DISTRIBUTION STATE ESTIMATION: OUTCOMES FROM A FIELD IMPLEMENTATION AIMED AT TACKLING MV VOLTAGE MASTERING IN THE PRESENCE OF DER

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ABSTRACT

Smart Grids operation definitely requires enhanced real time observability and Utilities are heading towards it. However, observability deployment among network operators is not always driven by comprehensive operational needs. In this matter, Enedis (the French DSO) developed with EDF R&D support a proper approach which consists in a deep analysis of smart grids operational needs on a priority use case (i.e. Voltage mastering in presence of DER) along with a study of dedicated observability requirements.

This paper describes Enedis and EDF R&D approach which leads to the implementation of a Distribution State Estimator (DSE) along with dedicated sensors. It presents the results of DSE experiment performed on VENTEEA Smart Grid demonstrator.

INTRODUCTION

After a short description of the studies that led to the choice of a specific DSE type (Accurate Voltage profile DSE), the paper presents DSE principles and its feeding with real time data.

A particular focus follows on the field experiment outcomes i.e.:

- the DSE principles validity,
- DSE-Sensors combined efficiency,
- sensors optimal quantity and location,
- Adequacy of DSE to feed operational needs.

The focus on DSE experiment also pinpoints its robustness / resilience to sensors failure and discusses the capacity to detect slow sensors drift.

Finally the paper describes the major outcomes of the closed loop activation of the Voltage regulation function on the basis of DSE voltage constraints detection (once the validity of the state estimation had been truly verified).

The paper then elaborates on the perspectives of a common deployment in France on MV networks of DSE and Voltage Regulation function.

DSE: TYPE AND PRINCIPLES

A DSE is a non-linear optimization that uses a limited number of measurements acquired by a SCADA, combined with the network model in order to estimate the electrical state of the network in “real time”.

The estimator presented in this paper and developed at EDF R&D is based on an objective function similar to the one generally used by transmission operators: it is a weighted least-square constrained approach where voltage amplitude and phase angle at each node are considered as primary state variables.

References [1] and [2] give details on the studies that led to this choice.

As currently implemented, this estimator is dedicated to MV voltage estimation in order to feed the voltage regulation function. It requires voltage measurements on the MV busbar and on a limited number of nodes on each MV feeder. It also requires active and reactive power measurements on each feeder at the primary substation and on generators injecting on the MV feeders. The power consumption on every HV/MV substation is provided to the estimator via load models.

Field implementation

The DSE is an algorithm imbedded in the DMS of Enedis, at the regional control centre level. The field tests are being performed on a rural primary substation located in eastern France in a windy area where the deployment of wind turbines is well advanced. The primary substation has a 20 MW HV/MV transformer and 5 MV feeders (out of which one has a 6 MW wind farm injecting on it and another is dedicated to a 12 MW wind farm).

The site was chosen owing to the very presence of the 6 MW wind farm connected to an otherwise consuming feeder: such a context is indeed favourable to the occurrence of a voltage increase on the feeder voltage profile around the injecting node, naturally invisible to the sensors located at the primary substation.

A rule of thumb originating from simulations resulted in the installation of a voltage sensor at each remote controlled switch site on the feeders (on average 3 per feeder). However the existing RTUs were unable to collect the MV voltage measurements and a dedicated RTU had to be added on each site to perform this task.

The measurements are 10 min averages synchronized and retrieved in real time by the DMS via the dedicated RTUs, using GPRS communications.

Similarly, a dedicated RTU was installed at each generation site in order to collect voltage and power measurements.

At the primary substation, monitoring and control technology including sensors had to be upgraded in order to provide the required measurements (active and reactive power on each feeder) and to control remotely the setting of the voltage regulator of the HV/MV on-load tap-changer (OLTC).

The real time adjustment of the voltage setting of this regulator is the basis of the voltage regulation scheme for which the DSE was originally conceived: the voltage profile of each feeder is estimated and when this profile goes beyond authorized boundaries, a new voltage setting is calculated to solve the problem, if possible.

