VOLTAGE DIP MONITORING AND ANALYSIS IN ENEL DISTRIBUZIONE NETWORK

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ABSTRACT

This paper deals with the problem to identify the origin of voltage dips. The dips present in Medium Voltage system can be caused by problems in the MV networks or by problems in High Voltage systems. It is important to be able to assess their origin as the utilities in this case should be responsible only for the events due to faults occurred in their networks. In this contest any preliminary activity focused on the forecasting of the weight that different percentages of voltage dips of different origin could have on voltage dips becomes a priority.

INTRODUCTION

Enel Distribuzione (ED) is activating one of the largest campaigns of power quality monitoring in the world. The installation of about 3500 power quality analyzers (class A IEC 61000-4-30) at all the Medium Voltage (MV) busbars of the High Voltage/Medium Voltage (HV/MV) substations was completed in the 2014. The primary goal is the analysis of the voltage dips in the respect of the innovative regulation introduced by means the resolution 198/2011 by the National Authority on Electricity, the AEEGSI (Autorità per l'Energia Elettrica il Gas e il Sistema Idrico) [1]. As a first step toward the economic regulation of voltage quality in the Italian distribution networks, the resolution 198/2011 specifically imposes of measuring and recording all the voltage dips occurring at all MV busbars of all HV/MV substations (HMSS). The time of start, the duration, the involved phases, the value of the retained voltage, the origin are some of the features to be recorded for each voltage dip.

To properly manage a so large dimension of recorded data, ED is developing a specific tool inside the ED PQDW (Enel Distribuzione Power Quality Data Warehouse) that represents the wider program of analysis and control of the power quality aspects in the distribution network of ED [2].

The main problem approached in the first phase of the analysis is the characterization of the origin of each voltage dip. The origin of a voltage dip establishes the responsibility of that voltage dip. The aim is to detect which and where is the primary event that caused each recorded voltage dip.
With reference to the voltage dips due to short circuits, the responsibility of a voltage dip is of the network where the short circuit originating that voltage dips happens. As known, the voltage dips pass across the transformers of the HMSS, and propagate through the networks with paths not always linear and easily predictable especially in the presence of meshed configurations of the network. This means that the responsibility of a voltage dip is not always of the network where that voltage dip was measured.
In the literature some methods have been proposed to ascertain the voltage dip origin mainly using current and voltage information, as reported in [3]. These methods would require at least the installation of measurement devices for current and voltage that, in some cases, must also record the values before the voltage dip happens. A further method has been proposed in [3] that uses only information on the voltages but it requires measurement devices at both sides of the transformer that interconnects two grids. All the methods mentioned above are not applicable to the real cases that have to be analysed according to the resolution [1]. In these cases, in fact, only the voltage dip information at MV busbars are available.

In this paper the preliminary results obtained analysing the first voltage dips registered (more than 50000) will be presented, with particular attention to different rules adopted for establishing the voltage dip origins.

VOLTAGE DIPS: STANDARD AND INDICES

The most important national and international standards do not contain any maximum values for the voltage dips. The standard IEC 61000-2-8 [4], however, recognizes that the phenomenon must be characterized at least in the plane (amplitude, duration). The new standard EN 50160 [5] defines the tables which classifies the voltage dips at each site of the Low Voltage (LV) and MV distribution networks. Figure 1 shows the table referred to MV networks.

Residual voltage ***u*** %	**Duration** ***t*** ms				
	10 ≤ *t* ≤ 200	**200 < *t* ≤ 500**	**500 < *t* ≤ 1 000**	**1 000 < *t* ≤ 5 000**	**5 000 < *t* ≤ 60 000**
90 > *u* ≥ 80	CELL A1	CELL A2	CELL A3	CELL A4	CELL A5
80 > *u* ≥ 70	CELL B1	CELL B2	CELL B3	CELL B4	CELL B5
70 > *u* ≥ 40	CELL C1	CELL C2	CELL C3	CELL C4	CELL C5
40 > *u* ≥ 5	CELL D1	CELL D2	CELL D3	CELL D4	CELL D5
5 > *u*	CELL X1	CELL X2	CELL X3	CELL X4	CELL X5

Fig.1: Classification of dips according to residual voltage and duration according to the EN 50160 [4]

The values of each cell in the table of the Fig.1 are not given, but the EN 50160 states that the a product should cope with voltage dips as indicated in the cells A1, B1, A2, B2, for the class 2, and A1, B1, C1, A2, B2, A3, A4 for class 3, being classes 2 and 3 defined in EN 61000-4-11 and in EN 61000-4-34 [6, 7].

