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Grounding Fault Model of LVDCSUS for Analyzing the System Grounding Fault Characteristics

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Introduction

An low voltage direct current supply and utilization system(LVDCSUS) grounding fault model is proposed for analyzing the grounding fault characteristics of the system in a fault condition. The derived grounding fault model has the following features:

(1) The variation of system state parameters under various fault conditions is simple to acquired by inputting the system state data in the normal condition.

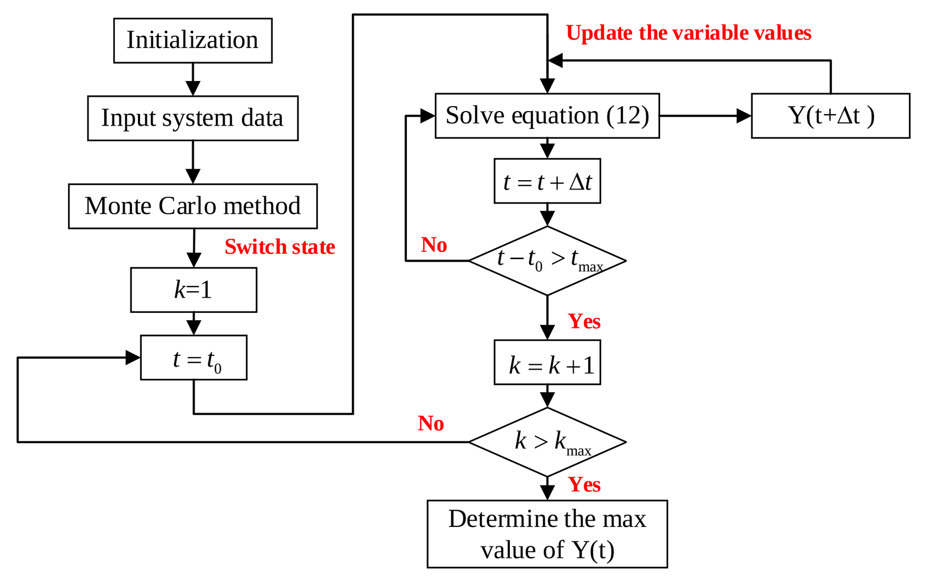
(2) Compared with traditional models, the impact of switch state on the topology of the fault circuit is considered in this grounding fault model.

(3) The maximum system fault current with different grounding resistance is easy to calculate based on the grounding fault model.

Flowchart of the model solution algorithm

The Fourth-order Runge-Kutta method is utilized to obtain the accurate value

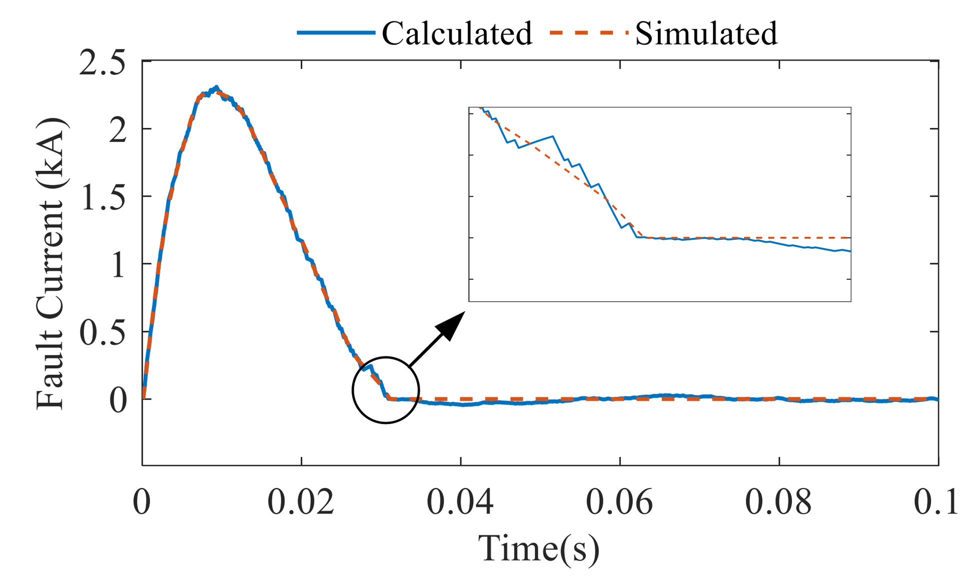
The Monte Carlo method is utilized to simulate the switching state to estimate the maximum fault current.

