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Analysis of the oscillations caused by harmonic pollution in isolated synchronous generators

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ABSTRACT

This work analyses the oscillations caused by harmonic pollution in isolated synchronous generators. The main contribution is founded on the identification and quantification of the electric torque magnitude, which goes on to become oscillated due to distorted currents arising from the non-linear loads. Besides this, this work presents the same analysis for voltage on the dq0 domain, currents induced on the damper windings, along with the oscillation on the load angle and field current.

Contents

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1. Introduction

Electric energy consumed by commercial establishments, industries and individual consumers is predominantly produced by synchronous generation. This is due to the fact that this form of generation can be easily put into parallel operation with an electric power system. The scenario in industrialized countries is one of synchronous generators all connected by transmission lines, supplying electricity through loads distributed among various areas, which spread over thousands of square kilometers. These machines also are able to operate in isolation, supplying loads to areas of difficult access, where high costs make the implementation of a power transmission line impractical. These machines can also be seen as an emergency unit for industries, hospitals among others [1].

The Brazilian energy crisis that occurred in 2015, worsened by the prolonged dry season, and intrinsically linked to the low levels in hydroelectric reservoirs put the country's energy system in a state of high alert. The consequences took the country close to instituting energy rationing, besides the already high tariffs placed on energy bills [2]. The solution found, a priori, in both financial and technical terms is a possible power source. These have advantage of being used in diesel generator groups in emergency generation systems, as well as isolated operation, preferably at peak demand for industry and commercial establishments, under the intention of increasing reliability and supply, but at the same time reducing energy production costs, in view of the more expensive kWh at peak demand [3,4].

According to data from the National Electric Power Agency (ANEEL), there was an expansion in isolated synchronous generation due to the worry put by residential clients concerning the critical scenario witnessed in 2015, where the distinct possibility of blackouts was faced. Therefore, the concept of diesel groups has grown in its acceptance and has been given more space in residential complexes, houses and condominiums, with the intention of supplying the whole demand in cases of grid supply loss [5].

Faced with this scenario, there arises the concern based on the study of synchronous generators operating in isolation, as in a majority of cases the loads are considered to be non-linear, especially when dealing with residences, industrial and commercial establishments, loads such as air conditioning, compact lamps, computers, among others.

The growth of these loads on consumption demand has intensified, due to the numerous applications that power electronics offers. The switching of electronic devices is responsible for harmonic generation, which causes current distortions and consequently upon the voltage in a specific electrical system.

Salient pole synchronous generators that operate in isolation tend to suffer greater damage caused by the presence of harmonic content. This occurs due to its single circuit nature, thus the only means for the harmonic currents to circulate is between the generator and the load, which is different to a generator connected to an infinite bus bar, where the generated harmonic currents are able to circulate through the electric power system.

Therefore, in producing a study related to harmonics in synchronous generators, it should highlight the contribution of the following papers:

In [6], the study of disturbances is analyzed on the voltage and current waveform on an isolated synchronous generator, which supplies a non-linear load, where the synchronous generator uses an exciter powered by a bridge rectifier connected to the very terminal of the machine.

In [7], the model of a synchronous generator is described, which includes harmonic impedance on the impedance array of the equivalent circuit of the machine. The effects from salience and magnetic saturation are also taken into account. This model is validated by means of computational simulations in the time domain.

Subsequently in [8], a model of the synchronous generator in the abc domain considers the spatial harmonics, the Park transformation is applied to the fundamental stator flux, with the aim of calculating the fundamental voltage generated and the load angle. This study also considers the impacts caused by the spatial and temporal harmonics (caused by non-linear loads) on the load angle, detecting the presence of a current 6 times the fundamental current on the synchronous generator field. Therefore, the work of this author does not contemplate the study of electromagnetic torque oscillations caused on the synchronous generator in a non-sinusoidal regime.

In another study described in [9], harmonics caused by an internal failure on the synchronous generator are contemplated, the model also considers spatial harmonics caused by distribution of the machine windings. However, this study does not consider the effects caused by temporal harmonics on the synchronous generator in steady state.

Another relevant aspect is given attention in [10], which presents the harmonic effect over the voltage regulation on the synchronous generators in a non-sinusoidal regime, which analyses different levels of harmonic distortions produced by the non-linear load.

A study that provides approximations close to those of this work is described in [11], where the behavior of the electrics and mechanics of the synchronous generator are investigated, which supply a 6 pulse non-controlled rectifier. However, the article is limited to the comparison of distorted waveforms and cites an induced current of the sixth harmonic in the generator field. However, it does not include an investigation of the electromagnetic torque oscillations.

The study in reference [12] analyses the electromagnetic torque oscillations of harmonic currents, it also shows that these oscillations cause vibrations in synchronous machines; an equation is used to identify these oscillations. However, this study does not mention the sixth harmonic and its multiples and neither quantifies them.

Another study that provides even closer approximations to those presented herein is proposed [13], where the components for the seventh and fifth oscillated harmonic are presented on the rotor windings. However, there is no study made for identifying oscillating torque of the sixth harmonic.

A study made concerning mechanic resonance with the sixth harmonic and its multiples is presented in [14]. However, this study considers a current distortion that is relatively low, when compared to the actual situation of harmonic distortion in isolated generation. A mechanical analysis is performed in relation to electromagnetic torque. However, the authors limit the presence of the sixth harmonic and its multiples induced by the electromagnetic torque. They also do not mention its influence on other electric variables, such as the voltage and current induced on the rotor windings.

In this manner, in relation to the other studies cited in [6–14], this brings an analysis of the oscillations caused by harmonic pollution in isolated synchronous generators. Highlighted here is the identification and quantification of the oscillations that appear on the principal variables of the machine, giving emphasis to electric torque, voltage in the dq0 domain, the induced currents on the damper windings and the field, along with the load angle of the machine. All these variables are computationally analyzed through providing the harmonic spectrum and the mathematics associated with its behavior through the decomposition of the Fourier series.