Regarding the indices, the most frequently adopted in the technical literature to characterise the performance of the node k are:

- the RFI-Xk, which stands for RMS Variation Frequency Index for voltage retained in site X k, is an index that measures how many times the amplitude of a dip in the node k is below a given threshold X, typically expressed in percentage of the nominal voltage.
- VDAk, which stands for Amplitude Voltage Dip, is an index that measures the amplitude of the voltage of the dip in the node k. VDAk can be related to a single dip or multiple dips registered at the same node. In the latter case we will refer to its mean value (μ [VDAk]).
- Nk, the number of dips in the node k; it is equal to the value of the index RFI-90k.

The indices RFI-Xks have the advantage of providing information about the frequency and amplitude of the dips; the index VDAk is particularly suited for probabilistic characterization.

The most frequently used indices to characterise the performance of a system are:

- the SARFI-X which stands for System Average RMS Variation Frequency Index, is the weighted average of the RFI-Xk of all the N nodes of the system.
- the SARFI-X95, which stands for System Average RMS Variation Frequency Index 95th percentile, is the 95th percentile of the SARFI-X.
- SAVDA, which stands for System Average Voltage Dip Amplitude, is the weighted average of the VDAk of all the N nodes of the system.

RESPONSIBILITY OF DIFFERENT NETWORK OPERATIONS

Typically, most of voltage dips experienced at the busbar of a user comes from the feeding system; the "endogenous " dips, ie those that arise within the distribution system of the user, are statistically few.
That is valid in general, however may exist also some situation where the voltage dips originating from the consumer plant can affect also the supplying network; this is possible in case of particular industrial processes or internal short circuits.
Remaining in the most probable case, the assessment of the origin of the dips coming from the feeding system characterised by networks with different interconnected operators is a crucial problem. Only knowing the origin of the voltage dips it is possible to define which operator is responsible and, therefore, will pay for it in case of performance worse than the maximum limits. Moreover, any damage caused by a voltage dip at user’s plant has to be attributed to the network operator that caused it. In Italy the operator of the HV network is TERNA, the operator of the largest MV network is ED; the two networks are interconnected in several points in all the National territory.
The resolution of the AEEGSI [1], in addition to imposing the measure of the voltage dips at all MV bus bars of all HMSS, indicates the method in [8] to discriminate the origin of the voltage dips.

First of all, the method distinguishes against voltage dips recorded at the busbars of the same HMSS and fed from the same HV network from those recorded in HMSS fed from different HV networks.

In the first case, the origin of two voltage dips is in the network HV if all the following conditions are valid:

i) the residual voltage of the all voltage dips differ by no more than 3%;
ii) the instants of occurrence of all voltage dips differ not more than 60 ms;
iii) the durations of all voltage dips differ not more than 20 ms.

In the second case, the origin of the voltage dips is in the network HV only in the presence of the signal of start of the distance protection of the HV network, where available. In the case of unavailability of the signal of the distance protection, the origin is in the HV network only in the absence of the signal of start of the overcurrent protection system of the transformer of the HMSS.

The method practically establishes just local conditions, so any comparison between registrations in different HMSS is valid.
The method, however, does not cover some real conditions that affect the voltage dip phenomenon; in particular:

- generally, the method how to establish when the origin of the voltage dips is in the HV network, that means that all the other voltage dips are originated in the MV network;
- the on load tap changers of HV/MV transformers can generate secondary voltages different more than 3% during the normal operation, that means that a HV
- voltage dips will be detected as several MV voltage dips (because of i);
- the previous phenomena affect also the duration of the voltage dips, so even in this case a HV voltage dip will be detected as several MV voltage dips (because of iii);
- the distance protection detects the short circuits just in the protected HV feeder, so if the voltage dips is caused by another event in the HV network (for

example a short circuit in the 380 kV network that generates a wide dip), it will be detected as a MV voltage dip.

