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ScienceDirect

Energy Procedia 134 (2017) 616–625

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Conference on Sustainability in Energy and Buildings, SEB-17, 5-7 July 2017, Chania, Crete, Greece

Design and modelling techniques of permanent magnet fault current limiter

Asmaiel Ramadan*, Faris Alnaemi

Department of Engineering and Mtahematics, Sheffield Hallam University, Sheaf Street, Sheffield , S1 1WB, UK.

Abstract

The design approach of the permanent magnet fault current limiter (PMFCL) was investigated. The result of recent published model was assessed using 3D FEM solvers and the discrepancy in the results was evaluated. A new design method for the PMFCL based on the inductance-current profile is presented. The new design method is more accurate than the classical analytical design methods in determining operating current range at steady state and fault conditions. The transient 3D FEM solver was used to model the dynamic response of a PMFCL design and the results have been compared with an air-cored fault current limiter of similar specifications.

Peer-review under responsibility of KES International.

Keywords: Permanent Magnet; fault current limiter; magnetic circuit; FEM modelling; electric power

1. Introduction

Renewable energy is becoming the most important technology for electrical power generation. The integration of more renewable energy resources to the electrical distribution systems impose a lot of technical challenges, among these are the continual increasing level of short circuit current. Classically, when a fault takes place, the short circuit current is over eight times that of the load current. The high short circuit current rapidly increases the high mechanical and thermal stress on the equipment [1]. Fault current reduction permits the interconnection of large networks without replacing the infrastructure, improves transient system stability, and reduces the cost of apparatus [2]. Fault Current Limiter based on permanent magnet biased Saturation (PMFCL) has recently been paid attention by a lot of researchers and scientists [3-5].

* Corresponding author.
E-mail address: uberardi@ryerson.ca

Peer-review under responsibility of KES International.
10.1016/j.egypro.2017.09.572

According to the results of published research, the major design parameter is the optimum biasing capability of the permanent magnet [6]. This paper review the techniques used in design and analysis of the PMFCL, the previously reported results will be verified against more comprehensive design approach using 3D nonlinear FEM design tool. The PMFCL chosen for this paper is the configuration reported in [4, 5].

Nomenclature

A	*Magnetic vector potential.*
B	*Magnetic flux density, Tesla (T)*
B_r	*Remanence, Tesla (T).*
e	*core.*
H	*Magnetic field intensity, Amber/meter (A/M)*
H_c	*Coercivety, Amber/meter (A/M).*
J	*Current density, Amber/meter (A/M).*
L	*Inductance (Henry).*
l	Length, meter (m)
M	*Magnetization vector*
m	*Magnet*
N	*No of turns*
R	*Magnetic Reluctance, Ampere/weber(A Wb^{-1})*
r	*Resistance (ohm)*
r_{si}	*Saturated core reluctance Ampere/weber (A Wb^{-1}).*
r_{ui}	*Core unsaturated reluctance, Ampere/weber (A Wb^{-1}).*
S	*Cross sectional area, square meter (m^2)*
S_c	*Coil cross sectional area (m^2)*
FEM	*Finite Element Method*
PMFCL	*Permanent magnet fault current limiter*
$Ø$	*Magnetic flux, Weber (Wb)*
μ_m	*Magnet permeability, Wb/(A m).*
μ_s	*Core permeability, Wb/(A m)*
λ	*Flux linkage (Weber).*

The model under consideration is going to study and investigate the PMFCL previous published results in [4] by means of 3-D MagNet FEM. In this work the magneto static flux density based on the model magnetic circuit equations was calculated and compared with the 2-D and 3-D magneto static at the case when no current is flowing in the limiter coils. Then, the steady state 2-D and 3-D current/ inductance is evaluated to determine the device behavior with increased load current and to predict the transient capability at the instant of a fault. Finally, the results from time step dynamic model coupled to the electrical circuit is presented to verify the previously published results and highlighting the realistic reasons for discrepancies.

1.1. Principle of operation

The PMFCL model consists of rare earth permanent magnets poles as a source of providing the magnetic flux essential to saturate the magnetic cores, the limiter coils carrying the ac supply current and two iron-cores as shown in Fig. 1. The utilization of two core configuration permits the core to act should the fault currents occur in the positive or negative half cycle of ac excitation. The PMFCL behaves, in normal operation, similar to an air-cored reactor with a low inductance due to saturation. While during the fault condition either of the cores comes out of saturation and thus inherently rushed to a high inductance state that immediately limits the high short circuit current.