Experiment launched

Once the primary substation had been upgraded and the MV voltage sensors (innovative low cost capacitive dividers), had been installed on the network, once the dedicated RTUs had been deployed and the GPRS communications made suitably reliable (the whole process lasted about 2 years), the field experiment was allowed to begin: first DSE alone, then DSE with voltage regulation on open loop and then closed loop. The closed loop has been operational from mid-November 2016.

Moreover, for the monitoring of the experiment, some high accuracy measuring devices have been installed in the primary substation, on the generation injecting nodes and on "end of feeder" secondary substations.

DSE FIELD EXPERIMENT OUTCOMES

DSE principles validity

On figure 1, we can observe the voltage measured by sensors on the primary substation busbar and on each of the instrumented nodes of a given feeder. The x-axis gives the chronological number of the 10 min average measured and the y-axis is the MV voltage in kV.

These measurements feed the state estimator.

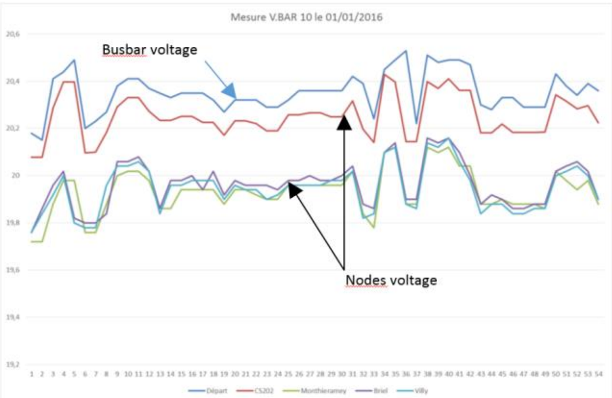

Figure 1: voltage measurements on an MV Feeder

On figure 2 (same axes as figure 1), we can observe the estimations related to the measurements illustrated on figure 1.

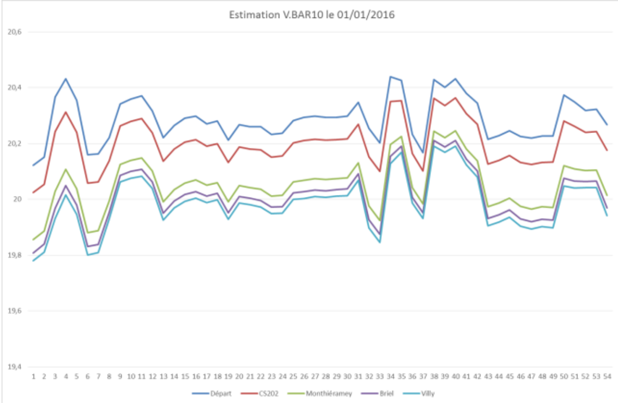

Figure 2: voltage estimations on an MV Feeder

We can notice that the state estimator tends to slightly smooth and restrict the evolution range of the voltage through time.

DSE-Sensors combined efficiency

On figure 3 (same axes as figures 1 and 2), we can observe the difference between the state estimation and the measurement on a biased sensor (value inferior to reality). In this case, the DSE tends to correct the faulted value.

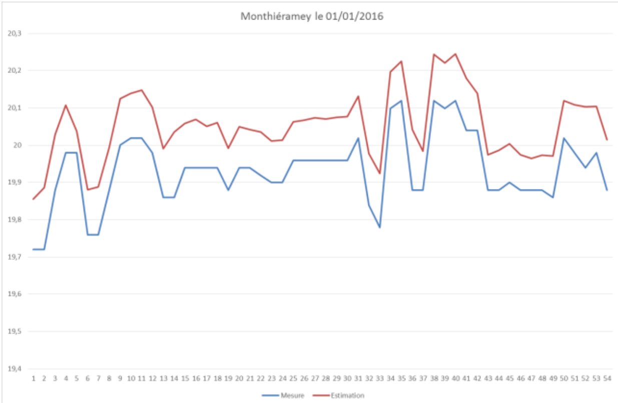

Figure 3: voltage measurement and estimation on a biased sensor

Sensors optimal quantity and location

The rule of thumb of "one voltage sensor per remote-controlled switch" seems to be rather satisfactory as the loss of one sensor on any feeder has been observed as not significantly altering the quality of the estimation whereas a degradation is observed when two sensors are lost on the same feeder.