To overcome such a difficulty, we conducted a broad analysis extending the method [8] for the voltage dips registered at the same HMSS to the case of voltage dips registered at different HMSS. All the voltage dips measured at all the busbars of the HMSS from 2009 to 2012 were considered.
The analyzed data derive from a previous power quality monitoring [2].
The following considerations are at the basis of the conducted analysis, and reflect the physical realization of the networks and the physicality of the phenomenon of the voltage dips.
The first aspect concerns the contemporary of the voltage dips: it is realistic that the same short circuit is the cause of contemporary dips registered at the busbars both of the same HMSS and of different HMSS.
The second aspect concerns the assessment of the definition of the contemporary of two voltage dips. It is realistic to define contemporary the dips with instants of occurrence even more than 60 ms. The analysis was conducted with different values (0 ms, 60 ms and 100 ms). The voltage dips that comply with this condition will be referred to as "aggregated dips".
The following assumption was made to establish the origin of the aggregated dips that were recorded at different stations or at the same station: if the total time elapsed from the instant of occurrence of the first voltage dip of the group and the last voltage dip of the same group is not greater than 100 ms, the origin is in the HV network, otherwise the origin is in the MV network.

DATA ANALYSIS

The analysis was conducted on the data measured at twelve HMSS of the Sardinia region during the year 2012.
Figure 2 shows the scatter plot of all the measured voltage dips without any aggregation.
The corresponding values of main indices of site and of system are reported in Table I. It is important to evidence that about 20% of the total voltage dips are severe voltage dips (amplitude below 50%).

Table I: Voltage dip indices

Station	RFI-90	RFI-80	RFI-70	RFI-60	RFI-50	RFI-40	RFI-30	RFI-20	RFI-10
Chilivani	64	21	15	2	2	0	0	0	0
Macomer	62	28	17	11	4	3	3	3	3
Monteoro	68	30	22	17	12	2	0	0	0
Nuoro2	113	55	35	26	20	14	4	0	0
Ollastra	109	51	22	17	5	1	1	0	0
Suergiu	104	62	31	19	7	6	5	2	0
S.Gilla	198	158	143	138	136	108	4	1	1
Sennori	122	82	51	28	18	15	1	1	1
Serbariu	76	45	29	21	16	16	15	8	2
Siligo	41	19	2	1	0	0	0	0	0
Tergu	78	48	37	20	9	9	9	9	9
Uras	110	50	29	10	8	3	0	0	0
System Indices	SARFI-90	SARFI-80	SARFI-70	SARFI-60	SARFI-50	SARFI-40	SARFI-30	SARFI-20	SARFI-10
	95	54	36	26	20	15	4	2	1

The worst performance is attributed to the station “S.Gilla” that presents 198 voltage dips, having 136 an amplitude not greater than 50%.

Table II shows the results obtained with the procedure described in the previous Section applied with different ranges of aggregation, i.e. 0 ms, 60 ms, and 100 ms.

Table II: Results of the origin assessment with different range aggregation

Aggregation range	0	60	100
MV origin	922	873	854
HV origin	223	272	291
Total dips	1145	1145	1145

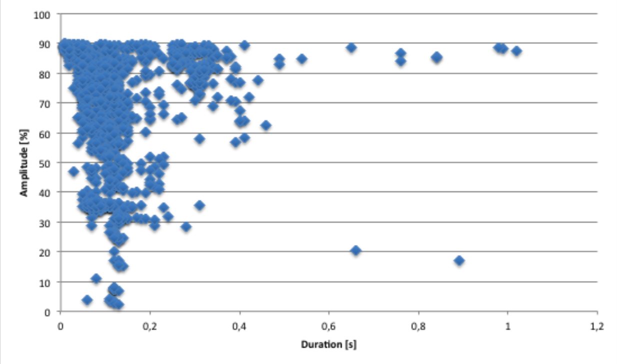

Fig.2: Scatter plot of all measured dips in the twelve HV/MV substations in Sardinia in 2012

It is evident that:

– the most part of voltage dips is always originated in the MV network;
– from 60 ms to 100 ms the number of voltage dips originated in the MV networks passes from 77% to 75%, while from 0 ms to 60 ms passes from 80% to 76%.

