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Analysis of Causes and Effects of Harmonic Distortion in Electric Power Systems and Solutions to Comply with International Standards Regarding Power Quality

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Abstract. In recent years, power quality has gained importance due to increasing pollution in the electric system as a consequence of the proliferation of non-linear loads connected to the grid. For this reason, research has been intensified on this issue to improve power quality; especially through simulation models development using software tools, which allow studying the possible causes and effects of disturbances on the electric system and testing solutions to mitigate these power quality events. This paper focuses on analyzing by simulation a possible cause, effect and solution of harmonic distortion, as an example of using cloud-based platforms in order to get the power quality requirements of the future Smart Grid.

Keywords: Power quality, disturbances, simulation models, harmonics.

1 Introduction

Nowadays, there are countless loads which need power supply to work both in industries and in the tertiary and domestic sector. This fact has turned the electric power system into a fundamental cornerstone for economic and social development. For this reason, it is essential that power quality is as adequate as possible and keeps the voltage waveform within acceptable limits in terms of RMS value and frequency.

These parameters do not remain indefinitely in their nominal values because the electric system is not ideal. It may be affected in its normal operation unintentionally by electromagnetic signals called disturbances. These disturbances can be external to the power grid (due to lightning, natural disasters, accidents, etc) or internal to it, like large industrial receptors and even small power loads. In addition, the proliferation of electronic devices connected to the grid in recent years has made this problem worse.

These facts explain why power quality has gained relevance in the last decades. As a result, standards and regulations regarding power quality have being developed in order to establish acceptable values which guarantee a suitable electric supply.

An interesting approach to move forward in research about disturbances which affect the electric power system is based on examining their possible causes. In this way, this paper focuses on analyzing by simulation the implications of the presence of harmonic disturbances in the electric power system. Moreover, among the solutions to improve power quality, this paper exposes the importance, in the context of future Smart Grids, of designing cloud-based devices which enable consumers to monitor power quality parameters locally in their household, and upload that data to an Internet service to produce a crowdsourced perspective on power quality.

2 Contribution to Cloud-based Engineering Systems

Cloud computing, considered as the real-time delivery of IT infrastructure, services and software over the Internet or an internal web-based infrastructure, is an important tool for improving the power quality from a global perspective. Monitoring and collecting data allows determining the presence of disturbances, analyzing their causes and measuring their effects. But above all, cloud computing enables to make decisions about which solutions to implement to minimize the effects regarding poor power quality or reliability. In addition, stored data allows having information for predicting the occurrence of disturbances, in order to anticipate the causes.

One of the challenges of the future Smart Grid is to enable the active participation of consumers to modify electricity purchasing patterns and behaviours. It can be achieved via power quality monitoring in their household. These data would allow having cloud-based information of consumptions and the data processing will provide information as the interaction with neighbors regarding power quality. It will also help to make decisions to reduce power quality problems. In this way, the Open Power Quality research project carried out in the University of Hawaii [1] has demonstrated how the combination of a low-cost hardware and cloud-based software allows the consumers to monitor some parameters regarding power quality in their homes and upload that data to an Internet service. This project proposes a crowdsourced approach in which collection of data is made by consumers and is analyzed oriented toward the needs of consumers.

Another feature of the Smart Grid is to meet user demand for power quality and provide users with an optimal variety of power quality and price program. According to it, power quality monitoring and the development of a power quality information platform to manage the collected data and evaluate results is an important issue. Besides, another challenge of Smart Grid is the user-friendly and intelligent interaction between the customers and the power provider, trying to meet user needs with the best power quality and reliability. Trying to fulfill these challenges, a power quality unified information platform based on cloud computing Software-as-a-Service (SaaS) model is proposed in [2]. It promotes information sharing and friendly interaction between both power provider and consumers.

As an example of usable collaboration and interaction between consumers, in this paper a solution to eliminate the effect of harmonic distortion and the appearance of parallel resonance is proposed. The solution is as simple as using transformers of specific vector groups by consumers connected to the same Point of Common

Coupling (PCC). However, this solution is impossible to implement without monitoring locally and exchanging that information between users. It shows the importance of developing cloud-based platforms in order to get the power quality requirements of the future Smart Grid.

3 State of the Art

The use of simulation tools has become an interesting method to analyze disturbances which affect the electric power system and contribute to the study of power quality. In [3] a set of five simulation models is presented to simulate various power quality events in a distribution system using the SimPowerSystems blockset, like voltage sag, transient, notches and harmonics.

