THE VOLTAGE DIP PERFORMANCE ASSESSMENT OF THE ITALIAN MV NETWORK THROUGH GLOBAL INDICES

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ABSTRACT

After about 5 years of MV distribution network monitoring by the Italian system QuEEN, the PQ data collected by 600 instruments distributed all over the Italian territory can be considered sufficient to characterize the network from the point of view of events like voltage dips. The paper is focused on the voltage dip performance of the Italian MV network and deals with its characterization during the whole monitoring period by using suitable global indices at both national and regional level, preserving the statistical representativeness of the sample.

INTRODUCTION

The Italian MV distribution network monitoring system QuEEN (no less than 600 points of measurement, 400 of which installed in primary substations [1], [2]) has been collecting data since by now 5 years and the experience acquired in these years allows to draw a few general considerations on monitoring systems, and in particular, on the potentialities they have to provide useful statistical data concerning voltage quality in general and voltage dips in particular. In fact the monitoring activity can be considered by now a consolidated mean of characterization of the Italian MV network from the Power Quality (PQ) point of view once taken into account the fact that the system has been submitted, in the course of the years, to some technical updating regarding both measurement techniques and data evaluation methods [3].

Among other things the voltage dips performances assessment across the country, during a long-term period campaign, could be very useful for the regulation activity providing to have at disposal suitable methods of data reporting, that is, synthetic ways of reporting these performances. A possibility of presenting the networks voltage dips performances in a concise way is given by the evaluation of proper *indices*. The main advantage of these indices, in comparison with other reporting methods, besides that of conciseness (just a single number is provided in this case), is that of making it easier the comparison among voltage dips performances associated to different monitoring periods (**historical trend analysis**) or related to single distinct geographical sites/areas (**area performance assessment**). Hereafter, referring to a set of indices available in the literature and starting from the PQ data acquired in the period 2006÷2009 by the QuEEN system within its 400 primary substations, the historical trends of these indices have been analyzed at both national and regional level together with some further analysis oriented to assess the different behaviors of the Italian regions.

As regard the indices calculation procedure adopted, the indices are at first evaluated for every single voltage dip (**event indices**), according to their definition, up to obtained **site indices** by the direct sum of all the event indices associated to every single measurement site. **System indices** are, at last, evaluated by summing site indices over all the sites belonging to the system, that is, to the whole Italian territory or to any geographical aggregation under investigation [4].

VOLTAGE DIP INDICES

Indices of very easy evaluation are the "simple counting" indicators defined as the average number of voltage dips, per point of measurement, per year, which fall under a chosen immunity curve like that one for class 2 equipments (***N2a*** inde*x*) or that for class 3 (***N3b*** index). Referring to table 1 which summarizes the Italian MV voltage dip statistic for the year 2009 according to the EN 50160 standard, N2a (49,6) counts the voltage dips which fall outside the yellow cells while N3b (18,8) counts the dips which occur within the white cells.

	Average number of MV voltage dips per equivalent point of measurement (EN50160)					
		Dips durations (ms)				
		20-200	200-500	500-1000	1000-5000	5000-60000
Ures (%)	80<=D<90	34.9	7.5	2.0	0.6	0.0
	70<=D<80	17.1	5.3	0.6	0.2	0.0
	40<=D<70	28.2	5.3	0.6	0.1	0.0
	5<=D<40	9.9	1.7	0.2	0.0	0.0
	1<=D<5	0.2	0.0	0.0	0.0	0.0

Table 1: average number of voltage dips per equivalent point of measurement monitored in 2009 (EN 50160)

So the yellow cells correspond to the immunity area for class 2 apparatus, supposed to be connected to the public distribution network, while the yellow + green cells represent the immunity area for class 3 equipments that operate in an industrial environment. For these indices we observe that:

- they are easily comprehensible (it is a simple counting) and a low value of these indices correspond to a situation of network good performance;
- they do not point out the voltage dip duration and depth.

