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A Dynamic Equivalent Method for Electromagnetic Transient Simulation and Its Application in East China Power Grid

Fei Dou¹, Weiyuan Wang¹, Mengmeng Yang², Qinxin Huang² and Yifan Gao²

¹ State Grid Jiangsu Electric Power Co., Ltd., Jiangsu 210000, China

² East China Electric Power Design Institute Co., Ltd., Shanghai 200001, China

443945370@qq.com

Abstract. There is an inherent limitation when unbalanced faults in AC system are studied in large scale AC/DC power systems with electromechanical transient simulation. In order to make the electromagnetic transient simulation which is accurate in these situations possible, dynamic reduction must be done. A method based on support strength of generators is proposed. According to the connection form of low-voltage network with 500kV skeleton buses and whether there are generators in it, three reduction schemes are used to replace the corresponding low-voltage network. The dynamic parameters of equivalent generators are obtained by a time domain aggregation method. The equivalent results of planning data of East China Power Grid in 2020 show that, the method has high accuracy in power flow analysis as well as short circuit calculation. The proposed method greatly simplifies the original system while the characteristic of dynamic response remains.

1. Introduction

The electromechanical transient simulation program is generally used to analyse the safety and stability of the system under the condition of symmetrical fault or DC blocking of large-scale AC/DC power system. Since the response characteristics of the converter can only be based on the positive sequence fundamental phasor of the AC system, the electromechanical transient analysis program in the AC/DC system only uses the positive sequence phasor description at the fundamental frequency for the simulation of the AC network. The interaction characteristics between the AC and DC systems cannot be described at non-fundamental frequencies, so the electromechanical transient program simulation in the asymmetric fault of the AC system is inaccurate, and it is impossible to reproduce the transient process during the failure [1,2].

The calculation amount of electromagnetic transient simulation on the large power grid system is so huge that the existing electromagnetic transient simulation program cannot be carried out. As the scale of the simulation system is limited, the proper equivalent simplification of the research network needs to be performed before the calculation. The design of accurate and effective dynamic equivalent method is of great significance for the subsequent electromagnetic simulation research.

This paper uses the dynamic equivalent method based on physical equivalent to calculate the equivalent data of the 2020 East China Power Grid planning data. The results show that the equivalent system can not only ensure the steady-state power flow of the backbone network before and after the equivalent, but also ensure that the short-circuit current is approximately unchanged. The equivalent system greatly simplifies the origin system while maintaining a certain dynamic response similarity. It is suitable for further electromagnetic transient simulation analysis.



2. Dynamic equivalent method based on physical equivalent

2.1. Equivalence principle

The system that needs to be equivalent is layered according to the voltage level. It should be satisfied before and after equivalent as below [3,4]:

- (1) The power flow of the backbone network is unchanged;
- (2) The short-circuit current level of the backbone grid is unchanged;
- (3) The dynamic characteristics are consistent.

2.2. Equivalence structure

For a grid consisting of 500kV voltage-grade AC lines on the backbone grid, if considered that each unit in the supply zone is coordinated, it can be equivalent according to the standard structure of each 500kV bus and its connected low-voltage network.

For the 500kV backbone grid bus, there are two types according to whether it forms a ring network through its low-voltage network [5]:

- (1) The low-voltage network is connected by the same 500kV bus, called the independent supply area;
- (2) The low-voltage network is connected through different 500kV buses, called the joint supply area.

When performing the equivalent calculation, the equivalent program needs to first determine what type of network is in the low-voltage supply area. When the low voltage region is an active independent area, an active joint area or a passive area, the equivalent structure shown in the literature [2] is used respectively.

2.3. Equivalent parameter

The sum output of equivalent generators is equal to the sum output of the original generators. The equivalent load is used to balance the power flow of the boundary bus. The reactive compensation before and after equivalent remains unchanged. The leakage resistance parameters of the transformer is determined by keeping the short-circuit current constant before and after the equivalent.

In the actual power grid, as the electrical distance between the same low-voltage areas is relatively close, the generators are often seen as coordinated. The polymerization method of generator rotor motion equation is given below:

$$M^* \frac{d\omega}{dt} = P_m^* - P_e^* - D^* (\omega - 1) \quad (1)$$

$$M^* = \sum_{i=1}^n \frac{S_{Gi}}{S_G} M_i, D^* = \sum_{i=1}^n \frac{S_{Gi}}{S_G} D_i, P_m^* = \sum_{i=1}^n \frac{S_{Gi}}{S_G} P_{mi}, P_e^* = \sum_{i=1}^n \frac{S_{Gi}}{S_G} P_{ei}, S_G = \sum_{i=1}^n S_{Gi} \quad (2)$$

Among them, S_G, S_{Gi} are the capacity of the equalizer and the i generator. M_i, D_i, P_{mi}, P_{ei} are the generator inertia, friction damping, mechanical power and electromagnetic power of the i generator.

For the electromagnetic loop parameters of the equalizer, a typical simplified equivalent model can be used, in which the key parameters are obtained by polymerization, and the other parameters are based on typical parameters [2].