The operation of some industrial loads that cause pollution on the electric power system is also simulated in the literature. In [4] a steel plant and an underground traction system are simulated and an active filter is installed in order to mitigate the voltage harmonic distortion. In [5] the authors propose a steel plant using induction furnaces model and present a Unified Power Quality Conditioner (UPQC) to compensate possible voltage problems. Meanwhile, in [6] the electric arc furnace is modelled with a Static Compensator (STATCOM) to improve the power quality, while in [7], a composite filter is employed in order to reduce harmonics, voltage flicker and imbalance. Electrified railway is another industrial non-linear load simulated in [8], with a STATCOM with PSO-implemented controller to suppress harmonic distortion, voltage fluctuations and to compensate reactive power. In [9], electrified railway systems are analyzed too using several types of Flexible AC Transmission Systems (FACTS) for power quality improvements.

In the same way, in [10] harmonic currents demanded by some non-linear household devices are simulated and different kind of faults and harmonic pollution brought by power electronic devices in power system are also simulated in [11]. The authors of [12] expose a categorization of power quality events and show a simulation model to validate the impact of power quality on sensitive equipment. Finally, the purpose of [13] is to present a solution to voltage sags/swell, harmonic distortion and low power factor using Distribution Static Compensator (D-STATCOM), showing its effectiveness through a simulation model.

4 Simulation Case Studied

This paper focuses on simulating a cause of harmonic distortion in an electric power system, checking one of its worst effects and proposing a solution based on exchanging information about harmonic consumption between users. The simulation model is shown in Fig. 1 and the parameters are collected in Table 1. It is a three-phase low voltage electric power system modeled as a voltage source and a series grid impedance. In the PCC it is connected a linear resistive-inductive load with a capacitor bank in parallel in order to improve locally the power factor. At the same point, there are two non-linear loads, which are non-controlled three-phase rectifiers

connected to the PCC via isolation transformers. The capacitor bank and non-linear loads have breakers in series in order to be able to simulate the behavior of the system when these devices are connected or not.

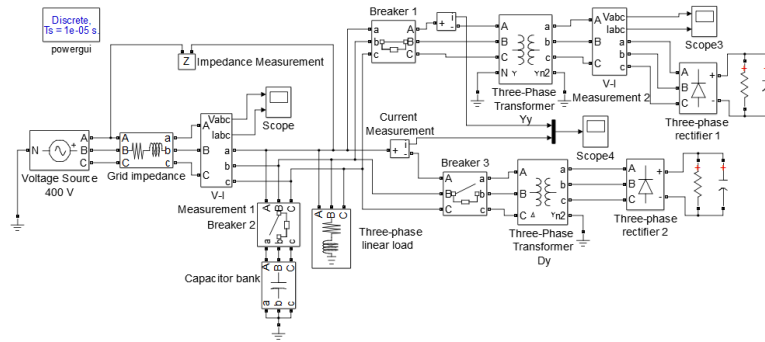


Fig. 1. Simulink model used to simulate causes, effects and solutions of harmonics.

Table 1. Parameters values used in the simulation model.

Parameter	Value	Parameter	Value
System voltage (V)	400	Linear load reactive power (kVAr)	40
Nominal frequency (Hz)	50	Transformers nominal power (kVA)	250
Grid resistance (mΩ)	25	Transformers transformation ratio (V)	400/400
Grid inductance (μH)	520	Three-phase rectifier dc voltage (V)	900
Capacitor bank capacitance (mF)	0.779	Three-phase rectifier resistive load P (kW)	500
Linear load active power (kW)	60	Three-phase rectifier capacitive load C (mF)	0.1

4.1 Causes

The main cause of harmonic distortion is the use of power electronic devices. The simulation model shown in Fig. 1 includes two three-phase rectifiers, demanding a current (downstream the transformers) with the waveform displayed in Fig. 2(a) with THD of 16.94% and dominant harmonics 5th and 7th (see harmonic spectrum in Fig. 2(b)).

4.2 Effects

Harmonics are responsible of many problems in electric power systems. The simulation model developed in this paper (Fig. 1) allows observing one of the effects caused by harmonics: resonance between capacitor banks for power factor correction and grid inductances, which amplifies the existing harmonics.

Fig. 1 represents a distribution power system that feeds a linear load connected to the same PCC as the three-phase rectifiers. In this case, breaker 1 is on and breaker 3

is off, so only the upper rectifier is considered. The linear load has a capacitor bank that is connected to the system after 0.5 seconds, in order to correct the power factor.