One way to take into account the main voltage dips features is to turn to "weighed" counting indices. Among them the "Discrete Severity Index", that, for a given voltage dip of duration t* and residual voltage V*, is defined as [5], [6]:

$$\mathrm{DSI\_x} = \frac{|\mathrm{V}^* - 1|}{|\mathrm{V}_{\mathrm{refx}} - 1|}$$

where V* is the residual voltage of the event in p.u. and V_{refx} is the voltage level of the immunity curve "x": this last one assumes different values depending on the immunity curve "x" to which it is referred (Figure 1).

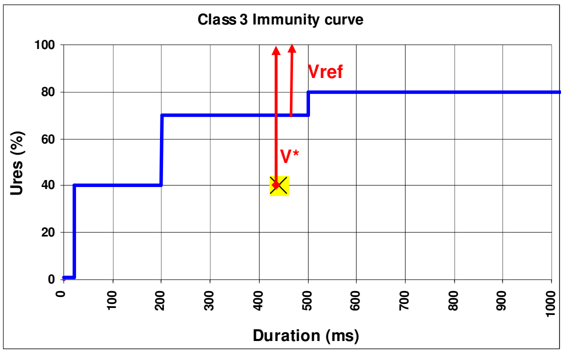

Figure 1: Discrete Severity Index referred to class 3 immunity curve (DSI_3b)

As can be observed:

- a value of **DSI < 1** is associated to an "ACCEPTABLE" disturb (it falls in the immunity area);
- a value of **DSI > 1** implies an event "POTENTIALLY DANGEROUS" (it takes place outside the immunity area);
- these indices take into account the events severity by estimating their distance from the reference immunity curve;
- they are not directly comprehensible.

Another index which takes into account both the event features (duration and residual voltage) is the **Missing Voltage Time (MVT)** or voltage lack during the event duration, proposed in [7], which is evaluated by the product between the voltage dip duration and the difference of its residual voltage from the nominal voltage (1 p.u.):

$$MVT = (1 - \dot{V}) * \Delta t$$

and is therefore expressed in pu*sec. It can be observed that MVT:

- is referred to the events duration and depth features even if it does not relate them to an immunity curve;
- it is not easily comprehensible.

The index MVT can be as well calculated referring only to the events falling under a given immunity curve. In this way the evaluation of the **system index** associated to such events is assured (MVT2 or MVT3 depending on the immunity curve we are referring to) and these indices will be considered "clean from" the contribution of those events which fall in the immunity area of the equipment.
Another index which has been proposed in the literature, and similar to the previous one, is the **Missing Voltage Time Area** or **MVTA**, that, given an event "i", is evaluated in analogy with the index MVT but referring to the 0.9 threshold (that is to the threshold for the definition of the voltage dip start):

$$\boldsymbol{MVTAi} = (0.9 - \dot{V}) * \Delta t$$

Looking at Figure 2, the index $MVTA_i$ corresponds to the dashed pink area. Such value is compared with the analogous one of "tolerable missing area" for the equipment $MVTA_{ref}$ (sky-blue area), defined on the base of a given immunity curve, referring to the immunity levels associated to the duration of the event (the 1st step of class 3 curve in the example).

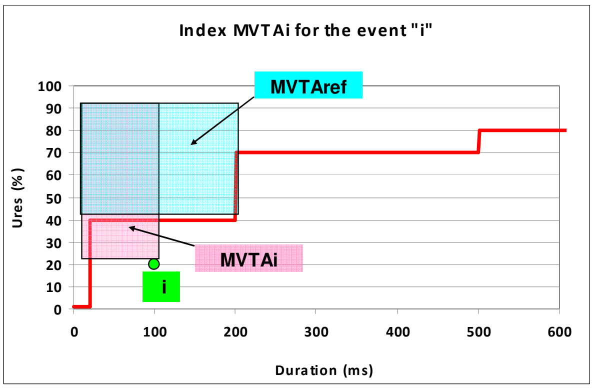

Figure 2: Definition of the index MVTA_3

The resulting index, MVTA_3 is calculated by the counting of all the events "i" for which it stands $MVTA_i > MVTA_{ref}$. Such index therefore performs a "weighted" count on an immunity curve on the base of "energy considerations", as explained in [8].

