DISTRIBUTED GENERATION AT DISTRIBUTION SYSTEM LEVEL RESILIENCE TO VOLTAGE DIPS – A REAL CASE

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ABSTRACT

In recent years, Distributed Generation (DG) mainly from renewable energy sources, has shown a significant increase in Portugal and is expected to keep that trend in the near future.

One of the issues regarding DG high penetration is that a voltage dip in the network can cause the disconnection of a significant number of DG, which, in turn, can possibly affect the system's stability and security.

This work presents a study performed over a Portuguese real case network incident in order to evaluate the Distribution side DG resilience to voltage dips caused by a fault in the Extra High Voltage (EHV) network. EDP Distribuição (EDPD) power quality (PQ) monitoring platform provided data regarding the country wide geographical occurrence of voltage dips at the distribution electric system originated from the fault at the transmission system. An algorithm was developed to analyse the available real metering data and identify which DG, connected at distribution level, had been partially or totally disconnected from the grid due to that transmission system fault.

The results show good correlation between the location of voltage dips and generation disconnection. The amount of DG lost in the event was small when compared with the total DG at the time of the incident. Given the fact that most of the DG (wind, solar, small-hydro and combined heat and power) were not designed to withstand voltage dips, which was not a requirement when most of them were installed, this event has proven the Portuguese distribution system high resilience to voltage dips.

INTRODUCTION

Due to environmental commitments the Portuguese electricity system has been undergoing major transformations, coming from the totally centralised and dispatchable big power plants connected to the Transmission network to the increasing non dispatchable Distributed Generation (DG) connected at the Distribution network.

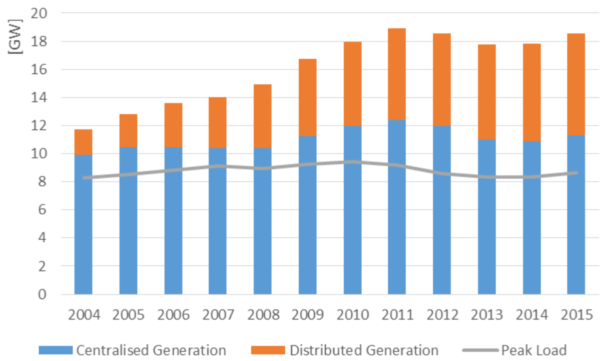

Figure 1 – Generation Capacity Evolution and Peak Load in Portugal

Figure 1 shows the evolution of the Electricity Generation Capacity and Peak Load over the last 12 years in Portugal. Initially, the low total share of DG in the overall capacity was not seen to be an issue for system stability and security and most of the DG was installed at a time where voltage dip withstand was not a requirement.

Nowadays with the exponential increase of the DG capacity together with the zero growth of the Portuguese electric power consumption one of the main concerns is that, in case of an EHV (Extra high voltage) fault which causes voltage dips, most of the DG disconnects from the grid, possibly causing a chain reaction affecting system stability and security. Although the current Portuguese network code has requirements for low voltage fault ride through (FRT) since 2010 most of this DG was installed at an earlier time.

During the year of 2016 a voltage dip originating from the transmission network was felt at large areas of the distribution system. This paper presents the study performed over the DG resilience shown in this incident. It was determined the amount of DG at distribution system level that had been disconnected from the grid due to that particular cause, allowing for the evaluation of the DG resilience to voltage dips.

EDPD PQ monitoring platform provided data regarding the geographical distribution of the voltage dip originated at the EHV and felt in MV busbars of HM/MV substations of the distribution electric system, while SCADA and metering system provided data regarding DG power output.

An algorithm was developed to estimate which DG, connected at distribution level, had been partially or totally disconnected from the grid due to that transmission system fault.

Despite the difficult weather condition which may have caused other non-related voltage dips the results have shown a good geographical correlation between generation lost and voltage dip.

DG IN PORTUGAL

Over the last decade the renewable energy generation almost duplicated its install capacity being wind generation the biggest contributor for that achievement.

According to 2015 technical data at the end of 2015 around 40% of total installed capacity was Distributed Generation (wind, solar, small-hydro and CHP) which is mainly connected to the distribution system network. Figure 2 shows the total DG connected to the distribution system network.

