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Permanent magnet fault current limiter for the power grid

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Abstract

With several significant advantages such as compactness, reliability, zero reset time, safe operation and fail safe, the permanent magnet fault current limiter (PMFCL) is a preferable solution to mitigate the fault current in power grids these years.
In this paper, the substation voltage level PMFCL device, aims to extend the capacity of the power grid, is presented. The dry type PMFCL that does not require DC excitation coils is designed and simulated by 3D FEM. The 3D FEM magneto static solver has been used as time saving approach to predict the device fault current limitation in case of a fault. The peak transient currents simulation results were in agreement with the RMS values obtained using the magneto static inductance-current profile. The effect of the PMFCL on the fault current mitigation has been compared with an air-cored of similar specifications and a useful reduction in the fault current has been achieved.

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Keywords: PMFCL, power grid, modelling results.

1. Introduction

As the application of renewable sources of electrical energy is fast growing, the power grid keeps expanding. Hence the ever increasing short circuit current is persistently becoming more severe, which endangers the reliability and stability of the power system operation [1]. Many means of limiting fault currents have been suggested in the past including upgrading fast circuit breakers, system reconfiguration, installing transformers with higher impedance, current limiting fuses, air-core reactors, etc. [2]-[5]. However, those methods were not satisfactory due to high estimated costs, lack of system security and reliability. A fault current limiter (FCL) is a changeable impedance device connected in series with a circuit breaker and has insignificant influence on the power system under normal conditions, but can limit the current within a predefined value during a transient condition.

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There are up to date approaches to limit the fault current such as the introduction of superconductors fault current limiters and solid state fault current limiters but they still fall behind in addressing one or more of the following concerns such as the running cost, installation cost, maintenance cost and reliability. Thus, it is very necessary to develop a preferable current limiting devise to reduce the rating of each element required, to lower the capital cost, thereby improving protection coordination [6]. With the recent advance in magnetic materials as well as geometry design research, permanent magnet fault current limiter (PMFCL) has recently attracted the interests of many researcher and scientists [2]-[5]. In this paper, a square shape topology, 11KV substation dry type PMFCL model is designed and simulated by 3DMagNet FEM. The modelling of the whole model is not suitable for engineering applications as it takes a long period of time to obtain the required results. As the model is quite large, only a quarter of it was simulated using 3D FEM magneto static and time-step solvers.

The device can be installed at the high voltage side of a 10MVA, step down transformer or at the low voltage side of any step up transformer of the same size such as 11/66 kV or 11/220 kV,…etc.

Nomenclature	
A	*Magnetic vector potential*
B	*Magnetic flux density (Tesla (T))*
e	*core*
H	*Magnetic field intensity (Amber/meter (A/m))*
J	*Current density (Amber/meter (A/m))*
L	*Inductance (Henry).*
M	*Magnetization vector*
m	*Magnet*
N	*No of turns*
n	*No of turns per unit length*
R	*Magnetic Reluctance (Ampere/weber(A Wb^{-1}))*
AC	*Alternating current*
A_e	*Core cross sectional area (m^2)*
A_m	*Magnet cross sectional area (m^2)*
B_r	*Remanence (Tesla (T))*
H_c	*Coercivity (Ampere/meter (A/m))*
DC	*Direct current*
kV	*Kilovolt*
vc	*Coil volume (m^3)*
FEM	*Finite Element Method*
mmf	*Magneto motive force (Ampere turn(AT))*
IF	*Fault current (Ampere (A))*
PMFCL	*Permanent magnet fault current limiter*
RMS	*Root mean square*
S_c	*Coil cross sectional area (m^2)*
λ	*Flux linkage (Weber).*
Ø	*Magnetic flux (Weber)*
μ_m	*Magnet permeability (Wb/(A m))*
ω	*Angular frequency (Rad/sec)*

2. Topology and operating principle

The 3.3m square shape model design, as shown in Fig. 1, incorporated four L shaped Neodymium Iron Boron magnets (PM), two grain oriented M4 electrical steel cores placed between the magnets, and copper coils wound around the two cores. The magnets are positioned in the corner between the two cores and they are placed in alternate polarity such that each two opposite magnets are magnetized in the same direction. The model parameters