The reduced value of variation of the origin due to different range of aggregation, in particular from 60 ms to 100 ms, is mainly due to two important aspects. Firstly, the electrical system of Sardegna is a small system than the rest of the electrical Italian systems. Secondly, the twelve monitored HMSS constitute a little part of the total existing stations.
However, it is interesting to analyse how the variation of the number of voltage dips originating in the HV network with different range of aggregation is distributed among the stations. Figure 3 shows the distribution of voltage dips originated in HV resulting with the different aggregation range (0ms, 60 ms and 100 ms) versus the twelve stations.

From figure 3 it is evident that:

– overall, the distribution of the variation is not uniform along the stations;
– increasing the aggregation range, some stations register an increased number of voltage dips originating in HV, in particular S.Gilla presents a huge variation;
– increasing the aggregation range, some stations

register reduced or no variation at all.

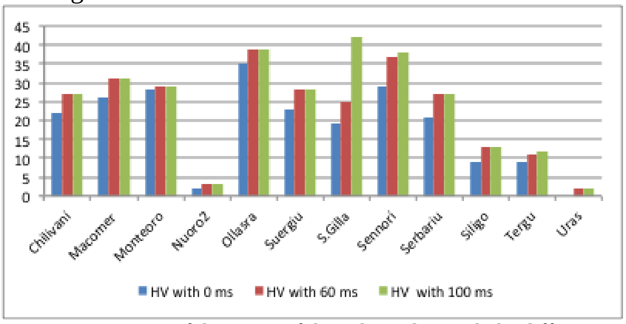

Fig. 3: Variation of the origin of the voltage dips with the different aggregation range (0 ms, 60 ms and 100 ms) versus the monitored stations

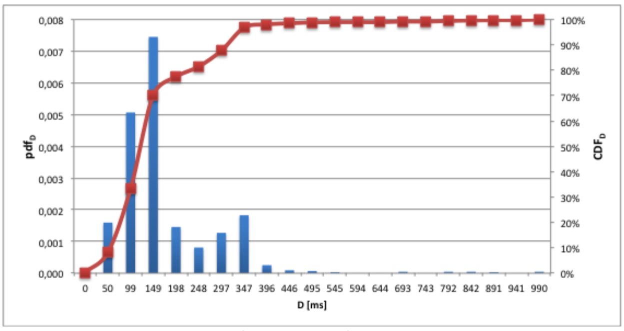

Fig. 4: Probability density function (pdf_D) and cumulative distribution function (CDF_D) of the duration of the measured voltage dips with origin in the MV network (range of aggregation of 60 ms)

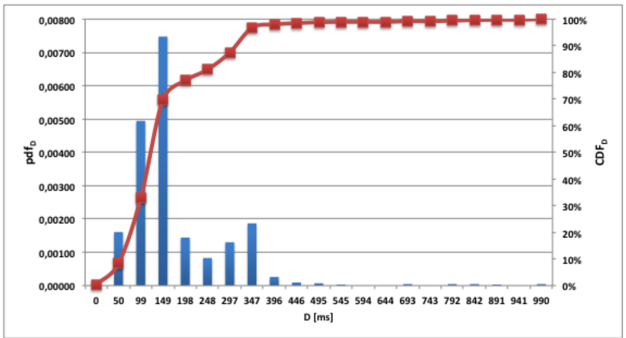

Fig. 5: Probability density function (pdf_D) and cumulative distribution function (CDF_D) of the duration of the measured voltage dips with origin in the MV network (range of aggregation of 100 ms)

Further analyses have been conducted on the duration of the voltage dips originating in HV and in MV with the range of 60 ms and of 100 ms.

From figures 4 and 5, it is evident that:

– the distributions do not present relevant variations;
– both the distributions present about 40% of the duration having value less than 100 ms.

CONCLUSIONS

In this paper the preliminary results obtained analysing the first voltage dips registered (more than 50000) was presented, with particular attention to different rules adopted for establishing the voltage dip origins.

The procedure indicated by the actual rules adopted by the Italian Authority of Energy to establish the origin of a voltage dip have been used and properly extended. The first results obtained on a reduced number of stations suggest to continue to analyse the subject with particular reference to more stations and more measured data.

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