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Ferroresonance in subharmonic 3rd mode in an inductive voltage transformer, a real case analysis

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ABSTRACT

This paper focuses on a ferroresonance incident in subharmonic 3rd mode captured in the electrical substation Rio Escondido (REC), in the northeast of Mexico. Bearing in mind that this kind of ferroresonance phenomenon is a sporadic event and difficult to record, the contribution of this paper consists of the analysis of this real-life ferroresonance phenomenon and to propose a practical solution that prevents these kinds of incidents. An analytical calculation to obtain the electrical parameters of a damping reactor used to damp out the ferroresonance phenomenon registered in the REC substation is reported.

Introduction

Ferroresonance occurs because of an interaction between a nonlinear inductance with series and parallel capacitances and low voltage [1]. In the event analyzed in this paper, ferroresonance occurred in the interaction between the nonlinearity of an inductive voltage transformer (IVT) with grading capacitors and conductor capacitance. Potential danger comes from a combination of the transformer and circuit breakers, which are equipped with grading capacitors. When the circuit breakers are opened, their capacitors can equalize the transient voltage at both ends of the breaker and possibly push the voltage transformer into saturation. In this case, the inductive reactance of the voltage transformer might be equal to the system's capacitive reactance providing a circuit for ferroresonance in which the nonlinear inductance acts as a "switch" allowing the energy trapped by the capacitance to be quickly transferred to other parts of the circuit during saturation. Therefore, this nonlinear phenomenon can induce discontinuous jump, amplitude responses, subharmonic responses or amplitude-modulated almost-periodic oscillations. This phenomenon can be suppressed by several methods, such as the use of resistance loading in voltage transformers, the use of disconnectors to remove grading capacitors trapped charge or the use of a damping reactor [1,2].

Recently, the problem of ferroresonance in the Mexican electric power system has assumed great importance due to repeated failures in the IVTs which cause their destruction and in some cases the loss of electrical power. Therefore real-time detection and the elimination of ferroresonance in IVTs are of extreme interest. The aim of this paper is to report the study of a ferroresonance case in subharmonic 3rd mode documented from a relay recorder, which to the best of the authors' knowledge has not been reported in the open literature, and demonstrate how the ferroresonance is damped out by installing damping reactors.

The event described in this paper occurred on January 8, 2011 at 4:34 a.m. in the 400 kV substation *Rio Escondido* (REC) located in the northeast control area of the Mexican interconnected power system and caused total damage in an IVT. The cause of the problem was a ferroresonant condition in a subharmonic 3rd mode characterized by present overvoltages at a 20 Hz frequency [3]. Since the recording of this phenomenon is unusual, its study through these ferroresonance's data captured in the field allows its reproduction through the appropriate representation of the substation in the Electromagnetic Transient Program (EMTP/ATPDRAW) in order to assess how the failure in the IVT occurred.

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Ferroresonance features and the computation of the IVT damping reactor

Ferroresonance is a type of nonlinear resonance characterized by sustained overvoltages and overcurrents, with highly distorted waveforms; it can damage the electrical equipment (thermally or from insulation breakdown) [4]. The main components that initiate ferroresonance are a voltage source, a closed-path involving capacitance, saturable inductors and low energy. The total capacitance of a substation is composed of grading capacitors, cable capacitance, bus bar capacitance, coupling between lines, capacitor banks, isolation capacitance and capacitive transformers. On the other hand, the saturable or nonlinear inductance is provided by reactors, power transformers and IVTs; additionally, systems with low resistance increase the risk of ferroresonance conditions. In the context of this paper, the magnetization reactance in an IVT is nonlinear due to the core saturation which is made of ferromagnetic material, so the overvoltages produced by the ferroresonance phenomenon cause severe dielectric damage in the IVT [5]. The formation of hysteresis is an independent factor which significantly impacts the ferroresonance modes. For an adequate hysteresis loops model, it must measure properly hysteresis loops at the power frequency considering the dynamic behavior of the core loss resistance [6]. In this work, a constant resistance was used to represent the total core loss.