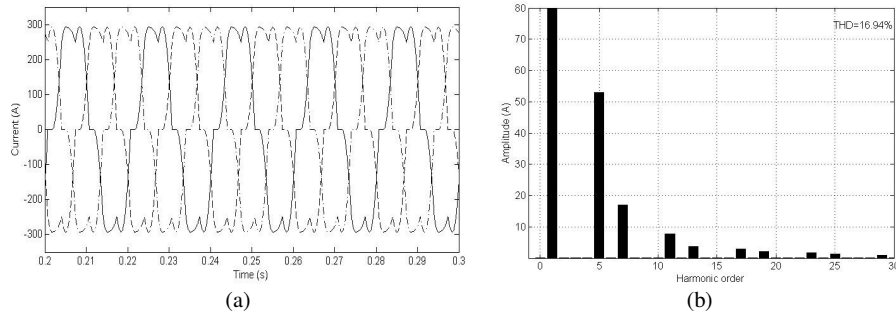


Fig. 2. Simulation results of the current demanded by three-phase rectifier: (a) waveform; (b) harmonic spectrum.

Simulation results are exposed in Fig. 3 and Fig. 4. These figures show the waveforms of PCC voltage in Fig. 3(a) and network current in Fig. 3(b), and how their distortion gets worse when the capacitor bank is connected to the system. As it can be seen, Fig. 4(a) indicates that the voltage has a THD of 14.59% before the connection of the capacitor bank. This fact is a consequence of the harmonic emission caused by the rectifier, distorting the waveform of the current to a THD=10.48% (Fig. 4(a)). However, after the connection of the capacitor bank, voltage THD grows up to 25.44% and current THD to 20.67%, as Fig. 4(b) shows. This increase of THD is due to the remarkable rise of the value of 5th harmonic, because a parallel resonance occurs at a frequency near 250 Hz. In this way, 5th harmonic rises from 27.19 V to 52.73 V in the case of PCC voltage and from 33.26 A to 64.51 A in the case of grid current. The 7th harmonic is also modified by parallel resonance, although less than 5th harmonic; it grows up to 12.12 V to 32.04 V for PCC voltage and from 10.59 A to 28 A in the grid current.

4.3 Solutions

The problems caused by harmonics can be mitigated by different solutions. This paper presents a solution to eliminate the dominant harmonics in the modeled system, that is, 5th and 7th harmonics. In case of two similar non-linear loads at the same PCC, instead of connecting them directly to the grid, they are connected via transformers with different connections. The implemented solution consists of the association in parallel of a Dy transformer with the Yy transformer that feeds the three-phase rectifier previously analyzed, as it can be noted in Fig. 1.

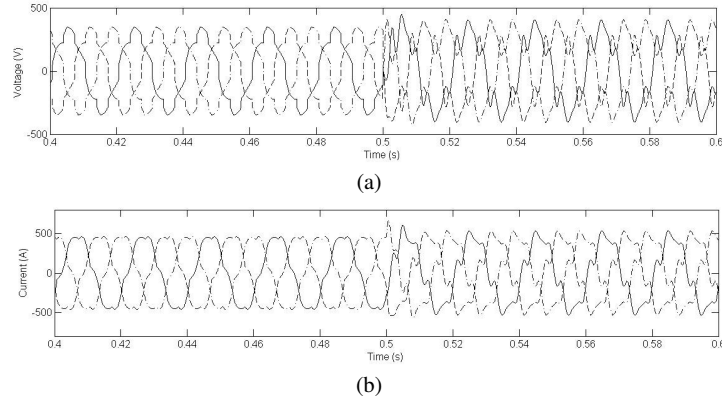


Fig. 3. Simulation results before and after resonance effect: (a) waveform of voltage in PCC; (b) waveform of network current.

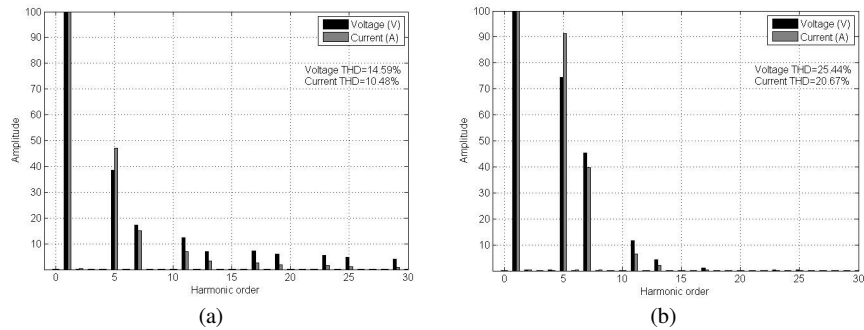


Fig. 4. Harmonic spectrum of voltage and current: (a) before capacitor bank connection; (b) after capacitor bank connection.

