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Feasible methods to evaluate voltage dips origin

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Abstract. The aim of the work is to compare the advantages and disadvantages of two feasible methods of evaluation of voltage dips "origin" intended as the network where the "fault" has probably occurred. The first method, mainly based on the simultaneous monitoring of an event by nearby primary substations connected to a common high voltage network, has been extensively applied since 2009 to the QuEEN (Quality of the Electric Energy) monitoring system data, by RSE within its research activity. The second one requests the monitoring of both primary substation medium voltage bus-bars and has been proposed as a possible method for the new on-going Italian national monitoring system, developed by the Italian DSOs, by a technical committee on National Monitoring. This method, which has been shared as a possible and feasible method by all the participants to the committee (DSOs, TSO, researchers and the Italian regulator), can be applied at a few QuEEN substations compliant with its requirements. The first method requires the knowledge of the high voltage network topology and, when applied at research level, requires time-expending visual analysis of voltage dips waveforms to compensate the lack of "confidential" information. The second method has lower effectiveness but, being a local method, can be applied also to networks including only one substation.

Key words

Voltage dip, voltage dip origin, MV distribution network, monitoring system, event propagation.

1. Introduction

Voltage dips monitored on the Medium Voltage (MV) distribution network can have origin from events occurring in the:

1) *medium voltage network itself;*
2) *high voltage network;*
3) *customers' plants connected to the MV network.*

A method that has been usually adopted by RSE since 2009 for research purposes to estimate, in percentage term, the annual amount of voltage dips of HV origin, is a "not local" or "global" method based on both:

- the "detailed analysis" of those MV monitored events characterized by correlated occurrence time and relevant to measuring units (MU) belonging to primary substations (PS) underlying a common High Voltage (HV) grid ("coincident" instants of voltage dips in the MV network are a proof of the HV origin of the event);
- the detection of events correlated to a signal coming from HV line distance protections, which is provided by the QuEEN monitoring system.

The Italian regulator (Autorità per l'energia elettrica il gas e il sistema idrico - AEEGSI), has recently promoted the monitoring of all the Italian primary substations at MV level [1]. In this context in 2012 AEEGSI has called a technical committee on the subject, composed of the Italian DSOs, TSO, RSE and the regulator itself, to assess the functional requirements of the measuring units for this system. In this context a feasible method to evaluate the origin of voltage dip has been shared within the participant to the committee as a possible simple way to get this information [2].

The method relies on the comparison of three characteristics (instance of occurrence, residual voltage and duration) of the events monitored by two or more bus-bars in a PS (local method). As a few QuEEN monitored primary substations[1] satisfy the conditions for applying this method, a comparison has been made between the two procedures in order to point out their advantages and disadvantages.

The final aim is to provide guidelines for PQ monitoring system managers who could be interested in applying these feasible methodologies for survey purposes. Referring to the possible origin of events monitored at MV level previously mentioned, these methods could be applied to identify events corresponding to cases 1) and 2) while case 3) is not covered.

[1] A few of the 400 QuEEN system primary substations have both the MV bus-bars monitored.

2. The methods

A. The global method

The evaluation of the percentage of voltage dips of probable HV origin takes into account the following contributions:

1) N° of events monitored at the same time at nearby PSs connected to a common HV grid[2] (Fig. 1);
2) N° of events correlated to signals coming from HV line distance protections.