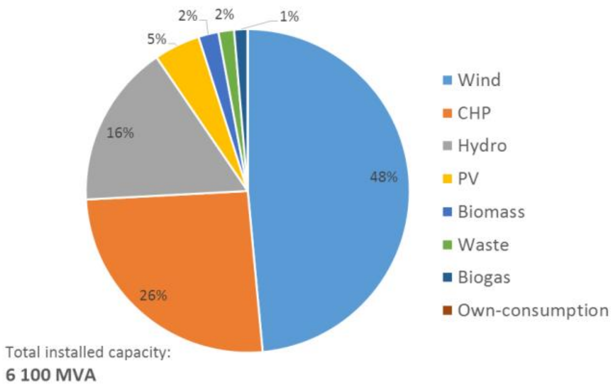

Figure 2 – DG connected at the distribution system level (DSO network) with available metering data

Network Code Requirements

In 2010, foreseeing the issue of having high values of distributed generation without any requirement regarding voltage dip together with the fact that wind generation technology was becoming a mature technology with broader capabilities, the Portuguese Government updated its network code regarding fault ride through capacity (FRT).

The Portuguese distribution system grid code rules that all new wind farms (WF) with more than 6 MVA of install capacity and all previously installed WF with more than 10 MVA of install capacity must keep connected to the grid during voltage dips, originated from three-phase, two-phase or single-phase faults whenever the voltage level remains above the curve shown in Figure 3. Moreover, none of these WF is allowed to consume active or reactive power during the fault or voltage recovery time.

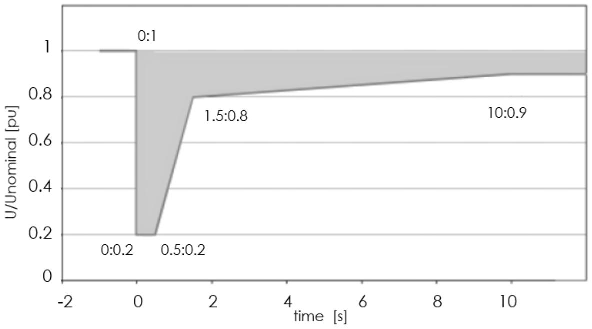

Figure 3 – Low voltage Fault Ride Through capacity for 3P, PP and PN fault

According to EDPD and Portuguese regulator, 50% of the total 2.96 GW of wind power install capacity connected to the DSO network have the FRT capacity being able to comply with the voltage dip curve shown in Figure 3.

Due to its lower total summed up install capacity, technically impracticability and/or economic non viability, all the other DG such as small-hydro, solar and co-generation were kept, at that time, without any voltage dip requirements.

DG RESILIENCE TO VOLTAGE DIP – REAL CASE

At 12:02 p.m. on February 14, 2016 occurred a fault at TSO network which have caused the trip of two EHV overhead lines located at north side of Portugal. The voltage dip originated from that fault was felt at the distribution system. The precise location of the two tripped overhead lines is highlighted in the Portuguese TSO map shown in Figure 4.

It should be noted that the February 4, 2016 was a day with very adverse weather conditions for which the Portuguese Institute for Sea and Atmosphere (IPMA) had previously issued an orange alert and that way there were other non-related voltage dips felt at the distribution system network.

Available Data

Power Quality

EDPD has a PQ monitoring platform based on 3 main technical elements, PQ monitoring devices, communication infrastructures and a management centre responsible for the management of the whole system. PQ monitoring devices are installed in the distribution network at some HV/MV substations and some MV/LV secondary substations fulfilling a biannual PQ monitoring plan due to regulatory requirements imposed by the national QoS Regulation code. In each one of these monitoring points voltage continuous phenomena data and voltage events, including voltage dips and swells are recorded.

