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Fast Equivalent Modeling of Cascaded Static Synchronous Compensator Under Higher Voltage

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Abstract: Cascaded STATCOM including huge number of sub-modules under higher voltage needs rapid modeling to analyze efficiently. This paper presents a discrete iterative algorithm based on equivalent modeling method, which can greatly simplify mathematical model of STATCOM under higher voltage. According to the mathematical properties of the sub-module DC capacitor, it is equivalent to a historical series branch voltage source with an equivalent resistance. By simplifying IGBT to equivalent variable resistor, H-bridge is simplified to an equivalent branch with PWMs. Control system can calculate each IGBT PWM pulse signal by embedding to the equivalent electric circuit. Created an iterative calculation algorithm for the equivalent circuit, and evaluated the two basic errors that are algorithm error and parameter error. By comparing ±100MVar STATCOM's waves between field data and simulation data, it is proved correct that the rapid equivalent modeling method. In-depth comparison of the key parameters of the theory and simulation instructions, it is very close between the theory and the practice, and methods can greatly simplify the analysis and simulation calculations.

1. Introduction

The cascaded STATCOM contains a large number of power modules, so the mathematical model is very complex and the simulation speed is extremely slow [1]-[3]. Therefore, for the characteristics of cascaded STATCOM with large-capacity, fast equivalent modeling is needed. A series of studies have been carried out in terms of equivalent modeling at home and abroad. As in the literatures [4]-[6], the matrix simplification method is used to study the rapid modeling of the H-bridge sub-module, the half-bridge sub-module and the clamped double sub-module of the flexible HVDC transmission system. The traditional module experiment is testing modules one by one. Obviously, that test is insufficient, especially in the distributed new energy field including thousands of photovoltaic converters and wind power converters consisting of H-bridges.

In this paper, the high-speed equivalent model of high-voltage STATCOM is constructed by discretization iterative method for the actual characteristics and requirements of cascaded STATCOM, and the comparison of the original model and equivalent model is present. Through the comparison of experimental and simulation data, the modeling method of this paper is in line with engineering practice. The comparison between the calculation error and the calculation time before and after the equivalent is used to illustrate the rapidity and accuracy of the modeling method.

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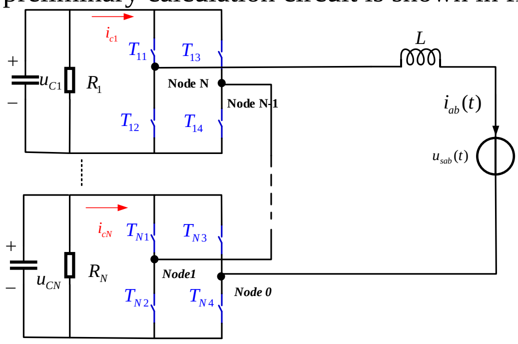
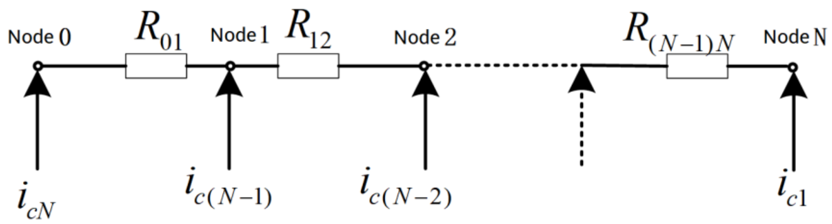
2. PRINCIPLE OF ELECTROMAGNETIC TRANSIENT QUICK EQUIVALENT MODELING.

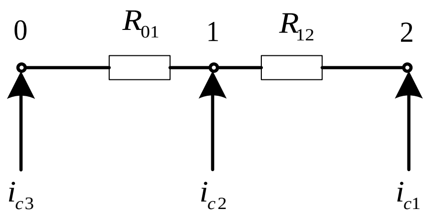
Take AB converter chain as an example to illustrate the algorithm in the electromagnetic transient simulation tool. First of all, the converter chain is equivalent to the chain circuit of switches, capacitors, resistors, etc. The preliminary calculation circuit is shown in figure 1 (a)and(b).



