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Published in:
Proceedings of 25th International Conference on Electricity Distribution, CIRED

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

UNLEASHING SURVEILLANCE AND CONTROL POTENTIAL IN SMART DISTRIBUTION SYSTEMS – THE NET2DG APPROACH

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ABSTRACT

Nowadays, the energy transition is increasing the occurrence of several issues in distribution grids worldwide being the most important ones related to voltage quality like flicker, swells, dips and bi-directional power flow [1]. Such challenges are added on top of the already existing faults like lightning strikes and short circuits, but also avoidable losses in the grid like the ones caused by unregistered users, or inefficiencies. However, the Smart Grid environment provides Distribution System Operators (DSO) with data and control possibilities never seen in low voltage grids. Nevertheless, such potential is difficult to fully unleash by small and medium DSO, who lack economic and manpower resources. Such challenges are reviewed in this paper as part of the on-going H2020 Net2DG project [2], firstly by studying existing statistics regarding faults, voltage quality and losses; then identifying the critical aspects and the current practices implemented by DSOs to solve such operational and planning challenges. Subsequently, modern grid-monitoring tools based on the forthcoming Advanced Metering Infrastructure (AMI) are analysed focusing on enabling the use of these systems by DSOs. Thus, this paper aims also to identify and to reduce the gap between academic research and practical application. This is done by facilitating the implementation of beyond state-of-the-art tools in small and medium DSOs which, a priori, would lack the resources to develop and maintain them, taking the ongoing Net2DG H2020 project as example.

INTRODUCTION

Smart Grid (SG) represents a game changing set of technologies to be fully implemented in the forthcoming years. Driven mostly by economical, political, environmental and technical factors; it represents the promise of a revolution that is already shacking worldwide networks, with a particular deep impact in distribution grids. Since LV networks have been traditionally characterized for their passive behaviour and simple operation, they did not require monitoring and control capabilities at the control centres. However, in addition to the traditional challenges present in such networks and due to several factors like an increment on the electrification, inclusion of renewable energy sources, dispersed generation, electric vehicles, heat pumps, etc.; the incidence of issues related specially to voltage quality and unsuitable protection schemes is being exponentially increasing, and, foreseeably, will keep such trend in the upcoming years. [1-2]

On the other hand, large-scale deployment of AMI and Photovoltaic Inverters (PVI) increases the available data to be used by modern tools when monitoring the grid. Such technologies are already widely spread through Europe, and their deployment will finalize before 2020. However, their use in grid surveillance has been marginal. Despite of lacking economic and human resources, DSOs are interested on having applications capable of estimating the grid's state in real time with a reasonable accuracy, on the one hand, while capable of diagnosing and locating faults on the other. Thus, now is time to fully exploit such underlying potential.

Therefore, this paper exposes the different issues identified by DSOs characterizing them based on statistical incidence, reviews the current common practices of the industry, and proposes how to overcome the distance between academy and industry in order to ensure the proper operation of distribution systems worldwide.

CHALLENGES IN DISTRIBUTION GRIDS

Whereas the very nature of the various issues found in distribution grids differs a lot from case to case, they share a common conclusion. At the end of the day, all of them represent, either a direct economic loss for the DSO, produce customer dissatisfaction or both. In this section, such problems have been classified into two different categories, traditional and modern.

Traditional Issues

In this category fall all those problems that have been detected by DSOs over the last century. While some of them have been reassessed and revised periodically after pertinent techniques or technological advantages were made, others have been kept in a state of inaction. Nevertheless, the SG environment should be capable to improve the situation. In general, issues collected in this section are:

- Natural Disasters: lightning impacts, falling trees, storms, earthquakes, flooding, etc.
- Short circuits: Both in the balance (i.e. three phase to ground) and unbalance (i.e. phase to phase) variants.
- Unregistered users: Non-technical losses or energy theft which, traditionally, only possible to identify by visual inspection, and although AMIs haven been included, it might be difficult to improve.
- Inefficiencies: Caused for example by incorrect TAP setting in the transformers, non-optimal voltage levels or topology selection.