The Dy transformer feeds another three-phase rectifier with an identical load than the first rectifier, and introduces a phase difference of 30° in the demanded current by the second rectifier. Therefore, the demanded currents by both rectifiers upstream the transformers are 30° out of phase between them, as Fig. 5(a) shows. Thus, the sum of both currents makes 5th and 7th harmonics to be cancelled; hence the current that flows in the system under these conditions (after 1 second of simulation) is much more similar to a sine wave (Fig. 5(b)). As a result, the waveform of voltage in PCC has been improved too (Fig. 5(c)). The harmonic spectra of both signals demonstrate the elimination of 5th and 7th harmonics and how their THD have been reduced to 7.07% in the case of the voltage and to 1.57% in the case of the network current, as Fig. 6(a) and Fig. 6(b) expose respectively.

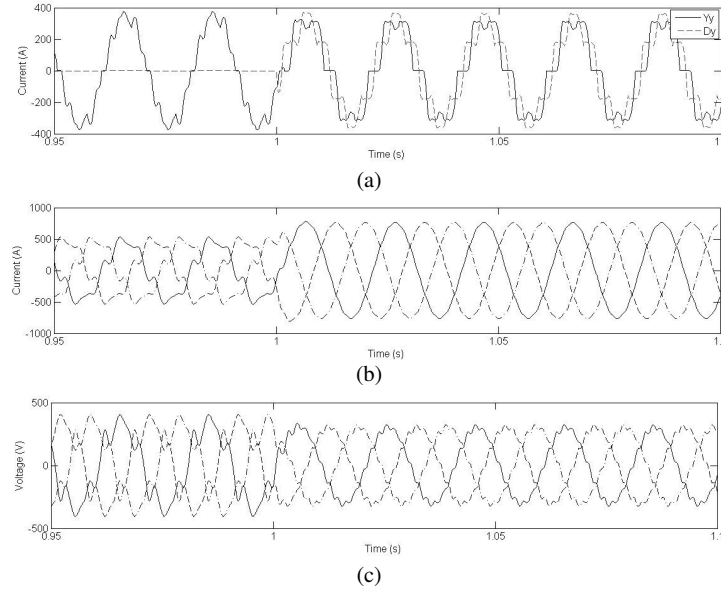


Fig. 5. Simulation results after implementing the solution: (a) waveform of current upstream in each transformer; (b) waveform of network current; (c) waveform of voltage in PCC.

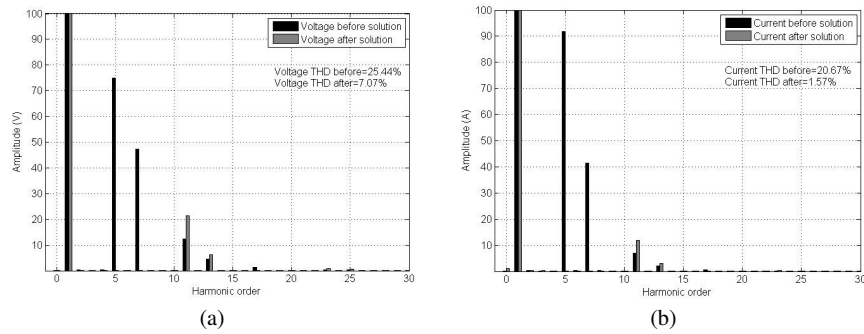


Fig. 6. Simulation results after implementing the solution compared with the previous results: (a) harmonic spectrum of voltage in PCC; (b) harmonic spectrum of network current.

5 Conclusions and Further Work

The development of simulation models to analyze disturbances in the electric power system has become an interesting research method for improving power quality. In this paper, a simulation model has been proposed to confirm a cause of harmonics, the

use of rectifiers connected to the network, and one of its effects, the appearance of parallel resonance between capacitor banks and the grid impedance. In addition, it has been simulated a possible solution to eliminate the 5th and 7th harmonics through a special coupling of transformers, as an example of collaboration between consumers through cloud-based computing. As further work, it is proposed to develop a prototype to validate experimentally the results obtained by simulation and to implement more simulation models to analyze causes, effects and solutions of other type of disturbances.

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