FEATURE ANALYSIS FOR VOLTAGE DISTURBANCES RESULTING FROM EXTERNAL CAUSES

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ABSTRACT

This paper presents the analysis of features for characterizing external causes of voltage disturbances captured in Spanish distribution circuits. The paper focuses on faults caused by animal/tree contacts, cable failure and broken insulator events. The extracted patterns from the Spanish power quality dataset have been compared with patterns previously extracted by the authors with an American dataset. The results show common patterns between voltage events in the american and Spainish dataset.

INTRODUCTION

In this work we focus on characterization of voltage disturbances generated by faults caused by agents external to the power system (animal/tree contacts, cable failures and broken insulator events). Such a type of events is difficult to characterize because the physical phenomena involved in their origin depends on multiple, variable and usually unknown parameters. Therefore, the challenges of developing tools to assist the diagnosis of disturbances reside on: one hand to characterize the events by a set of significant features and, on the other hand, to use automatic classification strategies to associate the registers with possible causes.

In this work we have focused on the characterization problem with the aim of extracting useful patterns to distinguish among animal contact, tree contact, underground cable failures or broken insulators. A reduced number of features have been used to describe events based on the previous experience described in [1]-[4]. A dataset collected by a Spanish utility has been used to extract classification patterns. The obtained patterns are the compared with patterns previously obtained by the authors in the aforementioned works with datasets collected in North America.

DATA DESCRIPTION

The voltage/current waveforms correspond to voltage sags produced by known causes (well documented) collected in the secondary side of HV/MV distribution transformers installed in 25 kV substations at northeastern Spain. The waveforms contain 128 samples per cycle and 50 cycles at fundamental frequency 50 Hz.

From the provided data we could distinguish the following subsets according to the documented causes: 6 (5,1%) events resulting from animal contact, 25 (21,4%) from tree contact, 46 (39,3%) from underground cable failure and 40 (34,2%) from broken insulator. In summary, 117 external-caused faults have been analyzed in this work. All of them were captured downstream from the monitoring device in 19 different distribution circuits.

FEATURE DESCRIPTION AND ANALYSIS

The features analyzed and are briefly described in this section. They were introduced in the aforementioned previous papers [1]-[4]. Since seasonal and daily condition have influence (direct or indirectly) on the apparition of voltage disturbances, authors have decided to separately analyze the set of features based on timestamp from those features directly computed using the three-phase voltage and current waveforms (waveform-based features).

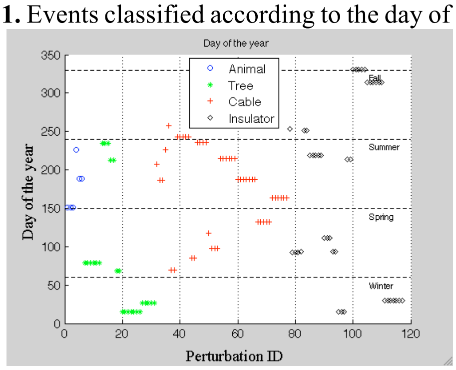
Features based on timestamp

'Day of the year' and 'Hour of the day' when the events occurred are analyzed in this section.

Day of the year

Figure 1 is depicting the day of the year when each analyzed event occurs. It feature indicates that most cable failures take place during spring and summer. It makes sense because underground cables are usually experiencing floods during spring as well as in summer due to some electric storms, which sometimes water achieves penetrating cable insulator and finally causing a voltage disturbance.

Figure 1. Events classified according to the day of the year

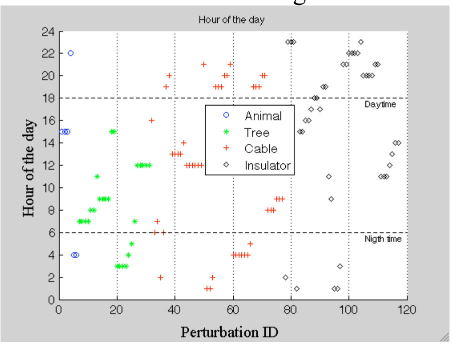


On the other hand, broken insulator events are spread out throughout the year, they do not apparently depend on the date. Likewise, tree-caused events mainly occur during winter and spring when the wind is usually strong and the trees have more foliage, respectively.

According to Figure 1, animal contact events occur only during summer, but it is not reliable due to the few number of animal-caused events.

Time of the day
Analyzing the time of the day (hour), one can see that most tree-caused event take place during daytime (6:00 to 18:00) while the rest of events are spread out on time (Figure 2).