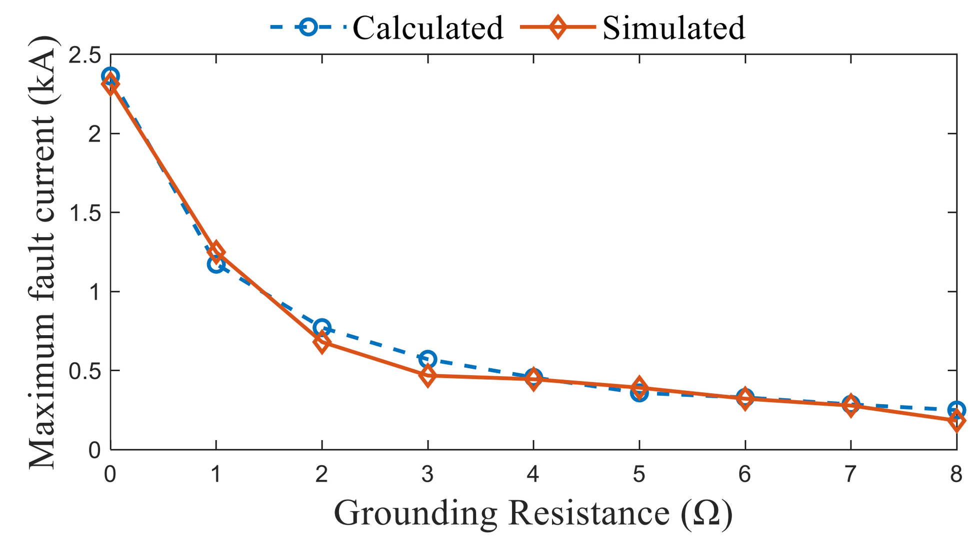


Results

As numerical results illustrate, the system grounding fault feature can be easily acquired by solving the proposed grounding fault model with a piece of code with a low computational burden. Additionally, the calculated result can offer theoretical guidance for improving the system transient stability. For instance, online adjustment of the converter switch state according to the calculated fault current is a reasonable remedy in fault condition to protect the system.

Fault current waveforms in case of single-line to ground fault

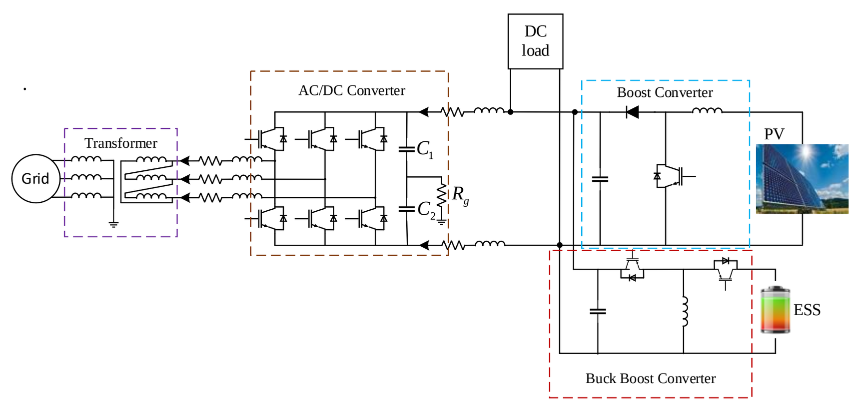




Maximum fault current under the single-line to the ground fault condition.

Case Study

Simulation time of the proposed system grounding fault model elapsed 0.03s under the AC ground fault condition and 0.1s under the DC ground fault condition, respectively. Additionally, a simulation is carried out in PSCAD/EMTDC in order to verify the effectiveness of the LVDCSUS grounding fault model.



Schematic Diagram of the LVDCSUS. On the AC side, the AC transformer neutral point earthing is selected in this system. Additionally, with the aim of realizing galvanic separation, the Y/Δ arrangement of the three-phase transformer, with the Δ-connection on the converter-side, is utilized to excludes the zero-sequence and system leakage current

$$A_0X(t)=B_0\frac{dY(t)}{dt}+C_0Y(t)$$

$$A_0=\begin{bmatrix}\alpha_1-\alpha_2 & -1 & 0\\ \alpha_3-\alpha_4 & 0 & -1\\ 0 & 0 & 0\end{bmatrix}\qquad \alpha_1=\frac{(S_1-S_3)}{2},\alpha_2=\frac{(S_2-S_4)}{2}$$

$$B_0=\begin{bmatrix}L_a & -L_b & 0\\ 0 & L_b & -L_c\\ 1 & 1 & 1\end{bmatrix}\qquad \alpha_3=\frac{(S_3-S_5)}{2},\alpha_4=\frac{(S_4-S_6)}{2}$$

$$\boldsymbol{S}=[S_1,S_2,S_3,S_4,S_5,S_6]^T$$

$$C_0=\begin{bmatrix}R_a & -R_b & 0\\ 0 & R_b & -R_c\\ 0 & 0 & 0\end{bmatrix}\qquad \begin{matrix}S_1+S_2=1,\ S_3+S_4=1,\ S_5+S_6=1\\ S_1+S_3+S_5\ge 1,\ S_2+S_4+S_6\ge 1\end{matrix}$$

The state-space model of LVDCSUS in normal condition.