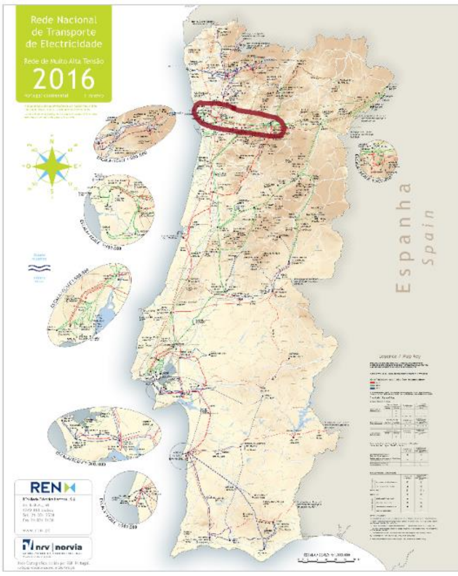

Figure 4 – Location of the two EHV overhead lines which have tripped on February 4, 2016

The PQ data used for the elaboration of this study were made available by the EDPD PQ monitoring platform, consisting of the voltage dips registered in 84 HV/MV substations, corresponding to 140 MV busbars, on the day of the incident under analysis.

Figure 5 shows voltage dips felt at the EDPD network during the fault. Near the zone of the fault, voltage level at the distribution system network has fell down to values of 0.4 pu of the nominal voltage for maximum time of 120 ms.

DG Generation Data

Regarding DG real generation data, EDPD has available two different data types: the real time SCADA data; and the metering data.

The real time SCADA data has instant DG power measures with a 5min. sampling and every time the power change ratio is faster than 1MW per 10seg. The metering data has 15 min. average power measures with the same 15min. of sampling ratio. For example, while in SCADA data the value of the variable at 12:00 p.m. is the instantaneous power at 12:00 p.m., in metering data it is the average power of the previous 15min. (11:45 to 12:00).

Then, for each day, the SCADA system should have a minimum of 288 instant power samples per day (in case there weren't any fast power generation changes during that day) while the metering data should have 96 samples.

For the identification of which DG had been disconnected from the grid due to the transmission system fault both available real time SCADA data and metering data were used.

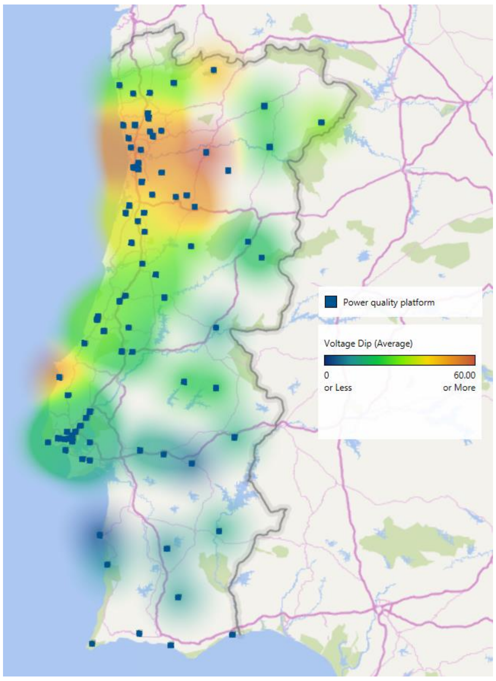

Figure 5 - Voltage dip at distribution system due to the fault at the transmission system

Figure 6 represents the total summed up DG real generation data registered by all the available meters for the day of the voltage dip occurrence. According to the data, and assuming that during the 15min previous to the incident the power generation didn't have significant variations, at the time the fault occurred there were 3.1GW being generated by all the DG connected to the distribution system network: 70% from wind; 14% CHP; 7% small-hydro; and 9% others (including solar).

Algorithm

An algorithm was developed to be used with the 15min. metering data. The developed algorithm data was then compared to the available real time SCADA data for accuracy testing. Several DG, which presented different behaviours during the voltage dip incident, were selected and its real-time SCADA data was used to improve the algorithm performance in identifying, through metering data analysis, the DGs which had been truly disconnected from the grid.

