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A quantitative comparison approach for different voltage dip characterization methods

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ABSTRACT

This paper presents a systematic approach to compare different methods for characterizing voltage dips in a quantitative way. A prediction error is calculated between measured and synthetic dips (reproduced from single-event characteristics for the measured dips) with respect to the way they impact the performance of a generic device. The proposed approach is illustrated by comparing seven different characterization methods and their ability to predict the minimum dc-bus voltage of a three-phase adjustable-speed drive. A generic model of such a drive is used for this. Based in this comparison it is concluded that characterization method for dips in three-phase systems should include unbalance and phase-angle jump.

1. Introduction

Voltage dips are among the most serious power-quality issues and have received a lot of attention because of their impact on industrial installations [1–3] and more recently also on production units [4]. In the latter case the term “fault-ride-through” is more commonly used.

To quantify voltage dips, so-called single-event characteristics have been introduced, where residual voltage and duration are the ones most commonly used and defined in IEC 61000-4-30 [5] and IEEE Std. 1564 [6]. An important reason for using just two single-event characteristics is to simplify the reporting of the quality of supply. It has however been shown by several studies [2,7–14] that also other properties of the voltage dip (like unbalance, point-on-wave and phase-angle jump) can have a significant impact on the performance of equipment. Additional single-event characteristics have been proposed to cover this [3,15–22]. Furthermore, it is known that a higher number of characteristics will give a more accurate representation of the event. What has been missing however is a quantitative comparison to be able to decide relevant grid performance characteristics. A transparent comparison is needed between different sets of characteristics or between different ways of calculating a specific single-event characteristic. Enabling such a comparison is the main purpose of the work that resulted in this paper.

There are two reasons for characterizing voltage dips:

- Extracting information about, e.g. cause of the dip, location of the event in the grid, state of the grid when the event occurred.
- Quantifying the performance of the grid.

The latter is the main driver behind voltage-dip characterization. Quantification of the performance of the grid should be related to the way in which dips impact equipment connected to the grid. Comparing different characterization methods is possible by relating to which extent the different sets of characteristics predict the impact of the actual dip on equipment connected to the grid. There is however a wide range of equipment sensitive to voltage dips and it will not be practically possible to cover all of them for a general comparison of characterization methods. Instead, generic equipment models are needed for the comparison.

This paper proposes a qualitative approach to compare different characterizing methods for voltage dips. The comparison is made based on the ability of a characterizing method to predict equipment behaviour. Although a range of characterization

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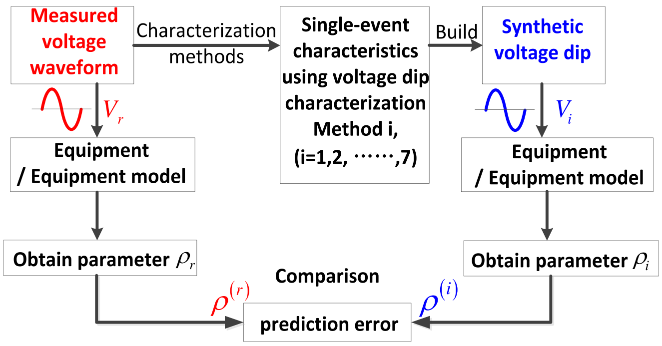

Fig. 1. The proposed method for comparing different characterization methods. (a) Measured dip V_r. (b) Synthetic dip V_1 from Method 1. (c) Synthetic dip V_2 from Method 2. (d) Synthetic dip V_3 from Method 3. (e) Synthetic dip V_4 from Method 4 (f) Synthetic dip V_5 from Method 5. (g) Synthetic dip V_6 from Method 6. (h) Synthetic dip V_7 from Method 7.

methods have been proposed, no quantitative comparison has been made due to the lack of a method for doing such a comparison. The proposed approach is illustrated by comparing seven different characterization methods using 235 sets of measured voltage dip applied to a simulation model of an adjustable-speed drive. Section 2 gives an overview of the proposed approach together with the quantifier and the generic equipment model used to illustrate the approach. Seven different ways of characterizing dips are presented in Section 3 and used for this illustration. The comparison of these seven methods is presented in Section 4, followed by discussion (Section 5) and conclusions (Section 6).