Figure 2. Events classified according to the time of the year

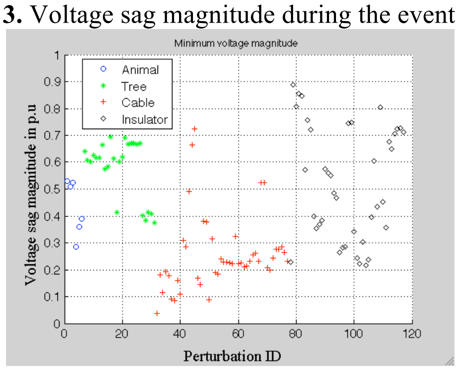


Features based on waveform

Waveform-based features are directly extracted from the three-phase voltage and current instantaneous values.

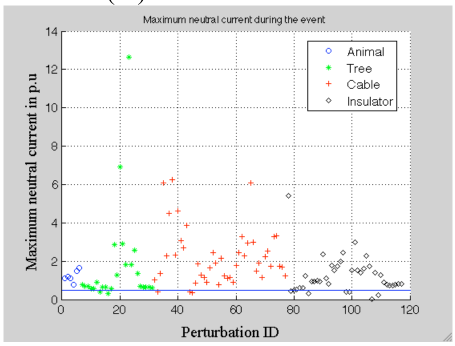
Voltage sag magnitude (*Vsag*)
This feature was analyzed in order to assess the severity of the voltage sag magnitude caused by the four different external causes. *Vsag* was computed as the minimum RMS voltage throughout the disturbance. The RMS sequence voltage was extracted using FFT with a 128-length sliding window. From Figure 3 can be elucidated that cable failures are the most severe faults since they have the lowest *Vsag* values. The rest of causes take medium *Vsag* values around to 30% and 70% of the prefault voltage value.

Figure 3. Voltage sag magnitude during the event (*Vsag*).



Maximum neutral current (*In*)
It corresponds to the maximum RMS neutral current during the quasi-steady state of the disturbance in per unity. The starting and ending transition instants were estimated applying a segmentation algorithm based on tensor analysis proposed by the authors [6]. It is expected that single-phase faults present *In* values much higher than during pre-fault. Animal/tree contact, cable-failure and broken-insulator are usually leaded by single-phase faults (Figure 4). The horizontal line in Figure 4 indicates 50% of the prefault phase current.

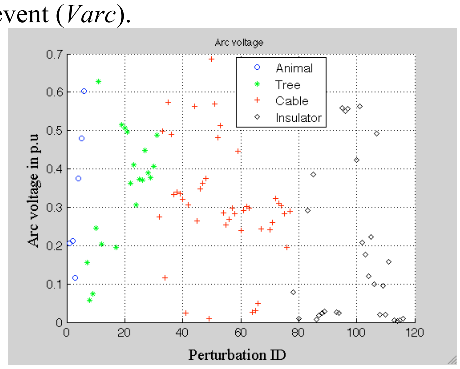
Figure 4. Maximum neutral current during quasi-steady state of the event (*In*).



Some events take *In* values lower than the threshold fixed for the prefault phase current what can be associated to not grounded faults. For instance, the event number 108 corresponds to a double phase fault in an overhead line provoked by an insulator breakdown.

Arc voltage (*Varc*)
This feature is conceived from the hypothesis that some faults experiment a self-sustained discharge (electric arc) at the fault point associated with their occurrence, it is expected e.g. in animal and tree branch contacts with overhead lines. The algorithm proposed in in [5][4] (applicable only for single phase faults) has been used to compute this feature (*Varc*).
From Figure 5, we can observe, that most part of cable failure events take arc voltage magnitudes around to 20% to 40% of the prefault voltage, while tree contact events take values around 30% to 50%. The few number of animal contact events avoids giving a reliable opinion about the *Varc* magnitude for this event external cause. Likewise, broken-insulator events are spread out on *Varc* magnitude, which means that self-sustained discharge can or cannot exist during an insulator breakdown. Thus, it is possible to conclude that tree contact events generally have higher arc voltage magnitude than cable-failures and broken-insulator disturbances.

Figure 5. Maximum arc voltage during quasi-steady state of the event (*Varc*).



Fault impedance magnitude (*Zfault*)
This feature was included in the analysis in order to find patterns between the fault resistance/reactance magnitude with the nature of each external cause. *Zfault* is computed as follow:

$$Zfault = Ztotal - Zpfl \quad (1)$$

Where,

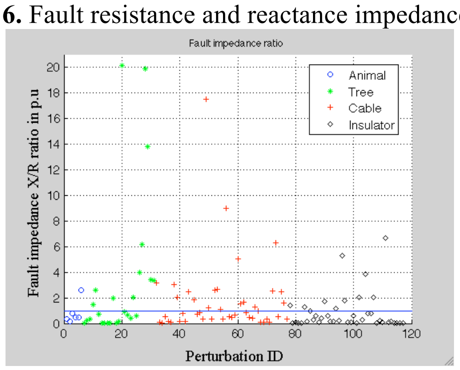
Zfault, Fault impedance (*Rfault+jXfault*).