INDICES TRENDS AT NATIONAL LEVEL

The historical trends analysis of the Italian MV voltage dip performance have been carried out in a synthetic and effective way by the evaluation at national level of the indices previously defined, as illustrated in Figure 3.

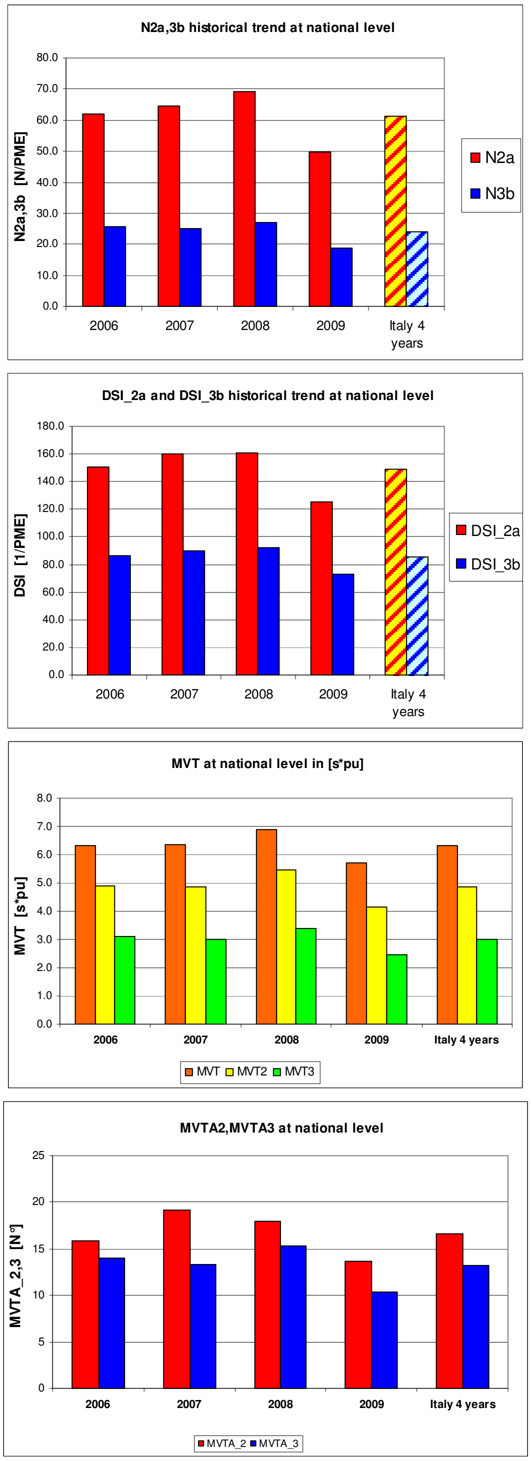

Figure 3: Historical trends of the indices: N2a, N3b - DSI_2a, DSI_3b - MVT, MVT2, MVT3 - MVT_A2, MVT_A3.

All the indices have been evaluated referring to both class 2 and class 3 immunity curves; the national mean value over the 4 years period 2006 ÷ 2009 is also provided as a reference for being then used for normalization purposes in Figure 4[1].