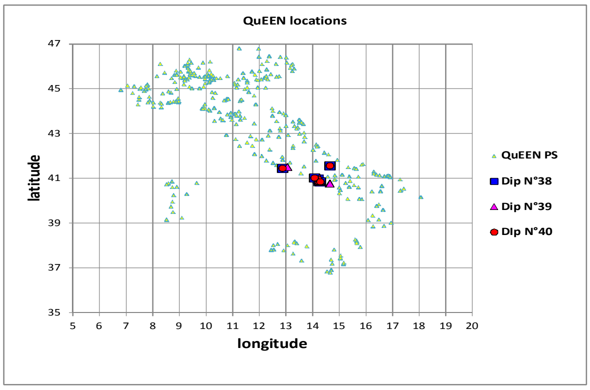
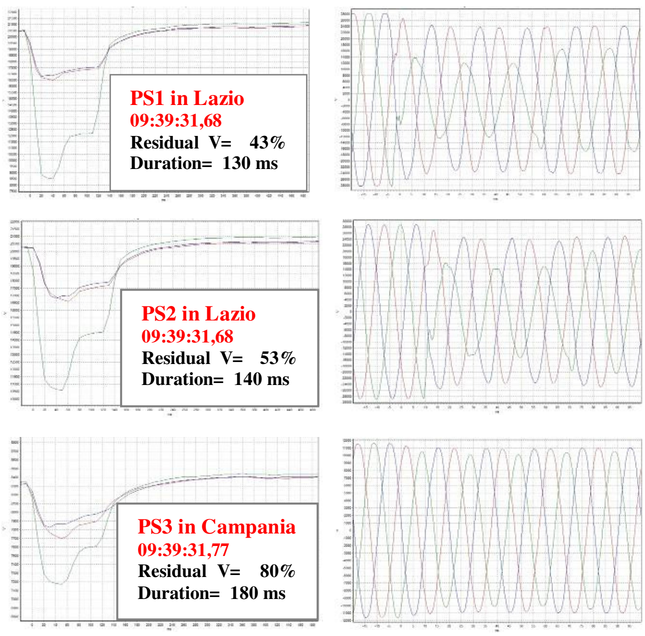


Fig. 1 Voltage dips of probable HV origin in accordance with the global method ("coincident" instants of voltage dips in the MV network are a proof of their origin in the HV network)

In case of significant difference in the main characteristics of the events monitored at nearby PSs, (time of occurrence, duration and residual voltage) the visual analysis of the waveform allow to assess their common HV origin. Fig. 2 shows an example of event (as its associated sequence of RMS value and voltage waveform) monitored contemporaneously (within 90 ms) at four different PSs in three Italian regions.



[2] The consultation of the Italian 380-220-150-132kV networks Atlas book is essential in these cases to identify the "common" HV networks.

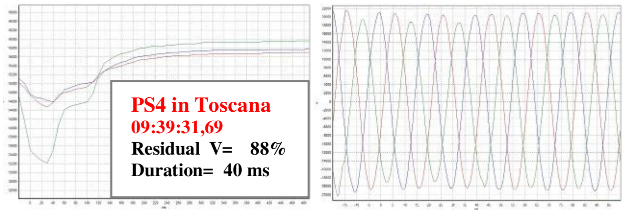


Fig. 2 HV origin event monitored at four different primary substations

The following remarks can be made:

- only the MU in PS1 (Primary substation 1) has received a signal from a HV line distance protection[3]. As the voltage dip monitored here is characterized by the lowest residual voltage (43%), this PS is probably the nearest to the fault;
- the characteristics of the event monitored in the nearby station PS2 (Primary Substation 2) are very similar to those measured in PS1;
- the event monitored at the farthest substation PS3 (Primary Substation 3) shows a significant difference in residual voltage, due to the different distance of the measurement location from the fault;
- the event monitored at PS4 (Primary Substation 4) show a significant difference both in residual voltage and duration. This can be explained with the reduced depth of this "multi stage" event whose "second stage" does not overcome the voltage dip threshold.

Sometimes difference of more than 1s in the occurrence time are measured due to GPS synchronization failures. The time info, in this case, are provided only once a day by the monitoring system. Visual analysis can help also in these cases.

B. The local method

The method applies to primary substations with two or more MV bus-bars monitored derived from a common HV grid (Fig. 3) and relies on the comparison of the recordings of the MUs installed at the bus-bars[4].