Ztotal, Impedance containing the line impedance and fault impedance (*Ztotal=Zline+Zfault*).

Zpfl, Impedance to the pinpoint fault location (*Rpfl+jXpfl*).

Ztotal has been computed using the faulted phase voltage and the neutral current phasors. It quotient contains information about the line impedance to the pinpoint fault location and the fault impedance since neutral current flows through of them. *Zpfl* has been computed using arc voltage algorithm [5][4], which also allows computing the existing impedance between the monitoring point and the fault point associated with disturbance source, so *Zpfl* does not contain information about *Zfault*. Hence, carrying out the difference between *Ztotal* and *Zpfl*, fault resistance (*Rfault*) and reactance (*Xfault*) impedance can be obtained.
Figure 6 is depicting the *Xfault*/*Rfault* ratio for each event. The horizontal line is located in 1 p.u. From it one can notice that tree-contact and cable-failure events present some fault impedances predominantly resistive (X/R<1) and some ones predominantly reactive (X/R>1). Conversely, the most part of animal-contact and broken-insulator events have fault impedances preponderantly resistive. It make sense because during an insulator event the conductor get in contact with another phase conductor, or with the crosshead, or directly with ground, thus the fault impedance will be more resistive, while tree-contact and cable-failure events the fault impedance can take reactive values due to the inductive and capacitive components of branch trees and the dielectric covering the underground cables.

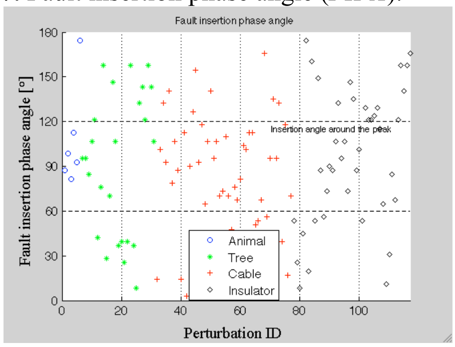
Figure 6. Fault resistance and reactance impedance ratio.



On the other hand, analyzing the fault impedance magnitude can be noticed that *Zfault* take manly low values for the four external causes analyzed in this paper.

Fault insertion phase angle (*FIPA*)
This feature has been proposed based on the hypothesis that faults caused by animals, trees and cables are inserted around the peak of the voltage wave, when the voltage gradient is maximum.

Figure 7. Fault insertion phase angle (*FIPA*).

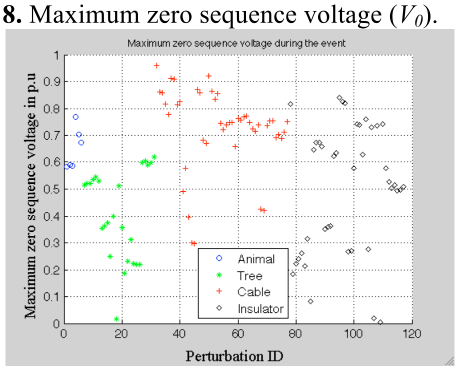


FIPA has been computed by analyzing deviation of waveforms with respect to the expected shape obtained from the fundamental prefault voltage waveform. The fundamental voltage amplitude (V_1) and the phase angle ($\varnothing_1$) are computed using FFT in a one-period-length sliding window during prefault. This serves as reference for the fault event and is used to compute its deviation, sample by sample. Sudden large deviation is associated with the fault insertion instant. So, the fault insertion phase angle is estimated at this time instant. The fault insertion phase angle in degrees (0-180) is plotted in Figure 7.
Most of the events associated with animal contacts and cable faults present a fault insertion phase angle around the positive/negative peak of the voltage waveform, that is, around 60 and 120 degrees (Figure 7).

Maximum zero sequence voltage (V_0)
It is perceived as an indicator of the degree of unbalance. That is, highly unbalanced events will present high zero-sequence voltage values. V_0 is computed during the fault event from the three-phase voltage waveform using (2).

$$V_0 = \max\left\{ RMS\left[\frac{v_a(t)+v_b(t)+v_c(t)}{3}\right]\right\}_{sag} \quad (2)$$

Figure 8. Maximum zero sequence voltage (V_0).



According to the results depicted in Figure 8, underground cable failures and tree contact events present high and low zero sequence voltages, respectively. Hence, cable failures are the most unbalance voltage events in comparison with the rest of causes.