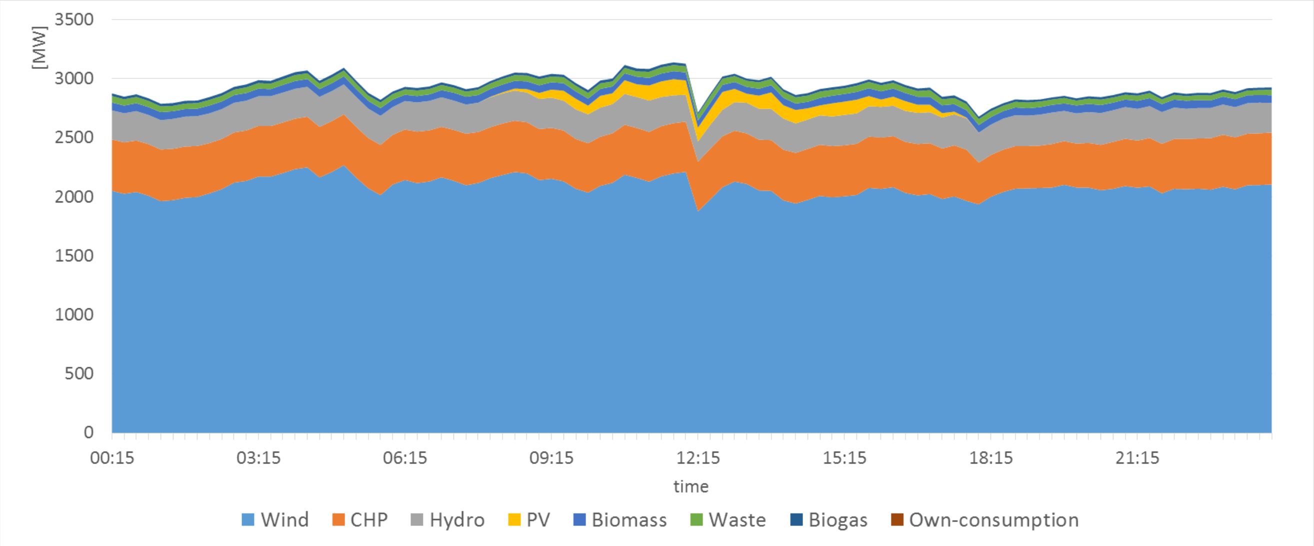

Figure 6 – DG real generation according to the 15min available metering data

The developed algorithm consists on the following equations:

$$\begin{cases} |P_{med4} - P_t| > 2 * \sigma & (1) \\ P_{t-1} - P_t > \alpha * P_{t-1} & (2) \end{cases}$$

$$P_{med4} = \frac{\sum_{i=1}^{4} P_{t-i}}{4} \quad (3)$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{4} (P_{t-i} - P_{med4})^2}{4}} \quad (4)$$

Where, given the fact that the fault occur at the 12:02 p.m. of 14 February, 2016:

- P_t is the 12:15 p.m. metering measures;
- P_{t-1} is the 12:00 p.m. metering measures;
- P_{med4} is the average generation power during the hour before the fault (4 sampes);
- σ is the standard deviation of the DG power during the hour before the fault;
- α is the threshold which defines minimum power loss to identify DG disconnection.

Equation (1) is intended to filter all power variations caused by the variability of the sources used by each DG and unrelated to the voltage dip incident. (2) is used to identify if a DG was disconnected by comparing the difference of the metering data of the sample before the event and the sample after the event with a threshold. Since Portuguese network code regulates that after a trip the DG has a minimum time of 3 min. to reconnect to the grid, the minimum admissible value for α should be 0.2.

Results

Using the developed algorithm several analysis for different values of α were performed. Each results were compared with the available DG real time SCADA data and it was identified the value of $\alpha = 0.45$ as the more reliable and realistic both in terms of total DG lost as in terms of DG lost for each type of technology. This value of $\alpha = 0.45$ means that each DG which disconnected itself from the distribution system network due to this specific voltage dip incident took at least 7 min. to fully recover to its previous output power generation.

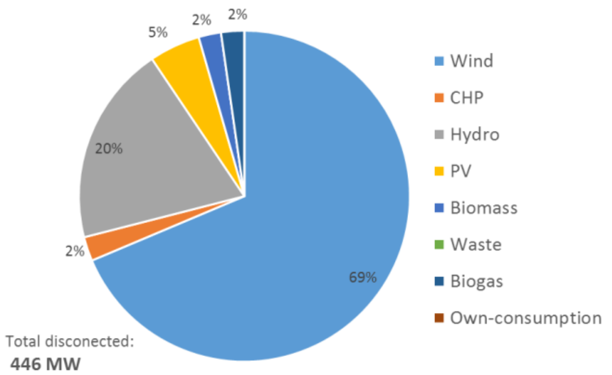

Figure 7 – Total DG lost at distribution system due to the fault at the transmission system

94 DG which have been partially or totally disconnected from the grid due to the transmission system fault were identified. Figure 7 shows a graphical representation of the total DG by generation type. 2.68 GW (86%) of the total DG kept connected to the grid contributing for the system stability and security.