Modern Issues

In this category fall, all those problems that have been detected recently and that will, foreseeably, become worse in the future unless some actions are taken. Most of these challenges are caused by distributed energy resources, but also the penetration increase in power electronic interfaces and new loads like Heat Pumps (HP) and Electric Vehicles (EV). In general, issues collected in this section are related to voltage quality, such as:

- Flicker: visual fluctuation of a lamp's brightness due to rapid voltage variations. [3]
- Dips & swells: They are respectively a temporary reduction or increase of the RMS voltage respect to a specified value. [3]
- Bidirectional Power flow: Traditionally, current flows from upper to lower levels of the Transmission and Distribution systems, after the inclusion of distributed generation, this is not always true. [3]
- Harmonics: Sinusoidal voltage with a frequency equal to an integer multiple of the fundamental frequency of the reference voltage. [3]

STATISTICS

In this section, the occurrence incidence of the aforementioned issues and faults is covered. The focus is on the Nordel system (Scandinavia and Baltic areas) due to the available data, however, this conclusions can be extrapolated to any other country.

In [4] is stated that around 80 % of the outages occur at distribution level (< 25 kV) while the rest are registered at higher voltages. It also points out the reduction in the number of outages suffered after the conversion towards underground cables. Additionally, from [5] some general rules can be stated: Most of the events occur in Over-Head-Lines (OHL), most of the faults occur at 132 kV, the most common short-circuit is phase to ground, and voltage drops down of 75 % last several cycles, while those down around 25 % last up to minutes.

Figure 1 presents the fault trends from 1996 to 2015 in the Scandinavian countries. Such graph presents a clear increasing tendency regarding number of faults, especially in the last years, when the penetration levels of distributed generation has drastically increased.

Figure 2 presents the average outage minutes per consumer per year in Nordel, while Figure 3 classifies each individual fault according to the cause for the years 2015 and 2016. Special attention should be given to the fact that the cause of most outage are not identified; due to its relevance regarding minimizing their occurrence.

CURRENT PRACTISES USED BY DSO

Existing practices are defined as the problem solving approach used, in general, by DSOs in their daily activities. Such endeavours can essentially be divided into two different problematics, voltage events and grid losses.

Voltage Events

In general, DSOs rely on consumers' phone calls to identify voltage issues. Most of the time, complaints are related to alarms from equipment, apparel not working of blinking lights, which is caused normally by incorrect TAP settings or low substation capacity. If the issue does not fall under such categories, an analyser is installed in order to monitor certain parameters as according to [6].

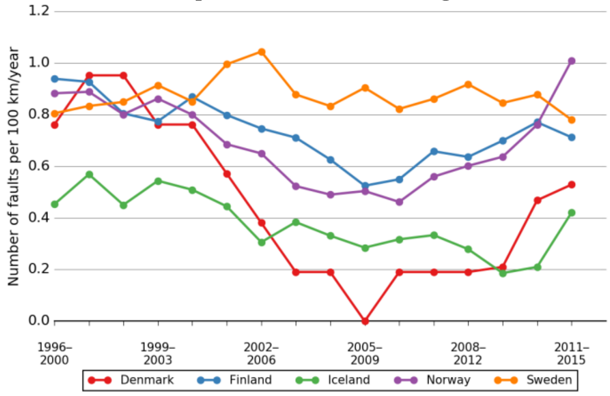

Figure 1: Fault trends as five-year averages in OHL in Scandinavian countries [4]

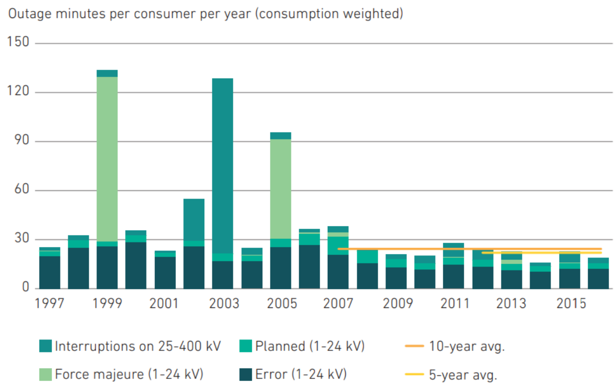

Figure 2: Outage minutes per consumer per year. [7]

