A Survey on Voltage Sag Events in Power Systems

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Abstract— **This paper aims to survey the techniques and methods described in literature to analyse and characterise voltage sags and the corresponding objectives of these works. The study has been performed from a data mining point of view.**

Index Terms— **Fault location, voltage sag (dip), pattern classification, Power quality monitoring.**

I. Introduction

Interest in analyzing, characterizing and classifying voltage sags has arisen due to their impact on the quality of supplied power [1][2][3].

Greater observability and controllability of any asset installed in the power system is expected (Intelligent Power Grid) [4]. Due to this, it is expected that a new market based on the exploitation of information technologies on the power grid [5] will develop.

Due to the increase of power quality monitors and consequently a great volume of data [6][1], the new goal of monitoring systems is to automatically transform this huge number of data into useful information. In this sense, a large number of papers report the use of techniques related to the monitoring of sags. In this work, these techniques have been surveyed inside of data mining principles [7].

The necessity to incorporate data mining and knowledge discovery mechanisms in power quality monitoring has been enounced since the late nineties [7][8][9].

More recently, Ibraim and Morcos have surveyed works involving techniques to assist in power quality monitoring [10]. Their work lacked a methodological approach.

II. Data Mining For Analysis Of Voltage Sags

The basic steps involved in a data mining project are used as a guideline to survey the literature.

A. Definition of objectives

Four main objectives have been identified:

1) Objective 0 - Analysis of sags: In this objective are the papers that emphasize in the definition of new attributes for the characterization of disturbances or in the discriminating properties of the proposed methods. They do not pursue a real power quality goal. A representative example is the voltage sag classification proposed by Bollen [11].

2) Objective 1 - Determine the underlying causes: This objective involves developing methods to automatically associate registers of sags with the causes that originated them [3].

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3) Objective 2 – (Fault) Location of origin of sags: This objective is treated with two approaches: first, to determine an *accurate location* of the sag source [12]-[19]; second, to identify a *relative location* with respect to a measurement point [20]-[23], in [24] are compared.

4) Objective 3 – Power Quality Assessment: We include within this goal all of the works oriented at exploiting the results of measurement campaigns performed by either utilities or *customers* [25]-[29].

B. Selection, organization and pre-treatment of data

Raw data useful for power quality monitoring goals are typically organized in several databases. A suitable combination of these will allow achieving the desired goals.

The *call center* database contains information about the location and causes of the affectation. *Power quality monitors* provides registered waveforms. Commonly, these waveforms are stored in a proprietary format or in standard format (comtrade, csv, and pqdif) [29]-[31]. The *network control center* database provides information related with switching, relay operation, maintenance actions, etc.

1) Data Selection: The selection criteria have to be defined according to the goals before starting the analysis. For instance, register with magnitude greater than 0,9 p.u and duration lesser than half cycle have not to be selected.

2) Organization: Indexing in a complete database is needed when a large number of parameters are used instead of flat structures.

3) Pre-treatment of data: The RMS sequence of voltage and current waveforms is typically obtained. SFT and a sliding window of one cycle are commonly used to compute it [27][2][32][33].

C. Feature extraction and subsequent transformation

To extract features some authors propose segmentation of the waveform in states, and they distinguish stationary and non-stationary parts [3][34]. An additional method based on mathematical morphology and fractal techniques is presented in [35].

Some identified relevant features computed by the authors are as follows:

1) Voltage sag magnitude - S_a, S_b, S_c: It can be defined for each phase, but sometimes the deeper phase is used to characterize the whole sag.

2) RCV and PN factor F: These features containing information about the type and unbalance grade of the voltage sag, respectively [11][2][36].

3) Fundamental voltage component - V_1: DFT is usually used to compute it. Some researchers use $|V_1|$ as a feature itself, and others use $V_1(t)$ to obtain all the other features.

4) Characteristic phase angle jump: This feature is used to characterize voltage sags led by single-phase faults [37].

5) Loss of voltage - L_v: This is defined as the integral of the voltage drop during the event [2].

6) Sequence voltage - V_0, V_1, V_2: Their use in fault location analysis is very common, for example [38][39].

7) Ratio of the currents – I_{sag}/I_{ss}: This is the ratio between the fault and prefault currents. It can be used to determine the relative location of the sag source [40][41].

8) Second order harmonic current - $|I_2|$: This current is relatively large when the transformer is energized [40][41].

Exploratory Data Analysis is a data mining task that establishes relations between features and the intended objectives. Several statistical tools can be used for this purpose, such as PCA[1] [42], FDA[2] [42], PPEDA[3] [43], CA[4]. For instance, the use of PCA analysis, applied to a set of sags characterized by sag magnitude features for fault location identification objectives, is shown in Fig. 1. The rhombuses are the faults located in the first section of the circuit [44]. This behaviour allows discriminating the distance between the measurement point and the fault location.