Notice that the actual value of the DG that remained connected to the network during the EHV voltage dip is probably higher than 2.68 GW (86%). During the 15min time frame (from 12:00 to 12:15) several voltage dip caused by faults in the HV and MV were felt. Several wind power plants also reported temporary shutdowns due to icing or excessive wind speed. Due to the limitation of the analysis with the 15 min. period it is not possible to filter these events leading to a pessimistic value.

Despite almost 70% of the total lost generation were from wind power technology and the detected voltage dips where inside the curve represented on Figure 3, given that only 50% of the total install capacity have FRT capacity, only an estimated 1% didn't comply with its requirements.

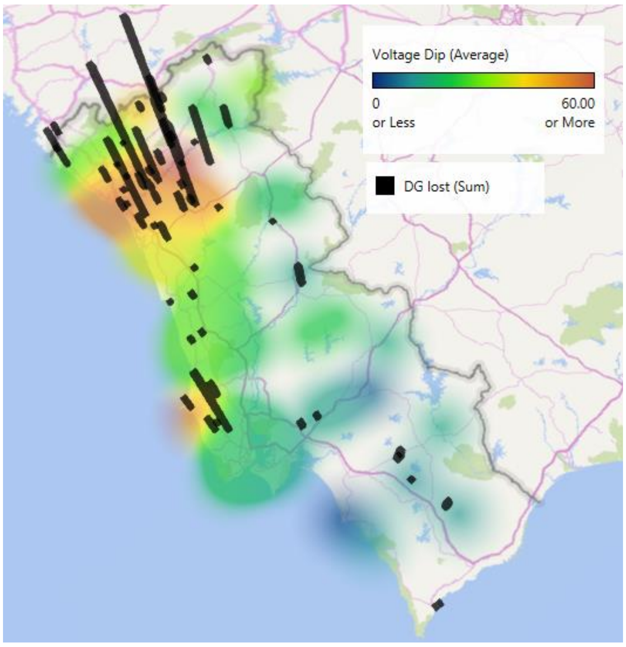

Figure 8 - Voltage dip and DG lost at distribution system due to the fault at the transmission system

Figure 8 shows voltage dips and DG lost at the EDPD network for the analysed fault. There's a good correlation between the location of voltage dips and generation disconnection.

Regardless of February 14, 2016 has been a day with difficult weather conditions and some of the identified generation disconnection and voltage dip could have been motivated by other HV and MV faults, it hasn't affected the good correlation between the location of voltage dips and generation disconnection.

CONCLUSIONS

On 14 February, 2016 a fault at the transmission system caused a voltage dip which was felt at the distribution system network. Nowadays, with the exponential increase of the DG capacity together with the zero growth of the Portuguese electric power consumption, one of the main concerns is the DG resilience to voltage dips.

A study was performed over this specific incident and an estimate of the amount of Distribution side DG that disconnected from the grid, thus not contributing for the system stability and security, was determined. EDPD PQ monitoring platform, real time SCADA data and metering data were essential for the execution of the study.

It was estimated that a maximum 86% of the DG power present at the Distribution network remained connected despite the Transmission side voltage dip. This value is pessimistic due to the limitations of the available data which only had a 15 min. time resolution. During the 15 min. time frame when the event occurred several voltage dips originating from the HV and MV network were also felt. Also, several wind power plants reported temporary shutdowns due to icing and excessive wind speeds. The real result is expected to be larger than 86%.

The 86% value is a good result because most of the DG in Portugal was installed at a time when the grid connection requirements did not comprise FRT. And in absolute value, 446MW, is the equivalent of disconnecting a large power generating group at the EHV.

The FRT characteristic of the DG connected generating plants presented a good behaviour.

This results show that the Portuguese distribution system presented a high resilience to voltage dips which can be attributed to good planning and interconnection protection system design. The DSO is, therefore, having a sizeable contribution to the overall network stability, reliability and system security.

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