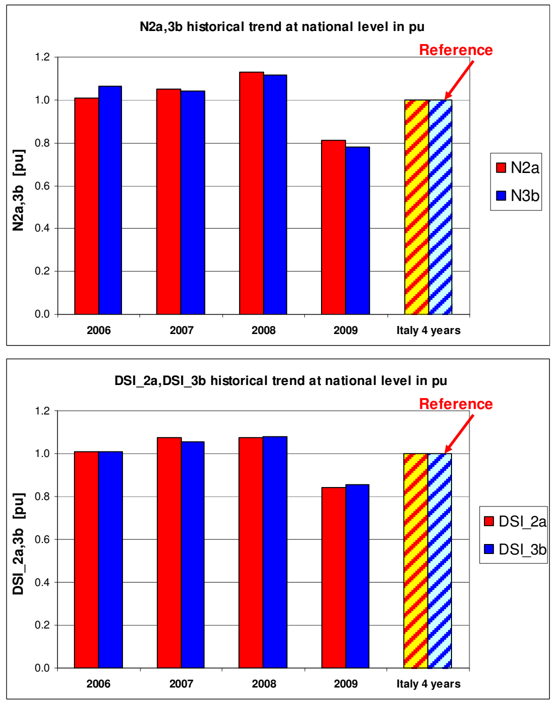

Figure 4: Historical trends for the "counting indices" normalized to the national mean value over 4 years

At national level it can be observed a slight rising trend for the first 3 years followed by a decrease in 2009 for almost every system index, showing a very similar behaviour. The annual variations of the indices here shown can be considered however rather contained if compared with the remarkable annual variability of site indices investigated in a previous paper [4]. Looking at the trends in Figure 3 it can be noticed a remarkable difference in the values assumed by an index, in the course of the same year. depending on whether the calculation is referred to class 2 or class 3 curves.

Under the assumption made in Figure 4, of evaluating the indices on the base of a common national reference, it has been possible to get a characterization of the network performance in a more independent way from the immunity curve chosen for the index evaluation. So, in case of adopting an index referred to an immunity curve, the application of a normalization procedure could help with getting its independence from such curve.

1 The reference value has been chosen in such a way as to have a value derived from a long term statistic concerning the real situation under examination.

INDICES TREND AT MACRO AREA LEVEL

The historical trends of the indices have been analyzed also at macro area level. The Italian territory has been subdivided into four macro areas (A1=North West, A2=North East, A3=Central Italy and Sardinia, A4=South) in order to have almost the same number of measurement sites in each of them and to be able in this way to compare the network performances in the different macro areas [2]. Macro area indices have been evaluated by summing up site indices and extending such sum to the sites belonging to the same macro area. The macro area trends, reported in Figure 5 for the indices N3b, DSI_3b and MVT, prove the existence of remarkable territorial differences in the network performance when voltage dips are concerned in particular for the macro area A4, during the whole course of the four year period. The other macro areas show some performance variability, from year to year, but their behavior is in line with the national reference chosen.

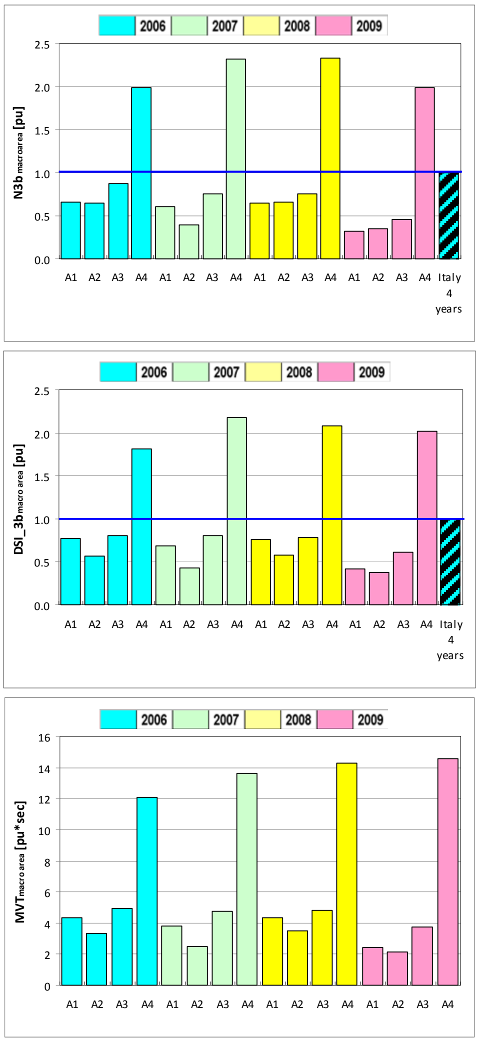

Figure 5: Historical trend of macro area indices N3b, DSI_3b and MVT (only the last one is not normalized)