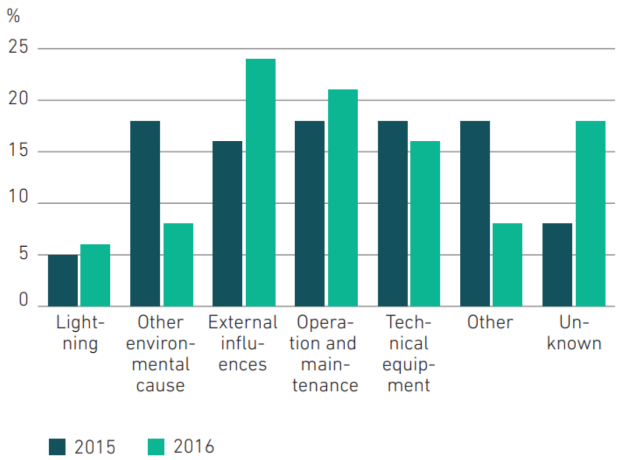

Figure 3: Outage causes during 2015 and 2016 [7]

On the other hand, when a customer requests permission to connect a generator, an evaluation is performed to ensure the adequate operation of the system. Firstly, active and reactive power are monitored for two weeks. Then the necessity for grid reinforcements is assessed with a simple grid model. However, measurement campaigns longer than 2 weeks at customer level are not used in such evaluation

Grid Losses

The losses estimation is based on the direct measurement of power flow at substation level and manual reading of electricity meters at consumers level and small generation units. If there were any missing readings, such values are extrapolated from the recorded ones. Finally, such value is multiplied by the annual average energy price in order to estimate the economic losses as presented in Figure 4.

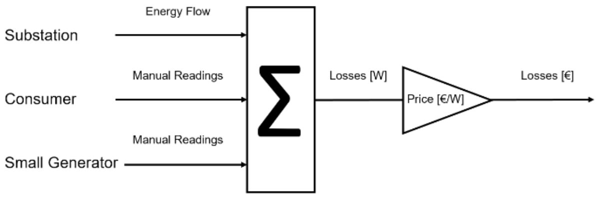

Figure 4: Losses estimation concept [8].

Discussion

Such approaches are over simplistic and completely outdated, since none of them make use of modern measuring and communications platforms. In the first case, DSOs are driven by customer dissatisfaction in order to even be aware of the existence of a problem. Then, the actual identification and solving process is time consuming due to the lack of available data. Then, the connection process of a generation unit takes an unacceptable amount of time due, again, to the lack of recorded data. Not to mention that the study covers basically voltage levels and currents, but doesn't asses flicker, harmonics or any other parameter. Finally, the losses assessment is performed based on manual readings from meters, which implies a large economic and human resources impact while also being inaccurate since the readings are not time synchronized. Due to the way the data is recorded, DSO can not use the actual price of the electricity which adds more error to the economic estimation.

In conclusion, current practices are outdated since:

- Event identification relies on complaints
- The event's cause is not identified in a high percentage of the cases.
- Unacceptable amount of time and personnel efforts used in the process.
- Unacceptable level of error.

ROLE OF AMI AND PVI

Especially AMI, but also PVI are already widely spread through Europe. In general, both system can provide high quality measurements of a different number of grid's variables and parameters. Subsequently, they are also able to process such data in a simplistic way (i.e. obtaining averages). Finally, they send the information upstream into the central systems; such communication can be performed with different technologies, like radio, internet, fibre, etc. However, despite the numerous features of these devices, the available data is, currently, not being retrieved as often and as well as it could, thus missing a great opportunity of increasing the visibility of distribution grids. It is worth mentioning how the measurement error for both technologies ranges between 1 to 4 % depending on the monitored parameter [8].

Advanced Metering Systems (AMI)

Motivated by EU legislation, smart meters are being installed at household and commercial level, but also in substations. Their mean penetration in Europe is over 80 % with some countries like Spain with 100 % deployment already [9]. These meters provide measurements of voltage, current, power and energy with 1 to 15 minutes intervals on 3 phases. In fact, these devices are able to monitor parameters related to power quality like flicker, harmonic distortion, etc.