2. The comparison approach

2.1. The overall approach

The overall approach is shown in Fig. 1, where V_r is a measured voltage waveform (left-top). A characterization method consists of a set of single-event characteristics and the way in which they are calculated. Using these characteristics, a synthetic voltage dip is build (right-top) for each characterization method, the waveform of which is referred to as V_i with the subscript i referring to the characterization method. The impact on a generic device is calculated for the actually measured dip and for the synthetic dips. With this aim, both the measured voltage dip V_r and all the synthetic waveforms V_i are applied to a generic equipment model Values for a performance index (ρ_r for the measurement, ρ_i for the synthetic dip) are calculated. The difference between ρ_r and ρ_i is used to compare the characterization methods.

The prediction errors are calculated that quantify the accuracy with which the synthetic dip predicts the impact of the actual dip on the device. This is repeated for many recorded dips and for the different characterization methods. The statistics of the prediction errors are used to compare those methods. The approach will be illustrated in Section 4 for a specific general device model (to be introduced in Section 2.2) and for a specific aspect of the performance (Section 2.3). Seven different characterization methods for dips in a three-phase system (to be introduced in Section 3) will be compared for this illustration.

The voltage dips used for the study presented in this paper, were all obtained from field measurements using commercial power-quality monitors in two European medium-voltage networks in two different countries. The recordings were all scaled to a nominal voltage of 400 V. Voltage waveforms were obtained for the actual dip and for a number of cycles before and after the actual dip. The same frequencies used were 96 and 128 samples per cycle. In theory it would be possible to use simulations for this approach, but that would require a very detailed model including all the load impact and other random variations that impact voltage dip waveforms.

2.2. Generic device model

For the same general type of equipment, different manufacturers often implement different hardware components, different topologies and different control algorithms. To predict the impact of voltage dips on a specific device, it is important to include all those details. However to compare characterization methods, a generic device model is more appropriate. Such a model should include the main properties of the device with respect to voltage dips, without the need to obtain manufacturer-specific data. To illustrate the comparison approach, a generic device model of a three-phase adjustable-speed drive is used. To predict the impact of voltage dips on a specific device, assessing the key parameter performance is the usual way proposed in the literature [2,13]. The drop in dc bus voltage which results from the sag will cause maloperation or tripping of the drive controller or of the PWM inverter. Dc voltage is an important parameter for ASD and is the analyzed parameter in this paper. The model is built in Matlab/Simulink, with the same parameters as in Ref. [13]; see details in Appendix A and Fig. 11. The model consists of a three-phase rectifier followed by a capacitor and a constant-power load. It was shown in Ref. [14] that this model is able to describe the impact of balanced and unbalanced dips on the dc bus voltage. The main cause of device failure is the unwanted tripping of the under-voltage protection of the dc bus. The capacitor size is important for the equipment performance during the voltage dip. Three values of the capacitor (75, 165, and 360 µF/kW, as in Refs. [1,14]) are used in this study.

2.3. Prediction error

The impact of the measured and synthetic voltage dips on the generic device is quantified through the value of the lowest dc-bus voltage during the voltage-dip event. The lower this value, the higher the probability that the under-voltage protection trips. A lower voltage will also give higher post-dip inrush current and therewith a higher probability that the overcurrent protection will trip the device. A lower dc-bus voltage will also increase the impact on motor torque and speed. The lowest dc bus voltage under the measured voltage dip is represented by $\rho^{(r)}$ and the lowest value under the synthetic voltage dips for characterization method i is represented by $\rho^{(i)}$, as shown in Fig. 1.

The smaller the difference between these two values, the better the characterization method in predicting the device performance. To quantify this ability of the characterization method to predict equipment performance, two quantities are introduced: the "*absolute prediction error*":

$$\delta_i = \frac{\rho^{(i)} - \rho^{(r)}}{\rho_{nom}} \times 100\% \quad (1)$$

And the "*relative prediction error*":

$$\varepsilon_i = \frac{\rho^{(i)} - \rho^{(r)}}{\rho^{(r)}} \times 100\% \quad (2)$$

ρ_{nom} is the average value of the dc bus voltage before the dip.

When $\rho^{(i)} - \rho^{(r)}$ is positive, the predicted value of the minimum dc-bus voltage is larger than the one in reality. The synthetic dip is thus less severe for the equipment than the measured dip: i.e. the characterization method underestimates the severity of the dip. Similarly, when $\rho^{(i)} - \rho^{(r)}$ is negative, the characterization method overestimates the severity of the dip.