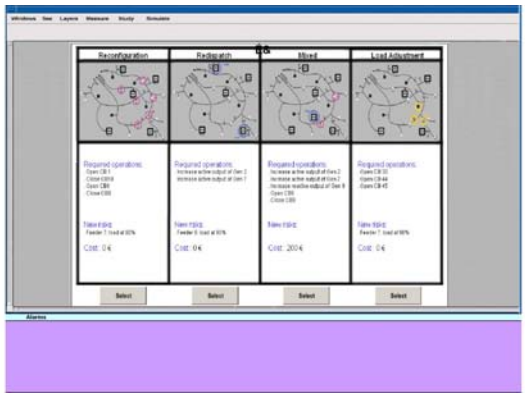

Figure 4: Solutions proposed

Next Hour Situation

The objective is to prepare the network operation in the next hour. It allows to observe the flows and the voltages evolution in the next hour. DSE generates the real time situation of the network. Situation Awareness adjusts the load curves of each ML/LV transformer and the generation profiles for the next hour and runs the Load Flow calculation.

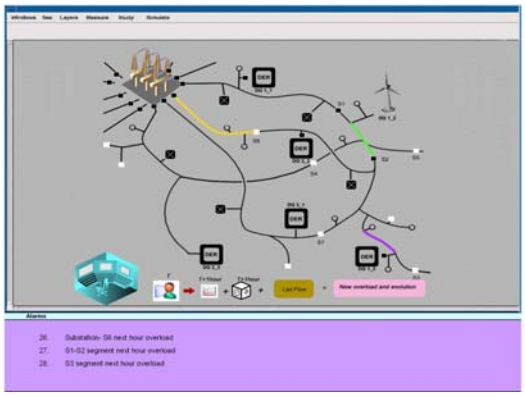

Figure 5: Next hour overload

For example, the Control Centre operator can display the next-hour evolution of the current in each line (see Figure 6). Evaluating the different curves, he decides if the problem is important and/or long-lasting and needs an action or if the problem will be disappear rapidly and does not require any action.

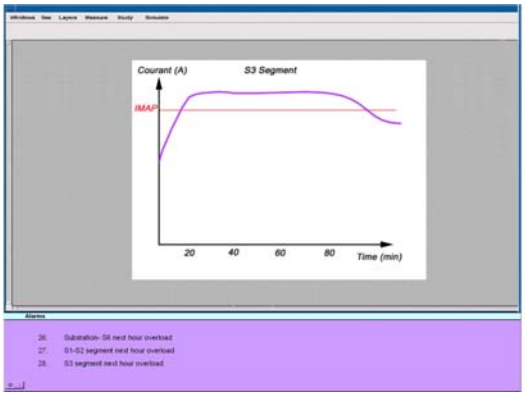

Figure 6: Next hour current evolution of a line

Furthermore, it is possible to calculate and visualize the flows and the voltages after the Contingency Analysis.

For each problem, Situation Awareness runs the application to find the possible solutions (see Figure 4).

Insufficient active and reactive reserves

The objective is to detect the weaknesses of the network in order to respect the active/reactive reserve margins in real-time and during the next hour. These reserves could be provided by generators declared as reserve units and by loads that propose flexibility services. Situation Awareness detects and displays the load shedding and the reserve units (see Figure 7).

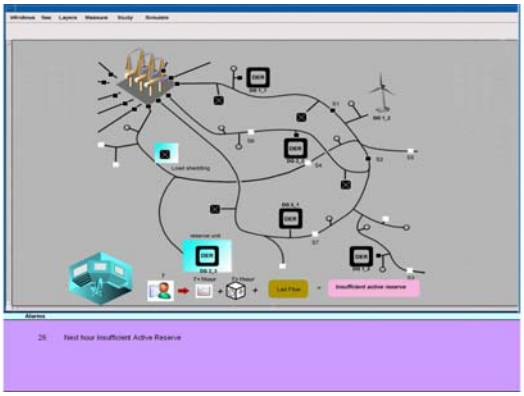

Figure 7: Next hour insufficient active reserve

It is possible to use this function for both normal operation and Contingency Analysis (see Figure 8).

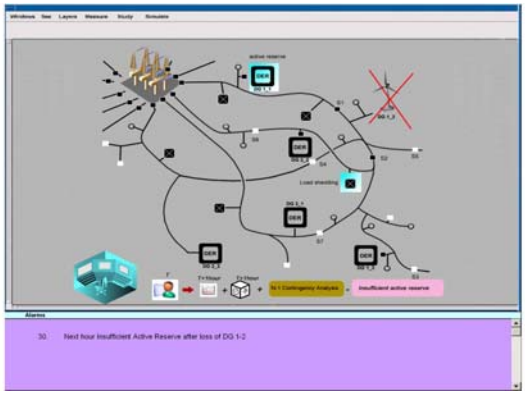

Figure 8: Next hour insufficient active reserve after loss of DG1-2

For each problem, Situation Awareness runs the application to find the possible solutions (see Figure 4).

FINAL CONCLUSION

State Estimation techniques can create value in the future context of the distribution networks (consolidation of control rooms, investment or refurbishment deferral, integration of an increasing number of DG) by enriching the real time knowledge of the network. State Estimation is the first module that is needed in order to assist the Control Centre operator, however most of its results will be visible and effective through a Situation Awareness function aimed at enhancing the quality and reliability of the supply.

The Situation Awareness function is moiré than a simple extension of existing Alarm Synthesis that are in use at some Control Centres (automatic interpretation of substation alarms). Situation Awareness function is key to offer high value to operation performance. In order to feed this new alarm log in the Situation Awareness tool, three critical modules have been identified as priority components to be developed:

- Next Hour State Estimation,
- Contingency Analysis,
- Severity Evaluation.

Another promising area of further investigations would be the interface of the Situation Awareness to load profile data basis, day-ahead planning and solution modules.