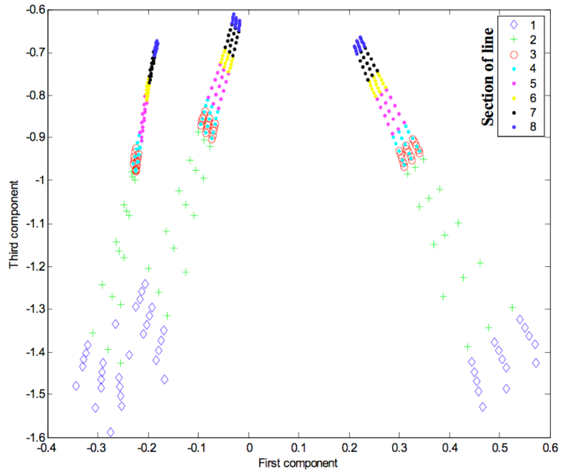

Fig. 1. Fault location analysis. Each symbol corresponds to a voltage sag. The sags are projected in PCA space [44].

Similarly, Fig. 2 shows how a combination of RCV, PNF, V_o, L_v, I_{ratio} and duration is used to identify unusual sags. Each dot represents a sag in the PCA space. The first, second and third component represent the depth, duration and loss of voltage. The dots located on the right-hand side correspond to the deepest sag events. These events could be considered as unusual sags.

MANOVA[5] is a statistical tool that allows determining which features are the relevant ones with respect to the goal.

D. *Specification of the methods to be used and analysis of data based on the chosen methods*

The analysis is focused on those methods used to achieve the Objective 1 and 2:

1) Methods to determine the underlying cause (Objective 1): In literature, few papers about the treatment of sags to infer the underlying causes have been found [40][41].

2) Methods to determine the source location (Objective 2): The algorithms [12]-[23] determine the source location without implement data mining strategies. Three main strategies have been proposed to estimate the *accurate location* of faults. These exploit information contained in the data.

[1] PCA - Principal Component Analysis
[2] FDA – Fisher Discriminant Analysis
[3] PPEDA – Projection Pursuit Exploratory Data Analysis
[4] CA – Cluster Analysis
[5] MANOVA – Multivariable Analysis of Variance

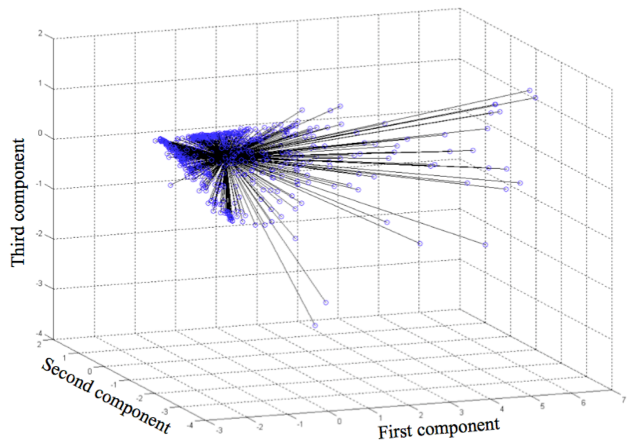

Fig. 2. Voltage sag events projected in the PCA space and identification of unusual events.

i. Deterministic and statistic classifiers: *Statistical classifiers* can be built by one or a combination of techniques based on statistical learning theory: ANN (RBF) [46][47], SVM, LAMDA [44] and FM [44]. SVMs and ANNs networks are compared in [46][47] to classify power quality events. A hybrid methodology based on LAMDA and Ratan Das algorithm [12] is presented in [44].

Expert system and fuzzy logic are commonly used *deterministic classifiers*. A comparison between a deterministic and statistical classifier based is presented in [3]. A fuzzy classifier to detect and classify power system events is described in [48]. *Deterministic classifiers* have not been used for fault location.

ii. Pattern matching or similarity-based methods: In this category, we have grouped those methods that try to identify a register using a previous example that had been correctly diagnosed. For example, in [49], gathered and simulated waveforms are compared. The best match is used to identify possible fault points. A similar method has been proposed in [38][39] using the sequence voltages.

iii. Topological Search: There is a group of strategies that takes advantage of the network topology. A representative work is described in [50] (only radial network). The *coverage* and *direction matrix* are introduced. Another recent algorithm determines the location based on the analysis of branch currents [51] (radial and meshed network).

E. *Evaluation and comparison of methods*

A 5x2 cross-validation [52] is an alternative to the 10-fold cross-validation method. It has greater independence between the training and test subsets than the cross-validation.

The *t-student* test has not been used to *compare* methods in power quality analysis. Comparisons based on the *t-student* test must be performed with pairs of methods. In [53] a test to compare more than two classifiers is presented. It is based on ANOVA and the Friedman test.

III. Conclusion

The main research objectives related to analyzing voltage sag event were identified. Most papers propose methodologies to discriminate between different power quality perturbations. Hence, methodologies to determine the causes of sag events have to be proposed.

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