(a) the preliminary calculation circuit in the electromagnetic transient simulation tool



(b) Standard circuit in electromagnetic transient simulation tool



(c) A standard circuit with three nodes as an example

Fig.1 Calculation Method of EMTP Simulation Tools

FIG. 1(c) illustrates the principle by taking the three-node point network as an example. If the injection current of each node is,, and, and the resistance between nodes is and, it is easy to write the voltage equation of its nodes as

$$\begin{bmatrix} i_{c3} \\ i_{c2} \\ i_{c1} \end{bmatrix} = \begin{bmatrix} 1/R_{01} & -1/R_{01} & 0 \\ -1/R_{01} & 1/R_{01}+1/R_{12} & -1/R_{12} \\ 0 & -1/R_{12} & 1/R_{12} \end{bmatrix} \begin{bmatrix} u_0 \\ u_1 \\ u_2 \end{bmatrix} \qquad (1)$$

The method proposed in this paper is to treat the converter chain as a cascade circuit as shown in figure 2. The voltage of each node is related to the resistance, current, current and independent voltage source voltage, and the calculation process of each power module is independent of each other.

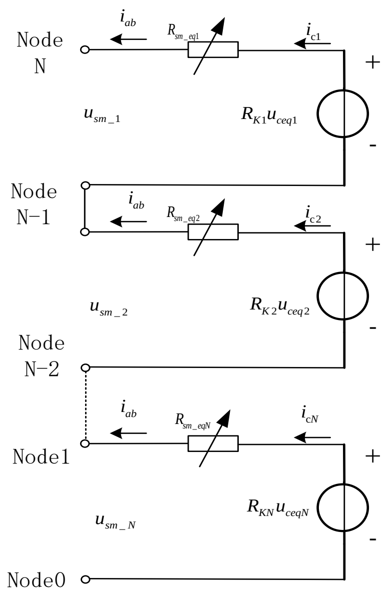


Fig.2 Equivalent circuit of the Proposal Fast Modeling Method

Since the calculation of each module is independent, if the expression of,,, and for the JTH module is used, then the voltage at each node of the converter chain can be solved without the whole network inverse. For a single module, the computational complexity of the above 5 expressions is O(5), and the computational complexity of N modules is O(5*N*). Therefore, when the number of power modules is large, the fast model can realize simulation acceleration.

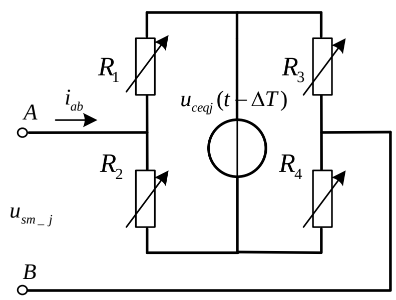
The iterative formula of the capacitor voltage is

$$\begin{aligned} u_{cj}(t) &= \frac{\Delta T}{2C_0} i_{cj}(t) + [\frac{\Delta T}{2C_0} i_{cj}(t-\Delta T) + u_{cj}(t-\Delta T)] \\ &= R_c i_{cj}(t) + u_{ceqj}(t-\Delta T) \end{aligned} \quad (2)$$

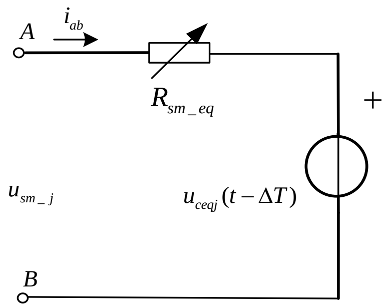
Among them

$$u_{ceqj}(t) = \frac{\Delta T}{2C_0} i_c(t-\Delta T) + u_c(t-\Delta T) \quad (3)$$

Therefore the circuit can be equivalent to Figure 3, and the operating status of CASCADED STATCOM is shown in table 1.