INDICES TREND AT REGIONAL LEVEL

The same kind of indices evaluation can be extended also to the Italian regions. In Figure 6 the analysis performed on 2009 data for the indices N2a and N3b are reported.
The regional indices have been calculated referred to the national reference adopted previously.
Even taking into account the problems of the regions statistical representativeness (not every region has got the same number of measurements sites) it can be observed that, for instance, the performances associated to macro area A4 in 2009, pointed out in the previous figures, do not concern all the regions of that macro area.
In fact, looking at the performances of the regions assigned to macro area A4 as compared to the national value (1 pu), it can be emphasize that Molise and Puglia do not overcome the reference national average value.

CONCLUSIONS

The voltage dip performance of the Italian MV distribution network has evaluated on the base of the QuEEN data, referring to the monitoring period 2006 ÷ 2009, by a set of synthetic system indices most of them referred to well known immunity curves**.** This reporting method appears particularly promising when trend analysis or comparisons among different aggregation of sites are concerned.
As to the results of the statistical analysis performed by these indices it can be said that:

- the historical trend of the indices shows similar behaviour;
- the adoption of a normalization procedure for the evaluation of the indices in pu can make their behaviour independent from any immunity curves on which they are based;
- historical trends analysis of the indices at macro area level point out the existence of remarkable territorial differences in the network performance;
- analogous analysis performed at regional level on 2009 data show that, once assessed the poor performance of a macro area on the base of historical data, not all the regions belonging to that area are responsible for this result.

In view of a future possible extension of the MV monitoring system [7], which would solve the problems of statistical representativeness when regional analysis are implied, and thank to the use of these indices, it will be possible to carry out a more in-depth analysis of the regional performance.

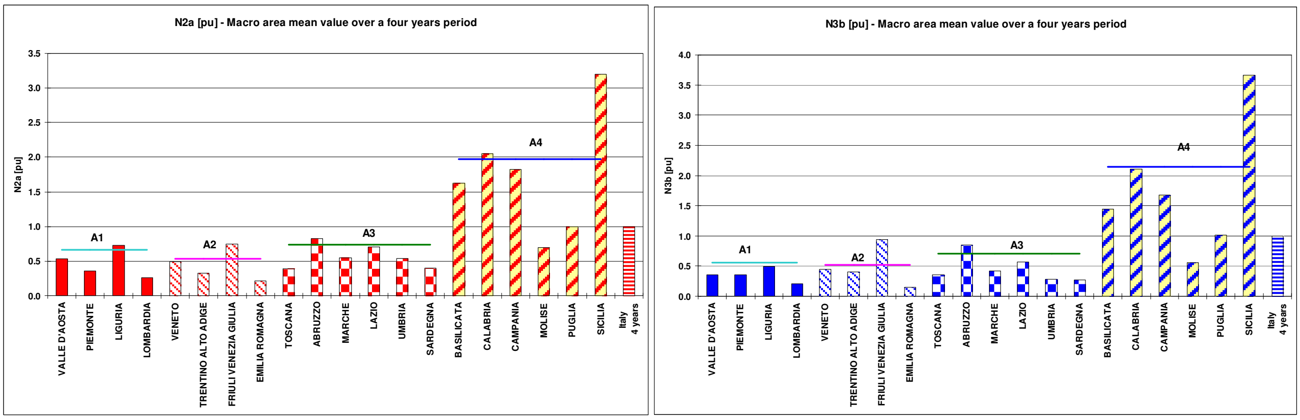

Figure 6: Evaluation of the indices N2a and N3b at regional level for the year 2009 and macro area mean values over a four years period (values are referred to the national mean value over the four years)

Acknowledgments

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