Photovoltaic Inverters (PVI)

The PVI is a key element coupling PVs to the grid. Depending on each country's regulations and the kind of installation they can be three or single phase. Oppositely to AMI, PVI are not officially calibrated to conform to a measurement class, however, their typical accuracy should be enough to improve the grid's monitoring.

TARGETED IMPROVEMENTS

The targeted improvements after the proper utilization of AMI and PVI as part of the SG in distribution grids are related to the increased monitoring of the network. The most important points are:

- Investment reduction: Since grid reinforcement will be calculated based on proper measurements.
- Increased renewable hosting capacity.
- Reduction of accidental damage caused to customer's equipment.
- Voltage variations decline and power quality improvement.
- Avoid customer's complaints dependency, increase customer satisfaction.
- Reduction of time and manpower invested in assessment and reparations.
- Increased efficiency.
- Increased accuracy of studies (i.e. state estimation, loses estimation, etc.).

However, all this advantages will only become real if adequate technologies and software applications are developed to be used by DSOs. Due to the general small size of these companies and their limited resources, it is highly unlikely that the required investment will be assumed by a single company to develop advanced tools and applications to increase grid observability. Therefore, the Net2DG project (under the H2020 EU fund) tries to partner several DSO and expert private companies with appropriate universities and research centres in order to develop such a tool as a joined effort between academy and industry. In order to meet the aforementioned objectives, 5 applications are envisaged: Outage Detection, Outage Diagnosis, Losses Estimation, Preventive Maintenance and Voltage Quality Monitoring [8].

CONSIDERATIONS TO BUILD A MODEL

A verification model ought to be used as validation for any developed application; in Net2DG noted as *Reference Grid Model (RGM)*. It must capture relevant scenarios, returning acceptable results from the applications prior to grid studies. However, different perspectives and points of view that can be used when developing such a model; in the following paragraphs is presented the scope agreed upon all the involved partners in Net2DG.

Type of Simulation (RMS vs EMT)

The fundamental difference in types of studies is the type of simulation; either RMS (phasor) or EMT. Briefly, disturbances affecting power systems are classified as: electromagnetic and electromechanical transients. Figure 5 compares both transients; the main difference from the point of view of the simulation approach is the necessary sampling time, which for EMT is about 10-100 µsec while 10-20 msec for RMS. Thus, despite of the fact that EMT is more accurate, the hardware requirements to run large distribution grids are more demanding or even impossible than the RMS equivalent model. Moreover, these requirements cannot be met; if real-time co-simulation is targeted as there is no available RT system that can handle hundreds or thousands of electrical nodes in EMT. Thus, the RMS approach may be the only feasible solutions. Also, RMS' time step allows to simulate large power grids with thousands of busses and generators including Real-Time co-simulation for reaching high TRLs. In addition, measurement devices are currently only able to record RMS values, leaving EMT as only suitable for small laboratory systems, but not for field implementation. Subsequently, the grid model should provide RMS values of voltages, currents, active and reactive power, phase angles per phase for a 3-phase low voltage grid at time resolution of maximum 1 second. Also, it should consider the particularities of transformers, OHL, cables and substations.

Targeted Types of Studies

The complexity of the problems found in distribution grids demands a broad analysis. Usual assumptions like balance state or pre-set voltage values are not acceptable. Therefore, the developed model should be able to analyse unbalanced 4-wire systems in order to account for every possible scenario to be encountered by DSOs in their daily activities. Additionally, and as a post-event analysis, the model should be able to asses all kinds of faults and short-circuits.

Mathematical Tools

The objective of the mathematical tool run on top of the grid model should obtain voltages and currents under defined load conditions, which can later be used to obtain also active and reactive losses. Such analysis is traditionally performed by means of a Load Flow or Power Flow; since it is the basic tool in planning and operation of any DSO. However, the main drawbacks of this tool are its unsuitability for real-time studies and that it uses assumed values in the system, not actual measurements. This was acceptable until the deployment of the AMI infrastructure, but not anymore.