Adequacy of DSE to feed operational needs

Due to incertitude, 1% is the required accuracy for the MV voltage estimation that allows to adequately modify the OLTC voltage setting.

According to the retrieved data, when comparing real measurements and estimations, this accuracy level has been reached.

MAJOR OUTCOMES OF THE VOLTAGE REGULATION FUNCTION CLOSED LOOP ACTIVATION

One shot tests of the closed loop

After a few months in operation, the state estimation was deemed to be reliable enough to be tested in conjunction with the voltage regulation function it was designed to serve.
In a first step, the voltage regulation function was tested in an open loop configuration in order to validate the relevance of the settings generated.
Then, in a second step, it was tested in closed loop but during day working hours only in order to facilitate the potential curative action of the field team in case of a sudden devious behaviour of the function.
After a few corrections on the software, the closed loop was eventually activated on a permanent basis mid-November 2016.

Test of the closed loop on a permanent basis

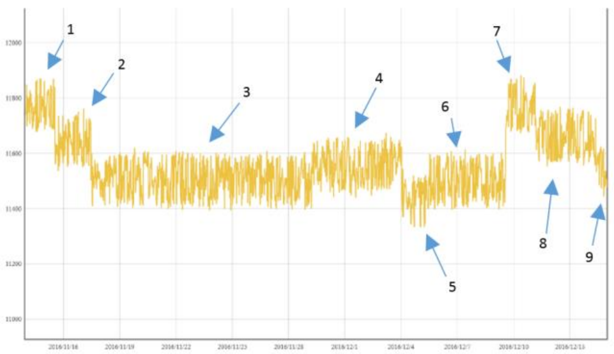

Figure 4: the centralised voltage regulation function in action

On figure 4, the x-axis is the date from mid-November to mid-December 2016 (10 min measurement points) and the y-basis is the medium voltage measured on the MV busbar of the primary substation.

We observe the voltage setting changes: first down 2 times (marks 2 and 3), then up (mark 4), then down (mark 5), then up (mark 6), up again (mark 7) and then 2 times down (marks 8 and 9), following the need of regulation as detected by the DSE. After each voltage setting change, the OLTC regulates the voltage around the new setting (“rapid” variations of voltage are then naturally observed). The initial setting (mark 1) was the setting calculated for permanent use by the classical planning studies methods.

The voltages hikes detected by the state estimator out of the authorized boundaries and requiring a change in the original OLTC voltage setting are rather few in number. Moreover, these are mainly “pessimistic” values as calculated by the function (a margin is added/subtracted to the estimation in order to anticipate coming problems of high/low voltage).
The occurrences for the need to increase the value of the setting are related to periods of low wind conditions along with high energy consumption owing to the use of electric heating (marks 4 and 6). On figure 4, the sharp hike in setting (mark 7) occurring near the end of the period is related to a momentary disability of the DSE and consequently a return to the default setting (the one calculated by classical planning methods for permanent use).

The behaviour of the function is satisfactory so far but more thorough analyses are required to reach a final conclusion.

Nonetheless, we can already state that the reliability and resilience of the telecommunications links are of the utmost importance to guarantee the functioning of the DSE and subsequently of the centralised voltage regulation function. It seems obvious but it is clearly an issue that has to be tackled as seriously as possible to be successful: the algorithms work well but they have to be fed as often and as well as possible by reliable real time measurements (which rely on the quality of the acquisition chain), all the more that the number of sensors has been optimised to the minimum needed!

PERSPECTIVES

Enedis goal is to deploy these functions on a large scale.
However, the next step will be to proceed to new tests on another demonstrator (Smart Grid Vendée), with a more complex configuration and on a wider area.
These tests are scheduled in 2017.
They should enable a more thorough analysis of the functions behaviour and a finer tuning of their parameters to improve their reliability and robustness.

REFERENCES

[1] O. Chilard, S. Grenard, O. Devaux, L. De-Alvaro, "Distribution State Estimation based on Voltage State Variables: Assessment of results and limitations", *CIRED 2009, Prague*, Paper 0524

[2] O. Chilard, S. Grenard, O. Devaux, "Methodology and results of a field experimentation of distribution state estimation in the French network", *CIRED 2011, Frankfurt*, Paper 0209