According to the state-space equation, the system states in the normal condition can be derived once the switching state is given.

$$A_\varphi X(t)+D_\varphi\frac{dX(t)}{dt}=B_\varphi\frac{dY(t)}{dt}+C_\varphi Y(t)$$

Single-line to ground fault

$$A_\varphi=\begin{bmatrix}0 & -1 & 0\\ 0 & 0 & -1\\ 0 & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\\ 1 & 0 & 0\\ 0 & 0 & 0\end{bmatrix}$$

$$B_\varphi=\begin{bmatrix}L_a & -L_b & 0 & -L_a & 0 & 0 & 0\\ 0 & L_b & -L_c & 0 & 0 & 0 & 0\\ 1 & 1 & 1 & 0 & 0 & 0 & 0\\ L_a & 0 & 0 & -L_a & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & -C & C & 0\\ h_aL_{dc} & h_bL_{dc} & h_cL_{dc} & -(h_a+1)L_{dc} & 0 & 0 & 2L_{dc}\\ 0 & 0 & 0 & 0 & -C & 0 & 0\end{bmatrix}$$

$$C_\varphi=\begin{bmatrix}R_a & -R_b & 0 & -R_a & -2\alpha_1 & 2\alpha_2 & 0\\ 0 & R_b & -R_c & 0 & -2\alpha_3 & 2\alpha_4 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0\\ R_a & 0 & 0 & -(R_{fa}+R_g+R_a) & -S_1 & S_2 & 0\\ 0 & 0 & 0 & 1 & 0 & 0 & 0\\ h_aR_{dc} & h_bR_{dc} & h_cR_{dc} & -(h_a+1)R_{dc} & 1 & 1 & 2R_{dc}\\ 0 & 0 & 0 & 0 & 0 & 0 & 1\end{bmatrix}$$

$$D_\varphi=[0]$$

Double-line to ground fault

$$A_\varphi=\begin{bmatrix}0 & -\left(1+\frac{2R_b}{R_{ab}}\right) & 0\\ 0 & \frac{R_b}{R_{ab}} & -1\\ 0 & 0 & 0\\ 0 & \frac{R_b}{R_{ab}} & 0\\ 0 & 0 & 0\\ 1 & -(h_a-h_b)\frac{R_{dc}}{R_{ab}} & 0\\ 0 & 0 & 0\end{bmatrix}$$

$$B_\varphi=\begin{bmatrix}L_a & -L_b & 0 & L_b & 0 & 0 & 0\\ 0 & L_b & -L_c & -L_b & 0 & 0 & 0\\ 1 & 1 & 1 & 0 & 0 & 0 & 0\\ 0 & L_b & 0 & -L_b & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & -C & C & 0\\ h_aL_{dc} & h_bL_{dc} & h_cL_{dc} & -(h_b+1)L_c & 0 & 0 & 2L_{dc}\\ 0 & 0 & 0 & 0 & -C & 0 & 0\end{bmatrix}$$

$$C_\varphi=\begin{bmatrix}R_a & -R_b & 0 & R_b & -2\alpha_1 & 2\alpha_2 & 0\\ 0 & R_b & -R_c & -R_b & -2\alpha_3 & 2\alpha_4 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & R_b & 0 & -(R_{fb}+R_g+R_b) & -S_3 & S_4 & 0\\ 0 & 0 & 0 & 1 & 0 & 0 & 0\\ h_aR_{dc} & h_bR_{dc} & h_cR_{dc} & -(h_b+1)R_{dc} & 1 & 1 & 2R_{dc}\\ 0 & 0 & 0 & 0 & 0 & 0 & 1\end{bmatrix}$$

$$D_\varphi=\begin{bmatrix}0 & \frac{-2L_b}{R_{ab}} & 0\\ 0 & \frac{L_b}{R_{ab}} & 0\\ 0 & 0 & 0\\ 0 & \frac{L_b}{R_{ab}} & 0\\ 0 & 0 & 0\\ 0 & -(h_a-h_b)\frac{L_{dc}}{R_{ab}} & 0\\ 0 & 0 & 0\end{bmatrix}$$