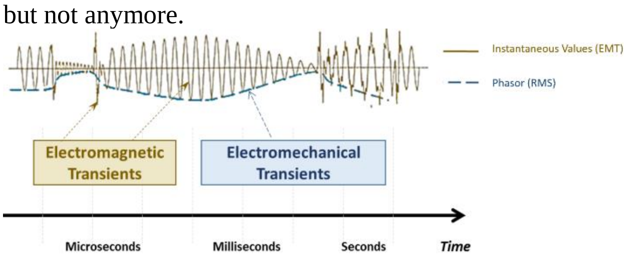

Figure 5: Electromagnetic vs Electromechanical Transients [8].

Then, in recent literature, other computational methods applied to electric networks are presented, such as Kalman Filters [10], Weighted Least Square Method [11] and Bayesian Estimator [12].
The basic common idea is that these methods will use real values to compute (estimate) the grid's state. The computational time of such estimators is fast enough to allow real-time applications provided a reasonable amount of error. Briefly, load flow and estimation will be used for different kinds of studies. In Net2DG the Weighted Least Square Method has been selected in the first run due to the fact that the critical drawback of this system is to have an error that depends of the initial state, which can be set to the voltage level of the substation; error that in practice is usually less than 1 %. Nevertheless, the selected method might be reviewed in the future.

Simulation Tool

In [8], 66 different power system analysis software tool were reviewed in order to choose the most suitable one attending to the aforementioned criteria. Resulting in only four suitable; in alphabetic order: BCP Switzerland, DigSILENT PowerFactory, MathWorks SimPowerSystems, and OpenDSS. The evaluated characteristics that led to this selection was: Maintenance, Support, Per-Phase analysis, Unbalance analysis, Fault Level and possibility of Control integration. Although, it is always possible to simply code from scratch a tool in C, Python or similar just to avoid paying licenses and the black box approach.

ACADEMY AND INDUSTRY BARRIERS

The main deterrents of the barrier between academia and industry are divided in purpose, format, perspective, availability and agenda.

- Purpose: Industry research's main objective is, to solve specific problems and achieve confidence before deploying the solutions. Whereas in the academic world this is not the case, being inquiry driven. Additionally, companies expect economical profit based on the research, while in the university this is not always the case. [13]
- Format: Academic papers layout and writing style are not aligned with the design process used in industry. Thus, practitioners usually find content of academic publications to be complex, abstract or uncertain, ultimately dismissing their interest on using such findings. [13]
- Perspective: Practitioners usually criticize academy for not considering critical implementation details, which impedes adaptation of academic findings into practical applications. Also, it is common that the academic world is not aware of actual issues present in the industry world. [13]
- Availability: Whereas academic research is usually peer reviewed and published in journals and books, industrial research tends to be confidential. It is quite common the lack of an aligned terminology between academy and industry, which causes a practical impossibility for the practitioners of coming across relevant research findings. Also they struggle in identifying with publications deserve attention. Finally, most of the academic research should be bought in order to be accessed, thus paywalls also pose a cost barrier for practitioners. [13]
- Agenda: Practitioners developing research in companies work on it full-time while generally in the academic world it is only part time, since they need to combine it with teaching among other duties. Also, industry works with tight timelines, while academy is more flexible. [13]

HOW DOES NET2DG MIND THE GAP?

In Net2DG, partners are focused on aligning objectives, which leads to combine perspectives and try to use the available synergies in order to move forward. However, the first step is to find a common language in order to ease the communication between all the involved stakeholders. Continuous per-reviewed work is used in order to avoid misunderstandings and to keep the perspective of joining cutting edge research with experience based knowledge.

CONCLUSION

The issues found in distribution grid are various and different, which cause, customer dissatisfaction, economical losses, but also hinder the deployment of distributed generation. However, modern technologies under the SG scope allow to increase the grid monitoring. Subsequently, DSOs and society have interest on developing tools and methods that can be used for this purposes. However, DSOs can not undertake alone such research; only by means of partnership with academy is possible. Such alliance is always positive since it reduces the gap between industry and academy, aligning objectives and perspectives; working both at the service of society. The NET2DG project fills in this gap by developing 5 applications demanded by DSO unleashing SG potential.

ACKNOWLEDGEMENT

This work was supported by the European Union's Horizon 2020 research and innovation program under grant agreement No 774145 within the project Net2DG.

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