(a) PRELIMINARY SIMPLIFICATION OF THE MODEL



(b) AND FINALLY SIMPLIFY THE MODEL

Fig.3 Equivalent Circuit of H-bridge Module

TAB1 MODULE PARAMETERS OF CASCADED STATCOM

Status	T_1	T_2	T_3	T_4	u_{sm}
Normal	1	0	0	1	u_c
	1	0	1	0	0
	0	1	0	1	0
	0	1	1	0	$-u_c$
Fault	-	-	-	-	0

Here,

$$u_{sm\_j}(t) = R_{sm\_eqj} i_{ab}(t) + R_{Kj} u_{ceqj}(t-\Delta T) \qquad (4)$$

Among them

$$R_{sm\_eqj} = \frac{R_1R_2(R_c+R_3+R_4)+R_1R_cR_4}{(R_1+R_2)(R_3+R_4)+R_c(R_1+R_2+R_3+R_4)} + \frac{R_3R_4(R_1+R_2+R_c)+R_3R_cR_2}{(R_1+R_2)(R_3+R_4)+R_c(R_1+R_2+R_3+R_4)}$$

$$R_{Kj} = \frac{R_3R_2-R_1R_4}{(R_1+R_2)(R_3+R_4)+R_c(R_1+R_2+R_3+R_4)}$$

$$i_{cj}(t) = \frac{(R_2R_3-R_4R_1)\cdot i_{ab}(t) - \sum_{i=1}^{4} R_i \cdot u_{ceq}(t-\Delta T)}{(R_1+R_2)(R_3+R_4)+R_c(R_1+R_2+R_3+R_4)}$$

According to literature [13], the control block diagram of high-power chain STATCOM is shown in FIG. 4. The current instruction of the converter chain is i^*_{abq} , i^*_{bcq} , i^*_{caq} , and the dc voltage instruction of the converter chain is. u^*_{dc} , u_{cab} 、 u_{cbc} 、 u_{cca} is the average value of each power module of the three-phase converter chain. m_i ($i=1,2,\cdots,3N$) is the modulation wave of each module calculated by the controller.

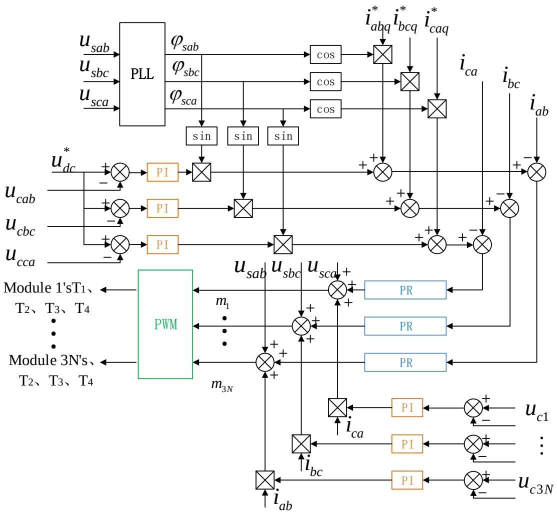


Fig.4 Control Graph of cascaded STATCOM r

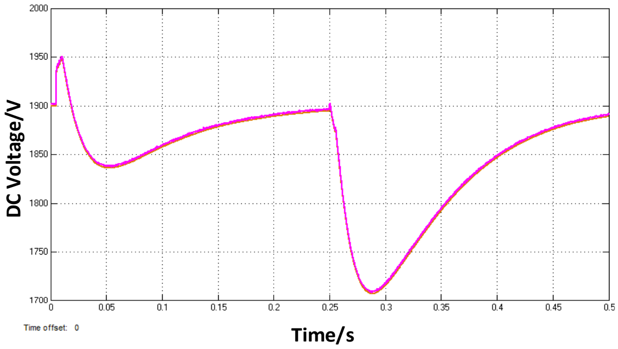
3. THE SIMULATION VERIFICATION

Compare with Simulink simulation. The basic parameters of the device in this paper are shown in Table 2, which is the appendix for the simulation model.

