Energy and Buildings 55 (2012) 494–499

Contents lists available at SciVerse ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Examination of major factors affecting voltage variation on distribution feeders

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ARTICLE INFO

Article history:
Received 24 May 2012
Received in revised form 25 July 2012
Accepted 21 August 2012

Keywords:
Distribution system
Power flow analysis
Power quality
Voltage quantity
Voltage variation

ABSTRACT

The main purpose of this paper is to investigate the major factors that affect the voltage variation on distribution feeders. This research focuses on the degrees of influence of major factors on the node voltage variations along distribution feeders. First, the definitions and related standards of power quality are introduced. Then, the major factors are identified, analyzed and compared, followed by a concise discussion and conclusion. The research results are of value to distribution engineers to improve operation and maintenance, and to design better distribution feeders.

1. Introduction

In recent years, the growing applications of electronic equipment and distributed generation (DG) have increased the interest in power quality. The recent growing impacts of power quality can be explained in two ways. First, equipment has become more sensitive to voltage disturbances. Second, the equipment used causes more and more serious voltage disturbances. Converter-driven circuits are widely used to drive modern equipment. However, the wide use of converter-driven equipment has led to a large increase in voltage disturbances. Thus, the modern electronic equipment is not only sensitive to voltage disturbances, but it also causes disturbances to other appliances.

In 1968, the oldest mention of the term "power quality" was published by Kajihara [1]. In the 1970s, high power quality was mentioned as one of the focuses of power system design. The term "power quality" is widely used to describe the potential power disturbance problem in industrial power systems. Power quality includes both voltage quality and current quality. Power quality is usually indicated by the node voltages, the line currents, and the system frequency. Among them, the voltage quality is one of the most important factors. Voltage quality measures the variance from the nominal voltage.

Some experts and scholars consider that the meaning of power quality is more general than voltage quality in industrial power systems, because the continuity of supplying power is included in power quality [2]. In recent years, many experts and scholars have investigated the different aspects of power quality. They have supposed that power disturbance phenomena consist of power interruption, waveform distortion, voltage flicker, frequency variation and voltage imbalance issues. Those are all related to voltage directly. The techniques for improving power quality in industrial power systems may involve state monitoring, reactive power compensation, noise filtration and system control.

In Ref. [3], a control strategy was proposed to expand the functionality of the existing nonlinear DG interface to not only control the active power, but also to manage the reactive power and mitigate harmonic, imbalance, and voltage fluctuations. In Ref. [4], some useful indices have been proposed to estimate short duration wave distortions which result from the sudden variations in nonlinear loads. The indices make it is possible to describe the system risk related to the burst occurrence and permit a suitable prediction of system behavior as a function of time. In Ref. [5], a building model of a typical Kuwaiti dwelling was presented to implement energy consumption analysis. The sensitivity analysis technique has been adopted to achieve building energy-saving through proper building design. In Ref. [6], a comparison between a simple artificial neural network (ANN) based model and a model based on physical principles as an auditing and predicting tool was presented to forecast building energy consumption.

In Ref. [7], an effective Energy Difference Multi-Resolution Analysis (EDMRA) method has been proposed for detection, localization and classification of different kinds of power quality disturbances.

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http://dx.doi.org/10.1016/j.enbuild.2012.08.021

The functional relationship to the minimum decomposition level (MDL) was presented to avoid unnecessary computational cost. In Ref. [8], a simple short-duration disturbance classifying method without other classifier was proposed based on S-transform and maximum similarity by comparing the distances between S-transformed module time-frequency matrices (MTFMs) of standard and tested short-duration power quality disturbance (SDD). In Ref. [9], an approach for identifying the frequency and amplitude of flicker signals that impose on the nominal voltage signal has been proposed. It has succeeded in estimating the voltage flicker frequency and amplitude. In Ref. [10], an electrical energy analysis of the hybrid photovoltaic-hydrogen/fuel cell energy system was performed to evaluate the power quality of the hybrid energy system.

