

Chapter 5

Ferroresonance in Power and Instrument Transformers

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ABSTRACT

This chapter describes the fundamental concepts of ferroresonance phenomenon and analyzes its symptoms and the consequences in transformers and power systems. Due to its nonlinear nature, the ferroresonance phenomenon can result in multiple oscillating modes which can be characterized based on the concepts of the nonlinear dynamic systems, e.g., Poincare map. Among numerous system configurations which can experience the phenomena, a few typical systems scenarios, which cover the majority of the observed ferroresonance incidents in power systems, are introduced. This chapter also classifies the ferroresonance study methods into the analytical and the time-domain simulation approaches. A set of analytical approaches are presented, and the corresponding fundamentals, assumptions, and limitations are discussed. Furthermore, key parameters for accurate digital time-domain simulation of the ferroresonance phenomenon are introduced, and the impact of transformer models and the iron core representations on the ferroresonance behavior of transformers is investigated. The chapter also presents some of the ferroresonance mitigation approaches in power and instrument transformers.

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INTRODUCTION

This chapter is organized to discuss several aspects of the ferroresonance phenomenon. The first part describes the basic ferroresonance concepts. Then the characteristics of known ferroresonance oscillation modes are introduced. The configurations that are vulnerable to the ferroresonance phenomenon are also discussed. Furthermore, some of analytical methods for the analysis of the ferroresonance phenomenon are presented. The time domain simulation approaches and the transformer core models are explained, and the last part of the chapter discusses the ferroresonance mitigation methods.

BACKGROUND

The term “ferroresonance” appeared in the technical paper by Boucherot (1920), to explain two possible operating conditions of the transformer core. Since then extensive experiments and research works have been devoted to describe the phenomenon, Iravani, et al. (2000). However, due to its highly nonlinear nature, the ferroresonance phenomenon has neither been well nor widely understood and still there exists misconceptions and unclear aspects of ferroresonance in the engineering community.

Ferroresonance is a special case of the resonance phenomenon, and can occur when a nonlinear inductance is connected in series or parallel with a capacitance. In a linear circuit, the resonance occurs when the capacitive reactance equals the inductive reactance at the circuit source frequency and can result in excessive currents and voltages. However, due to the inherent nonlinearity of the ferroresonance phenomenon, several steady state solutions may exist for a particular excitation condition and the range of circuit parameters. It is also possible that a system disturbance causes the circuit normal, steady-state operating condition to migrate to another stable operation point with

very high current and/or voltage magnitudes, i.e., ferroresonance operating point.

In the majority of ferroresonance cases, a series path including a saturable inductance and a capacitance is formed, and constitutes a series ferroresonance circuit. Another type of ferroresonance can occur during temporary power frequency overvoltage conditions. Under a normal three-phase operation, the magnetizing inductance of the transformer is in parallel with the system capacitance and if the transformer voltage is held below the saturation point, ferroresonance does not occur. However, during temporary power frequency overvoltage conditions, if the system voltage is not maintained below the core saturation point, the core is saturated and an exchange of energy between the system capacitance and the highly nonlinear magnetizing inductance of the transformer can occur. The rapid changes in core flux during this period can produce high overvoltages. Since in this case the reactance and capacitance are in parallel, this second type of ferroresonance is considered as parallel ferroresonance. An example of this type is the ferroresonance phenomenon of the inductive voltage transformer (VT) in an isolated neutral system.

Both types of ferroresonance can cause abnormal voltage (either low or high), across the transformer terminals and from terminals to ground. The high abnormal voltage due to ferroresonance is accompanied by abnormal transformer sound and, if sufficiently high, by equipment damage. The occurrence of both types of ferroresonance is often unpredictable as both depend on various parameters such as the cable length, the amount of system capacitance, the connection type and saturation characteristics of the transformers, and the amount of load or burden, Ferracci (1998). However, the occurrence of the phenomenon requires:

1. A non-linear inductance; which is the saturable iron core of the transformer or the reactor.

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