Electrical Power and Energy Systems 33 (2011) 1536–1541

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Analysis of lightning-caused ferroresonance in Capacitor Voltage Transformer (CVT)

A.H.A. Bakar [a,*], N.A. Rahim [a], M.K.M. Zambri [b]

[a] University of Malaya Power Energy Dedicated Advanced Center (UMPEDAC) Level 4 Block M, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka(UTeM) Hang Tuah Jaya 76100 Durian Tunggal

ARTICLE INFO

Article history:
Received 20 April 2010
Received in revised form 6 February 2011
Accepted 3 June 2011
Available online 5 August 2011

Keywords:
Lightning strike
Ferroresonance
Capacitor Voltage Transformer (CVT)
Ferroresonance suppression circuit (FSC)
Alternative Transient Program (ATP)
Basic Insulation Level (BIL)

ABSTRACT

Power networks contain capacitances and inductances that can saturate, presenting opportunities for ferroresonance to occur. Most power equipment is designed through linear theory but ferromagnetic materials are highly non-linear and when they resonate, the non-linearity produces currents and voltages that are larger than usual. Ferroresonance is a complex, non-linear electrical phenomenon. It can cause dielectric and thermal problems through overvoltage, an intrinsic phenomenon present in all networks. A network dynamic response to lightning and switching will be energy storage and release. The transfer of energy will propagate an overvoltage through the network and damage substation equipment when lightning strikes near the substation. Application of conventional mathematics is inappropriate to ferroresonance study in which actual events are simulated. Lightning strikes that occurred near a substation and that led to explosion of CVTs have been reported, so this study investigates the effect of a lightning strike on a tower with a 132 kV Capacitor Voltage Transformer (CVT). Alternative Transient Program (ATP) was used for the simulation which duplicated the lightning-strike effect that causes a CVT to explode.

1. Introduction

Capacitive voltage transformers are predominant sources of voltage signals for monitoring, protection and control applications at transmission level. High-speed protective relays are expected to make decisions based on signal produced by CVT, to preserve system stability and minimize damage to equipment. There have been recent reports in Malaysia on CVT failures and explosions at substations. They are:

(1) No output on the secondary side of the transformer.
(2) Hot spot on CVT main tank detected through thermo vision.
(3) CVT explosions.

Owing to energy stored in the capacitive, inductive and non-linear components of the CVT, under transient conditions the CVT may not follow closely its input waveform. A redistribution of the electric and the magnetic energies cannot occur instantly and the power system must go through a transient state before a new steady-state condition occurs.

Proper design of CVT components will ensure that under steady-state condition, the required output duplicates the input. During transients, CVT's energy-storage element and magnetic-saturation non-linearity however causes its output waveform to deviate from its input waveform. CVT ferroresonance during transients may cause thermal overstress, consequently deteriorating CVT components through over-voltage.

Application of conventional mathematics is not appropriate in studying ferroresonance [1] because analysis of the characteristic forced non-linear differential equations results in considerably complex algebraic equations. A ferroresonance study simulates actual events.

This paper investigates the effect of lightning on a 132 kV tower near the substation where several CVT explosions had been reported. Over-voltages induced in the phase conductor caused by strikes close to ground may happen too but they generally are below 200 kV and matter only to lower voltage systems. In Malaysia the minimum transmission voltage is 132 kV and its minimum BIL is 650 kV.

Owing to this and also to Malaysia's lightning current being typically more than 20 kA (up to the maximum 200 kA) the simulation thus investigates the actual CVT explosions that had occurred at the substation due to lightning.

2. Lightning strike and ferroresonance

2.1. Lightning strike

Peninsular Malaysia experiences frequent lightning strikes, regarded to be among the highest in the world with thunder-days averaging 200 according to the Malaysian Meteorological Department. Lightning occurrences vary with month, occurring frequently from April to June, and less so from December to

* Corresponding author.
E-mail address: halim5389@gmail.com (A.H.A. Bakar).

0142-0615/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijepes.2011.06.004