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DC ground fault

$$A_\varphi=\begin{bmatrix}0 & -1 & 0\\ 0 & 0 & -1\\ 0 & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\\ 1 & 0 & 0\\ 0 & 0 & 0\end{bmatrix}$$

$$B_\varphi=\begin{bmatrix}L_a & -L_b & 0 & 0 & 0 & 0 & 0\\ 0 & L_b & -L_c & 0 & 0 & 0 & 0\\ 1 & 1 & 1 & 0 & 0 & 0 & 0\\ S_1L_{dc} & S_3L_{dc} & S_5L_{dc} & 0 & 0 & 0 & L_{dc}\\ 0 & 0 & 0 & 0 & -C & C & 0\\ h_aL_{dc} & h_bL_{dc} & h_cL_{dc} & -L_{dc} & 0 & 0 & 2L_{dc}\\ 0 & 0 & 0 & 0 & -C & 0 & 0\end{bmatrix}$$

$$C_\varphi=\begin{bmatrix}R_a & -R_b & 0 & 0 & -2\alpha_1 & 2\alpha_2 & 0\\ 0 & R_b & -R_c & 0 & -2\alpha_3 & 2\alpha_4 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0\\ S_1R_{dc} & S_3R_{dc} & S_5R_{dc} & (R_{fp}+R_g+R_{dc}) & 1 & 0 & R_{dc}\\ 0 & 0 & 0 & 1 & 0 & 0 & 0\\ h_aR_{dc} & h_bR_{dc} & h_cR_{dc} & -R_{dc} & 1 & 1 & 2R_{dc}\\ 0 & 0 & 0 & 0 & 0 & 0 & 1\end{bmatrix}$$

$$D_\varphi=[0]$$

Grounding Fault Model of LVDCSUS

Three-line to ground fault

$$A_\varphi=\begin{bmatrix}0 & -\left(1+\frac{2R_b}{R_{ab}}\right) & \frac{R_c}{R_{bc}}\\ 0 & \frac{R_b}{R_{ab}} & -\left(1+2\frac{R_c}{R_{bc}}\right)\\ 0 & 0 & 0\\ 0 & 0 & \frac{R_c}{R_{bc}}\\ 0 & 0 & 0\\ 1 & -(h_a-h_b)\frac{R_{dc}}{R_{ab}} & -(h_b-h_c)\frac{R_{dc}}{R_{bc}}\\ 0 & 0 & 0\end{bmatrix}$$

$$B_\varphi=\begin{bmatrix}L_a & -L_b & 0 & 0 & 0 & 0 & 0\\ 0 & L_b & -L_c & L_c & 0 & 0 & 0\\ 1 & 1 & 1 & 0 & 0 & 0 & 0\\ 0 & 0 & L_c & -L_c & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & -C & C & 0\\ h_aL_{dc} & h_bL_{dc} & h_cL_{dc} & -(h_c+1)L_{dc} & 0 & 0 & 2L_{dc}\\ 0 & 0 & 0 & 0 & -C & 0 & 0\end{bmatrix}$$

$$C_\varphi=\begin{bmatrix}R_a & -R_b & 0 & 0 & -2\alpha_1 & 2\alpha_2 & 0\\ 0 & R_b & -R_c & R_c & -2\alpha_3 & 2\alpha_4 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & R_b & 0 & -(R_{fc}+R_g+R_c) & -S_5 & S_6 & 0\\ 0 & 0 & 0 & 1 & 0 & 0 & 0\\ h_aR_{dc} & h_bR_{dc} & h_cR_{dc} & -(h_c+1)R_{dc} & 1 & 1 & 2R_{dc}\\ 0 & 0 & 0 & 0 & 0 & 0 & 1\end{bmatrix}$$

$$D_\varphi=\begin{bmatrix}0 & \frac{-2L_b}{R_{ab}} & \frac{L_c}{R_{bc}}\\ 0 & \frac{L_b}{R_{ab}} & \frac{-2L_c}{R_{bc}}\\ 0 & 0 & 0\\ 0 & 0 & \frac{L_c}{R_{bc}}\\ 0 & 0 & 0\\ 0 & -(h_a-h_b)\frac{L_{dc}}{R_{ab}} & -(h_b-h_c)\frac{L_{dc}}{R_{bc}}\\ 0 & 0 & 0\end{bmatrix}$$

Grounding Fault Model of LVDCSUS

Conclusions

The system grounding fault model can provide the basis for the study on the variation of system state parameters in various grounding fault conditions to improve the transient stability of the system with the occurrence of grounding fault. The fault characteristic of the system can be obtained as long as the system state variables can be accurately calculated. The proposed model is only suitable for the system with the IT-AC and the neutral earthing on the DC side, the grounding fault model about other grounding structure should be more discussed and studied as future work.

References

1. Sun, K., Xiao H., Pan J. and Liu Y. VSC-HVDC Interties for Urban Power Grid Enhancement.
2. Sun K. et al. Operation Modes and Combination Control for Urban Multi voltage-Level DC Grid.