Ferroresonance modes

The classification of ferroresonant modes corresponds to steady-state conditions. In general, there are four modes of ferroresonance [7–9]:

(i) Fundamental. The voltages and currents are periodic with a period *T* equal to the electrical network period and can contain a variety of harmonics.
(ii) Subharmonic. The signals are periodic with a *nT* period which is a multiple of the period of the power supply from the electrical network. This mode is called subharmonic *n* or harmonic 1/*n*. Subharmonic ferroresonant states are usually an odd number [10].
(iii) Quasi-periodic. This is a non-periodic mode spectrum with discontinuity.
(iv) Chaotic. Its spectrum is continuous, i.e. it is not cancelled for any frequency.

One of the fundamental properties of ferroresonance is the fact that multiple stable solutions can exist under steady-state solutions. Therefore, small variations in the parameter value of the electrical system or a transient event could cause a sudden jump between two different stable states and produce two of the most common ferroresonance modes: fundamental and subharmonic [11]. The parameters which determine the ferroresonance mode are the following: (i) the coupling capacitance which determines the natural frequency of oscillation; (ii) the amplitude of the voltage source; and (iii) the resistive losses of the core.

Procedure to compute the IVT damping reactor

The ferroresonance phenomenon can be suppressed by using either a damping resistor or a damping reactor. In several recent works a damping reactor has been used [1,2,12] instead of damping resistors [13–15], as a magnetic switch connecting a resistance in series to the IVT secondary winding. Under normal operation conditions, the damping reactor is seen from the system as a high impedance device in order to prevent power consumption. On the other hand, when a disturbance occurs in the system, the damping reactor reaches its saturate state earlier than the IVT; thus the series resistor is inserted to damp the ferroresonance [2,13,14]. Fig. 1 shows the damping reactor location. Note that this device is not installed in the primary side; otherwise it would have the same saturation characteristics of the IVT.

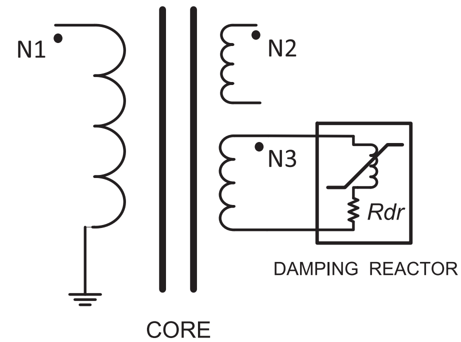

Fig. 1. The inductive voltage transformer with damping reactor.

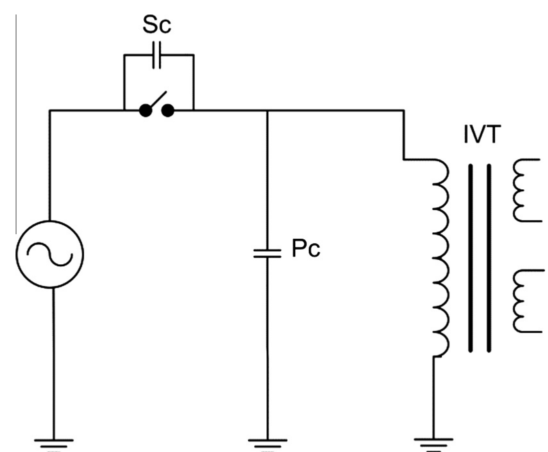

Fig. 2. Ferroresonant circuit.

An analytical calculation to obtain the damping reactor parameters which permit the damped out of the ferroresonance phenomenon registered in the REC substation, is reported in Appendix A based on the theory described in [16]. All possible topological configurations in the substation that could produce a ferroresonance phenomenon related to fundamental and subharmonic 3rd mode have been considered. The proposed ferroresonant circuit is shown in Fig. 2; it consists of a Series Capacitance (S_C), a Parallel Capacitance (P_C) and a saturable inductance provided by the IVT.

Based on this analysis, a damping reactor has been calculated with electrical parameters defined by a resistor R_{dr} with a linear resistance within the range of 0.11–0.15 ohms and a saturation voltage operating in the range of 76–162 V (see Fig. 1).

Event in electrical substation *Rio Escondido*

Substation Rio Escondido description

The Mexican electric power system is divided into nine regional transmission control areas; one of them, the Baja California Power System (BC-PS), is electrically isolated due to geographical reasons, and eight are electrically interconnected for improving reliability,