DISCUSSION

The results obtained with voltage events captured in the Catalonia (northeastern part of Spain) 25kV distribution circuits with those captured in USA 12.47kV circuits are compared In Table 1. The USA data were collected in Northeastern part of United State at overhead and underground cable distribution networks. The waveforms contain 128 samples per cycle, 10 cycles at fundamental frequency 50Hz. It is important to emphasize that regions are inside of the same geographical zone, that is, between Tropic of Cancer and Equator, therefore both share a similar climate throughout the year and comparisons based on weather conditions can be carried out. Spanish and USA data were captured during 2004-2007 and 2002-2006 respectively.
Each column in Table 1 represents a feature, while each column an external cause. Some common patterns have been founded in both power quality datasets. They are listed as follows:

- Underground cable failures occur during spring and summer, the reasons have been given in previous section.
- Animal contact events take place during daytime and the electric discharge occurs around the positive/negative peak of the voltage waveform. Cable fault are also inserted around wave peak.
- Tree contact events have low frequency oscillations around the fault insertion instant as well as low zero sequence voltage values, while cable fault have the highest ones. Hence, cable faults are the most unbalanced voltage events.
- Animal contact and cable events have the highest neutral current values. It makes sense because animals usually get in contact with one phase conductor and the grounded-crosshead, whereas cable faults start in one phase and the disruption evolve to another ones.
- Cables faults are the most severe voltage disturbances since these take the lowest voltage magnitude.

Table 1. Comparison between voltage disturbances captured in distribution circuits from USA and Spain region.

	Date		*Time*		*Varc*		*FIPA*		*HFO_1*		*Zfault*		*V_0*		*In*		*Vsag*	
Cause	U	S	U	S	U	S	U	S	U	S	U	S	U	S	U	S	U	S
Animal	Sp,Sm	Sm	Day	Day	↑	--	90º	90º	↓	↓		r	↓	↔	↑	↑	↑	↔
Lightning	Sm	×	--	×	↓	×	--	×	↑	×		×	↓	×	--	×	↑	×
Tree	Fall	W,Sp	Night	Day	--	↑	--	--	↓	↓		r, x, r+jx	↓	↓	--	↑	↑	↑
Cable	Sp,Sm	Sp,Sm	Day	--	↓	↔	90º	90º	×	↑	?	r, x, r+jx	↑	↑	↑	↑	↓	↓
Insulator	×	--	×	--	×	--	×	--	×	↑	×	r	×	--	×	↑	×	--

Note: U: USA region, S: Spain region, Sm: Summer, Sp: Spring, W: Winter, ↑↔↓: high, medium and low value, ×: Cause not available in the specific region, --: Not a representative behavior.

CONCLUSIONS

In this work several features based on time and another ones directly computed from the three-phase voltage and current waveforms have been analyzed. The behavior of each feature in each external cause has been identified. The values taken for each feature have been compared with voltage disturbances captured in Spanish and USA power distribution circuits. The common patterns between both have been listed and discussed.

Acknowledgments

This work is funded in part by the Ministry of Education and Science (Spanish acronym MEC) under the project DPI2006-09370, FPI (BES-2007-14942) grant. Authors express their acknowledgement to ENDESA DISTRIBUCIÓN for providing voltage events collected in its distribution networks.

REFERENCES

[1] V. Barrera, S. Kulkarni, S. Santoso, J. Meléndez, 2010, “Feature Analysis and Classification Methodology for Overhead Distribution Fault Events”, IEEE PES.

[2] V. Barrera, J. Meléndez, S. Kulkarni, S. Santoso, “Feature Analysis and Automatic Classification of Short-Circuit Faults Resulting from External Causes”, 2010, *European Transactions on Electrical Power* (Submitted) Manuscript ID: ETEP-10-0432.

[3] V. Barrera, S. Kulkarni, S. Santoso, J. Meléndez, 2010, “SVM-Based Classification Methodology for Overhead Distribution Fault Events”, ICHQP.

[4] Kulkarni, D. Lee, A. Allen, S. Santoso, T. A. Short, 2010, “Waveform Characterization of Animal Contact, Tree Contact, and Lightning Induced Faults”, IEEE PES.

[5] Djuric, M; Radojevic Z; Terzija, V., 1999, “Time Domain Solution of Fault Estimation And Arcing Faults Detection on Overhead Lines”, *IEEE TPD*, vol. 14, 60-66.

[6] J. Jagua, V. Barrera, G. Carrillo, J. Melendez, 2010, “Waveform Segmentation Based On Tensor Analysis”, IEEE ANDESCON.