In Ref. [11], combined AC and DC distribution systems accompanied by distributed resources (DRs) have been presented to replace custom power parks for more simple and effective operation leading to high power quality for AC and DC loads. In Ref. [12], a simplified but accurate enough annual energy loss evaluation method for branch circuits or feeders of a dwelling unit or building was proposed. In this method, the time to time and season to season changes in active and reactive power consumption for each appliance are considered. Using only arithmetic calculations but considering the locations and characteristics of all connected appliances along the circuits of a home or building, makes the simplified method efficient and accurate enough. In Ref. [13], the authors addressed how uninterruptible power supply (UPS) can become an energy efficient solution in high tech buildings. It was found that the main problems for the equipment installed were harmonics and voltage sag (dip). In Ref. [14], a detailed power flow solution approach was presented to evaluate the energy loss of branch circuits or feeders by considering the characteristics of discrete loads along the circuits. The detailed power flow solution approach has resulted in the explicit energy loss evaluations for branch circuits or feeders of a dwelling unit or building and their corresponding determination of the daily, weekly, monthly and annual system electrical parameters. All the techniques mentioned above focus on voltage. For this reason, many experts consider that power quality problems are voltage quality issues actually, and the term "voltage quality" is more suitable than "power quality" in some situations.

The paper is organized as follows: Section 2 introduces the definitions and related standards of power quality, Section 3 identifies and analyzes the major factors affecting voltage variation of distribution feeders, and Section 4 presents test cases and results. In Section 5, a concise conclusion is drawn.

2. Definitions and related standards of power quality

The main objective of this section is to introduce the definitions and the related standards of power quality.

2.1. Definitions of power quality

The term "power quality" is widely used to describe the electromagnetic phenomena in the power system. In IEEE Std. 1159 [15], power quality is defined as the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment. In IEEE 1159-1995, several aspects of power quality issues can be cataloged as transients, short duration variations, long duration variations, waveform distortion, voltage imbalance, voltage fluctuations and power frequency variations.

In a power distribution system, the operation voltages are not always in their desired ranges due to variations of loads along the feeders, actions of tap-changers of the substation transformers and switching of capacitor banks or reactors. The small variation from its corresponding desired value is so called voltage deviation or variance.

The short duration variation category is used to refer to voltage sag, voltage swell and short interruption. Besides, the long duration variation category is used to refer to sustained interruption, undervoltage and overvoltage.

2.2. Related standards of power quality

In a power distribution system, the control of power quality mainly focuses on the node voltages along the feeders. The standards in power quality area are applied to maintain the node voltages along the feeders within a permissible range. The related power quality standards are listed in this paper in order to provide available resource information for making particular power quality decisions, as shown in Table 1.

The standards released by IEEE, ANSI, NFPA and UL are involved in this table and the definitions of voltage quality can be found in IEEE Std. 141, 519, 1100 and 1159. In general, each country has its own national regulations for steady-state voltage tolerances, for example, ANSI has constructed certain standards for the voltage variation problems of the power system in the U.S.

The voltage variation related ANSI standards are classified into two groups: one is ANSI C84.1 for nominal voltage rating above 100 V through 230 kV [16], and another one is ANSI C92.2 for nominal voltage rating above 230 kV [17]. Electrical power suppliers in the U.S. generally accord with ANSI C84.1 for delivery of electrical power.

3. Factors affecting voltage variation of distribution feeders

In general, most voltage quality-related standards mainly aim at the steady-state voltage variations. In this paper, to understand the degrees of influence of the major factors that affect the steady-state voltage deviations in the primary distribution feeders, the major factors are discussed as follows.

3.1. System short-circuit capacity

The system short-circuit capacity stands for the short-circuit capacity on the high-voltage side of substation transformers. The system driving-point impedance is inversely proportional to the system short-circuit capacity. Usually, if the system short-circuit capacity is larger than 2000 MVA, the system driving-point impedance will be much smaller than the impedance of the substation transformer. Therefore, the effects of the system short-circuit capacity on node voltages along the feeders will be less than that of the impedance of a substation transformer. The system short-circuit capacities distributed at the nodes along primary distribution feeders are mainly varied with the locations of the nodes and the design of configuration of distribution feeders. Moreover, the configuration of primary feeders is mainly determined by the reliability and security concerns of system operation, not the voltage variations.

3.2. Rated capacity of substation transformer

The variance of node voltages along the feeders can be lessened by increasing the rated capacity of their feeding substation transformer. That is, the larger the transformer capacity is, the lesser voltage variation arises. However, one of the major disadvantages for increasing rated capacity of substation transformer is the rise in the short-circuit fault current level on the secondary side of a substation transformer.