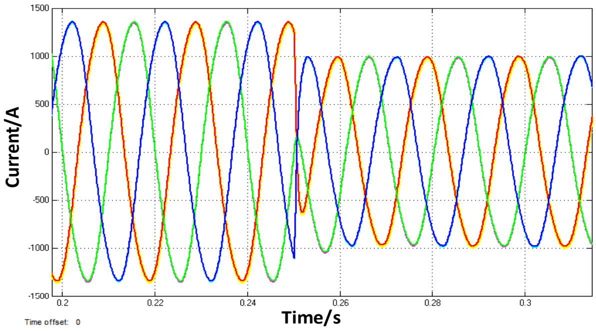
TAB2 MAIN PARAMETERS IN THIS PAPER

Parameters	Sign	Value/Unit
Simulation Time	T	0.5s
Module Number	N	40
Inductance	L	7mH
Angle Frequency	ω	100π
Rated Voltage(RMS)	V_{rate}	35000V
Rated Capacity	S	100MVar
Rated Current	I_{rate}	952A
Rated DC Voltage	V_{dc}	1900V
Capacitor	C_0	10000uF
Carrier Wave Frequency	f_c	250Hz

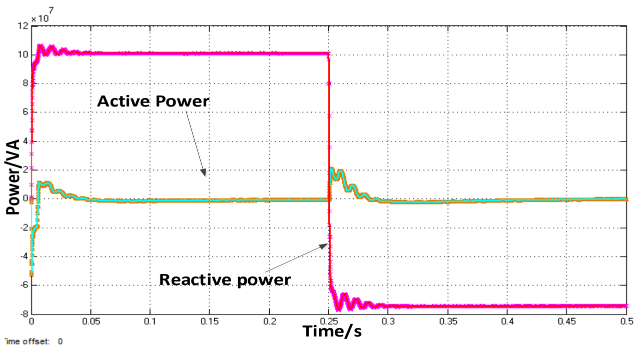
The results are shown in Fig5. Fig.5 (a) and fig.5 (b) are the dc capacitance voltage of the power module of the accurate model and the equivalent model. It can be seen that the error is approximately within 2.2v, and the relative error is 0.11%. In fig.5 (c) and fig.5 (d), the current waveform and its error of the two models of commutation chain are within 11A, and the relative error is 1.15%. Figure 5(e) and figure 5(f) are respectively the waveform and error of power. The error of active power is about 500kW, and the error of reactive power is 600kVar, respectively. Therefore, the total error of the model is less than 1.2%.



(a) DC voltage comparison between the accurate model and the equivalent model



(b)Comparison of commutative chain current between the accurate model and the equivalent model



(c) Power comparison between the exact model and the equivalent model

Fig5 Simulation results of the Accurate Model and Equivalent Model

The simulation execution time pairs for the three models are shown in Table 3.

TAB3 SIMULATION EXECUTED TIME STATISTICS

Simulation Step	Original Model/s	Equivalent Model/s
10^{-4} s	183	38
10^{-5} s	1598	331
10^{-6} s	15567	3452

Comparing the simulation execution time with simulation steps of 10^{-4} s, 10^{-5} s and 10^{-6} s in three different cases, it can be seen that the equivalent model is reduced by about 80% of execution time.

4. CONCLUSION

In order to solve the problem of slow off-line simulation speed of high-power chain STATCOM electromagnetic transient, this paper USES the circuit characteristics of h-bridge power module to

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model the equivalent converter chain and improve the simulation speed.In this paper, the simulation comparison of 35kV high pressure chain STATCOM is carried out. The results show that the simulation error of the proposed equivalent model is less than 1.2%, and the simulation execution time is reduced by 80%.

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