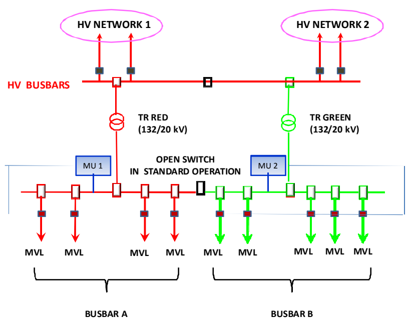


Fig. 3 Monitoring configuration for the local method

Two events are of probable common HV origin when all the following conditions are satisfied:

[3] In fact the event has been monitored at the same time by 19 PSs in the three regions but the signal from distance protection was received only at PS1.
[4] The method cannot be applied in case of closings of the PS's MV bus-bars switch.

the difference in their

- occurrence time ΔI_{stocc} is no more than 60 ms;
- duration ΔD is no more than 20 ms;
- residual voltage ΔV_{res} is no more than 3%.

The limits abovementioned are consistent respectively with the Real Time Clock uncertainty, the proper measurement uncertainty in the voltage dip beginning and end evaluation and the measurement chain uncertainty. The method can be applied to a small number of PS monitored by the QuEEN system which have both the MV bus-bars monitored.

3. Results of application

A. The global method

Some results of its application at national level are summarized in Table I and Fig. 4÷Fig. 6[5] [3]÷[7].

Table I

% events of probable origin in the HV network*	2009	2010	2011	2012	2013	average
	28	38	36	43	43	38

(*) over the total N° monitored at nazional level

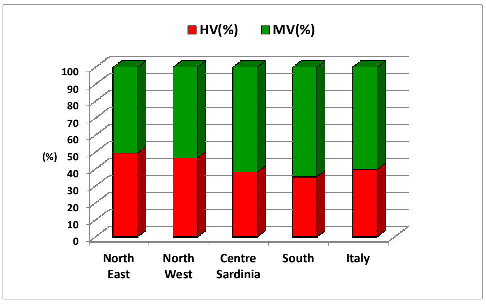


Fig. 4 Voltage dips of origin in the HV and MV networks in four Italian macro area (average on 2010÷2013 data)

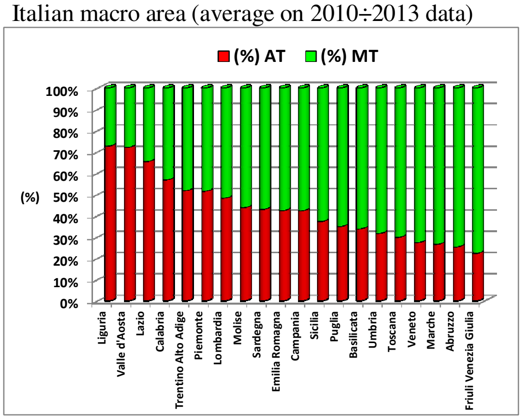


Fig. 5 HV and MV voltage dips presence in Italian regions in 2013

[5] The results for 2009 are in accordance with the estimation obtained in 2008 ÷ 2009 by applying another method at a small number of monitoring sites. This consists in a "point by point" comparison between the recordings made at the MV and HV bus bars of some PSs (the last ones supplied by the MONIQUE system of TERNA, the Italian TSO), and in the national transmission network.

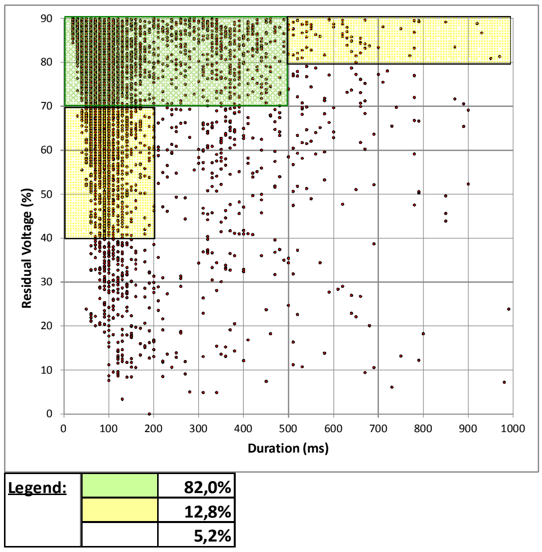


Fig. 6 Scatter plot of HV events monitored in the MV network in 2013

After some years of monitoring and global method application some conclusions can be drawn:

- about 38% of voltage dips monitored in the MV network have origin in the HV network at national level (see Table I). This percentage include only 7% of events associated to signals coming from distance protection.
- the higher percentage of HV events are monitored in the north of Italy (49% in North East, 46% North West) as shown in Fig. 4;
- referring to a single macro area, for instance North East in 2013, there is a significant variability among its regions behaviour (see Trentino Alto Adige vs Friuli Venezia Giulia in Fig. 5);
- about the 82% of HV events however occur in an immunity zone for equipment connected to the distribution network (green zone = Class 2 immunity zone) against the 5,2% of events which could be potentially dangerous also for equipment designed for operating in industrial environments (white zone = Class 3 non-immunity zone) as shown in Fig. 6 ([8]÷[9]).

B. The local method

The method has been applied at the data monitored in the period 2009÷2014 at three PSs (6 MV monitored bus-bars), located respectively in the North West, in the Centre and in the South of Italy. Even if on the base of a small set of QuEEN points of measurements, suited for the application, a first evaluation of the method effectiveness has been provided.
The percentage of voltage dips of the data set estimated of HV origin by the two methods, applied to the three PSs, are reported in Table II.

Table II

Global method		Local method	
HV (%)	MV (%)	HV (%)	MV (%)
27.4	72.6	14.4	85.6

Local method seems to be less effective in the estimation of HV events.

As the method is based on three conditions, applied in AND logic, further investigations have been carried out to focus on the origin of this weakness. The results of this analysis are illustrated in Table III. Taking into account the HV origin of the events assessed by the global method as a reference, it was possible to estimate the total number of failures of the local method in recognizing HV events and the percentage of these failures due the violations of each condition[6], that is the percentage of overcomes of each threshold.

Table III

Threshold overcomes (%)		
ΔI_{stocc}	ΔDuration	ΔV_{res}
69.8	11.5	18.7

The first condition is the most critical (~70% of threshold overcomes). This is probably due to the fact that QuEEN measurement units have been working 24h a day since 2006 and so it is possible to notice errors in GPS synchronization associated to data monitored in the last years. For instance, Fig. 7 shows the same event monitored in 2011 at the two MV bus-bars of a PS. The local method fails in evaluating its origin in the HV network, proved by both the waveforms similarity and the global method, because of the high difference (670 ms) in occurrence time measured, even if the other conditions are easily satisfied.

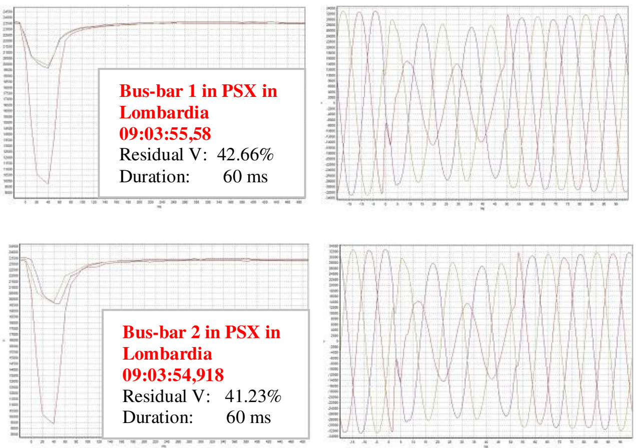


Fig. 7 RMS values sequences and waveforms associated to a HV event monitored at the two MV bus-bars of the same PS with a difference in occurrence time of 670 ms ($\Delta D_{uration}$ =0 and ΔV_{res}=1.43%).

