AC/DC/AC Grid Equivalent Model for Geomagnetic Storm-Induced Unbalanced Harmonic Studies

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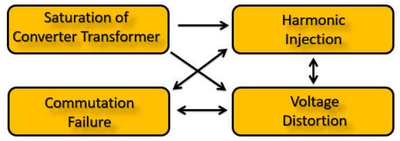
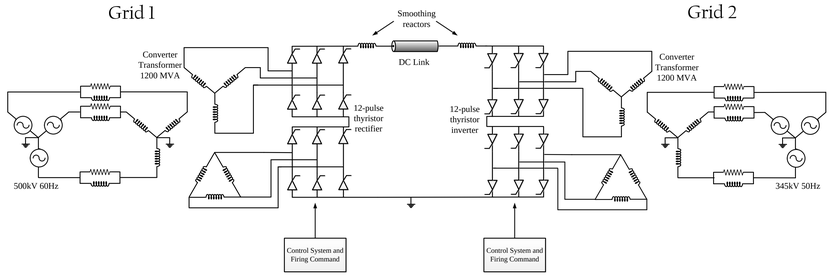
Introduction

Geomagnetic Disturbance (GMD) is a natural phenomenon initiated by solar activity. Solar coronal holes and coronal mass ejections (CMEs) are the two main categories of solar activity that drive solar magnetic disturbances on the Earth.

Possible Impacts on HVDC system

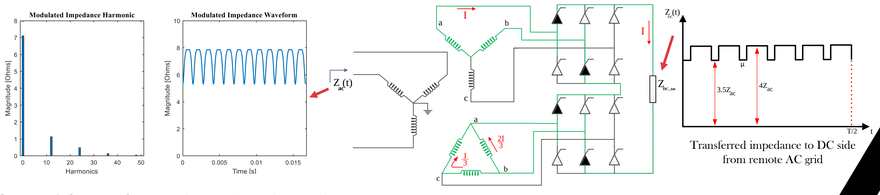


- Aim of this part of whole project is to introduce a novel numerical impedance model to represent HVDC system reaction for all harmonic components from disturbances. Accurate calculation has been provided to obtain time-variant transferred impedance by modulation process of 12-pulse bridge converters behind converter transformer. This model depends on converter and grid parameters and enables to analyze whole system without required further calculations in HVDC side. Impact of commutation overlap angle has been explained thoroughly in this work.
- Complete HVDC grid model simulated in EMTP including DC transmission link using 12-pulse thyristor converters between two AC systems operating at 50 and 60 Hz with voltage rating of 345kV and 500kV has been used to evaluate the impedance model proposed in this work.



Proposed Equivalent Model

In this study, remote AC side impedance has been reflected to DC side. And then, by using switching functions as representative of converter switching operation, reflected current has been obtained. Iterative optimization algorithm has been used to get time-variant impedance seen on the local AC side.



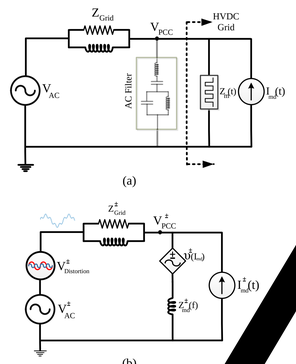
General form of Impedance Fourier series:

$$Z_m(t) = Z_0 + \sum_{n=1}^{\infty} Z_{12n}\cos(12n\omega t + \theta_{12n})$$

Figure in right shows the proposed equivalent circuit:

(a) General equivalent model of Grid on AC side including HVDC grid model;

(b) positive, negative sequence equivalent model of unbalanced and/or distorted grid.



Research Objective

★ Comprehensive study of influence of GMD on power system, and evaluation of existing challenges in forecasting, modeling, and risk assessment of key components of power grid.

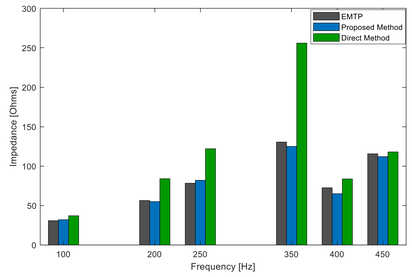
★ Investigation on geographical features, especially latitude and coastlines, and power system structure of New England, and their impact on HVDC grid.

★ Clarifying potential factors affecting HVAC power system which have deteriorating impact on one of HVDC systems planned by Eversource.

★ Identifying practical mitigating methods for avoiding or reducing entrance of GICs into the New England HVDC power grid.

Study Results

Proposed numerical equivalent time-variant impedance model has been defined in MATLAB to calculate the reflected harmonic components on AC and DC sides. To demonstrate the performance of this model, frequency dependent part of impedance in this model has been compared with direct impedance method introduced in [1]. This direct method has been used already for resonance phenomenon studies during geomagnetic storm in specific Quebec-New England grid. Effectiveness of proposed model has been demonstrated for the case of multiple injected harmonics which happens due to transformer half cycle saturation during geomagnetic storm. Figure shows reflected impedance values for worse case when positive and negative sequence of voltage harmonics ($4^{th+}, 7^{th+}, 9^{th+}, 2^{th-}, 5^{th-}, 7^{th-}$) with magnitude of 1 percent of fundamental voltage are applied simultaneously to the AC grid.



In the following Table, values of reflected voltage and current obtained from EMTP and proposed model have been given for injected unsymmetrical second harmonic as follows:

$V_a^1 = 500\angle 0$ $\quad V_b^1 = 500\angle -120$ $\quad V_c^1 = 500\angle +120$

$V_a^2 = 25\angle 0$ $\quad V_b^2 = 25\angle -150$ $\quad V_c^2 = 25\angle +150$

Harmonic order (60Hz fund.)	DC Voltage ($\frac{V_n}{V_1} * 100$)		Harmonic order (60Hz fund.)	AC Current ($\frac{I_n}{I_1} * 100$)	
	Simulated Grid(EMTP)	Proposed model(Matlab)		Simulated Grid(EMTP)	Proposed model(Matlab)
0	100	100	0	1.8	1.6
1	2.65	2.5	1	100	100
3	1	0.7	2	1.9	1.7
12	2.3	2	11	6	5.6
24	2.7	2.4	13	4.4	4.1
			23	0.7	0.5
			25	0.5	0.3

Highlighted Outcome

The major contribution of this work centers on achieving appropriate presentation HVDC system on AC side to facilitate disturbance analysis while saturation of transformers during geomagnetic storms. Implemented complete models for HVAC and HVDC models in EMTP along with numerical technique developed in MATLAB –to obtain equivalent impedance of HVDC system and remote end AC system – represent how interconnected system with its non-linear behavior reacts to wide range of harmonics. This toolbox will be used for designing and evaluating performance of different proposed filters to mitigate induced currents and harmonics generated from saturated transformers to avoid disturbance intervention from AC grid to normal operation of HVDC system by considering specific grid data planned and by Eversource.

References

[1] D. L. Dickmander, and et. al, "AC/DC harmonic interactions in the presence of GIC for the Quebec - New England Phase II HVDC transmission“ , IEEE Transactions on Power Delivery, vol. 9, no. 1, pp. 68-78, Jan. 1994.

[2] Randy Horton, and et al,“A Test Case for the Calculation of Geomagnetically Induced Currents”, IEEE Transactions on Power Delivery, OCT. 2012.