In case of GPS (Global Positioning System) synchronization errors, the monitoring system provides time-info once a day to the MU but when using different GPS for the two MUs it could remain a little difference in local time between the two units. The problem scales down for MUs just subjected to maintenance, that is to a simple GPS reset. The use of a single GPS for the two MUs should solve the problem.

[6] $-60ms \le \Delta I_{stocc} \le +60ms$;
$-20ms \le \Delta D_{uration} \le +20ms$;
$-3\% \le \Delta V_{res} \le +3\%$;

As to the violations of the condition on ΔDuration, which is the less frequent (11.5%), it is mostly associated to the failures of the others conditions.

The method failures due to $\mathbf{\Delta V_{res}}$ threshold overcomes are estimated about 18.7%. Further analysis have been carried out in order to understand how to reduce the number of this kind of violations. In our opinion this achievement could be the shortest way to improve the local method performance and make it more comparable to the global one. In fact if we take into account the following facts:

- ΔDuration threshold overcomes are usually linked to other parameters violations;
- the global method takes into account only the control parameter $\mathbf{\Delta I_{stocc}}$;
- $\mathbf{\Delta I_{stocc}}$ threshold overcomes could be reduced with maintenance practices and with the use of a single GPS for each PS;

the possibility to improve the method effectiveness relies mostly on the third condition. In this context we have estimated the probability of occurrence of a couple of events monitored at the two bus-bars in different $\mathbf{\Delta V_{res}}$ classes. The results of the analysis are shown in Table IV.

Table IV

Threshold extension						
±2%	±3%	±3,5%	±4,5%	±5,5%	±6,0%	±6,5%
81.4	92.9	95.7	96.6	97.7	97.7	97.7

A shift of the V_{res} threshold to 5,5% should assure that the 97,7% of couple of events analysed could be correctly recognize as of HV origin as far as the V_{res} control parameter is regarded.

4. Advantages and disadvantages

Advantages and disadvantages of the two procedures are summarized in Table V and discussed in the following.

Table V

Method	Advantages	Disadvantages
Global	good effectiveness	time consuming
	overall view of event propagation along the network	need of topological info from TSO for full automatic implementation
	difference in characteristics can be explained easily	make use also of signals from HV lines distance protections
Local	applicability at single PS level in automatic way	limited effectiveness
	no need of any signal from HV lines distance protections	redundancy in number of MU required
	no need of exchange of info with the TSO	the same GPS for both the bus-bars is needed

A. *The global method*

The method has a good effectiveness and allow to get an overall view of the event propagation along the network. Exceptions (significant difference in time occurrence) can be resolved by the detailed visual analyses or comparisons of the waveforms.

The principal disadvantage of the method is that its application, at present, is time consuming and requires both topological information on the transmission network and the cabling from the HV lines distance protections. Nevertheless in literature many authors[7] have already proposed different techniques to automatically analyse the event waveforms (Wavelet analyses, RMS sequence analyses, Kalman filter etc.) which could be a solution to the problem (in this contest some work is on-going in RSE on the application of some of these technique to QuEEN data). The method is particularly suited for survey monitoring campaign carried out in extended networks and that can be interested in checking the events propagation.

B. *The local method*

The main advantages consist in being applicable, in automatic way, also at a single primary substation and in not requiring any cabling from the HV lines distance protections or topological information. These characteristics make the method ideal for small extension networks.

Limited effectiveness in local method is principally due to:

- the possible operation of the two MV bus-bars at a slightly different voltage (due to tap-changer settings) causing the difference in control parameters (ΔV_{res}, ΔDuration) to overcome their thresholds;

- the use of two distinct GPS does not allow to delete possible synchronization failure errors.

4.Conclusion

Both the methods can be easily applied for survey purposes. The first method is particularly suited for survey monitoring campaign carried out in nationwide extended networks as it can provides useful information on events propagation. Local method is ideal for small extended networks monitoring, as it requires the monitoring of all MV bus-bars in the network. Possible improvements for the two methodology should regard respectively the automation of the global method and the customized refinement of the thresholds on the base of the standard operation mode of the network.

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