2.4. Dynamic Equivalent Method

The specific steps of dynamic equivalent method based on physical equivalent are as follows [6,7]:

- (1) Read the stable data and dynamic data files of the origin system;
- (2) Set the equivalent bus and the reserved bus, and scan the system according to the voltage level;
- (3) Acquiring reactive power compensation, generator steady state, dynamic data, backbone network currents, etc. in the equivalent region;

- (4) Calculate the short-circuit current of each bus on the system backbone network before the equivalent;
- (5) Judging the bus type of the equivalent region;
- (6) Perform dynamic equivalent calculation based on physical equivalents on the equivalence region;
- (7) Output steady state data and dynamic data files after equivalent.

3. Equivalence method verification

3.1. East China Power Grid AC and DC System

Based on the 2020 planning grid data of East China Power Grid, the dynamic equivalent is used to simulate the electromagnetic transient characteristics of AC and DC systems.

By 2020, there are 11 DC drops in East China Power Grid, namely Longzheng DC, Jinsu DC, Jinbei DC, Ximeng DC, Huaxin DC, Fengjing DC, Genan DC, Fengxian DC, Lingshao DC, Binjin DC, Zhundong DC. Among them, the DC drop points in Shanghai and Jiangsu are relatively concentrated. There are strong mutual influences and the transient process of interaction with the communication system is complicated[8].

This equivalent is considered to retain most of the 500kV backbone grids in Shanghai and Jiangsu, and to simplify the grids in Anhui, Zhejiang and Fujian. The scale before and after the equivalence are shown in Table 1. After simplifying the origin system with the proposed equivalent method, the equivalent system retains 7 DC drops and backbone grids containing 416 buses, 69 generators, 281 lines and 367 transformers.

Table 1. Scale of 2020 East China Power Grid system before and after equivalent.

System	Bus	Plant	DC	Transform	Line
Origin	5348	652	11	2231	6937
Equivalent	416	69	7	367	281

3.2. Steady state verification

Table 2 gives the comparison of the 500kV bus voltages before and after the equivalent of the East China Power Grid. The buses to be observed are the typical DC inverter buses of 500kV voltage. It can be seen from Table 2 that the steady-state voltage and power angle deviation of each AC bus are small. When the parameters of the backbone grid are unchanged, the bus voltage and power angle determine the power flow distribution of each line of the system. Therefore, the system power flow distribution after the equivalent is almost identical to the origin system[9].

Table 2. Comparison of AC buses before and after equivalence.

Name	Voltage level	Equivalent		Origin		Equivalent/Origin bus voltage deviation	Equivalent-Origin angle deviation
		Voltage/p.u.	Angle	Voltage/p.u.	Angle		
Huainan	1050	1.0037	14.6	1.0038	14.6	-0.01%	0
Nanjing	1050	0.997	9.36	0.9971	9.36	-0.01%	0
Shanghai	1050	0.9858	0.19	0.9862	0.2	-0.04%	-0.01
Suzhou	1050	0.9860	-0.12	0.9863	-0.11	-0.03%	-0.01
Zhundong	1050	1.0023	12.55	1.0025	12.55	-0.02%	0
Ximeng	1050	0.9916	6.5	0.9918	6.5	-0.02%	0
Tongli	525	0.9405	0.42	0.9406	0.43	-0.01%	-0.01
Zhengping	525	0.9604	6.17	0.9604	6.17	0.00%	0
Fengxian	525	0.9699	-2.52	0.9702	-2.51	-0.03%	-0.01
Fengjing	525	0.9852	-2.14	0.9866	-2.14	-0.14%	0

Name	Voltage level	Equivalent		Origin		Equivalent/Origin bus voltage deviation	Equivalent-Origin angle deviation
		Voltage/p.u.	Angle	Voltage/p.u.	Angle		
Huaxin	525	0.9738	-7.55	0.9742	-7.54	-0.04%	-0.01
Meili	525	0.9561	4.65	0.9561	4.66	0.00%	-0.01
Kunnan	525	0.9590	-2.14	0.9591	-2.13	-0.01%	-0.01
Shier	525	0.9778	-8.17	0.978	-8.16	-0.02%	-0.01
Waier	525	0.9706	-5.14	0.9708	-5.13	-0.02%	-0.01
Gulu	525	0.9684	-5.23	0.9686	-5.22	-0.02%	-0.01
Nanqiao	525	0.9812	-4.89	0.9817	-4.88	-0.05%	-0.01
Tingwei	525	0.9776	-4.26	0.9781	-4.25	-0.05%	-0.01
Fuyang	525	0.9779	0.91	0.978	0.92	-0.01%	-0.01
Pingyao	525	0.9764	1.17	0.9765	1.18	-0.01%	-0.01

3.3. Short circuit current level verification

The short-circuit current reflects the strength of the AC system. The DC commutation failure and its subsequent recovery have a great relationship with the strength of the AC system of the inverter. Therefore, it is very important to ensure the short-circuit current level of the system before and after the equivalent. Table 3 lists the comparison results of the short-circuit current of the 1000kV and 500kV voltage levels before and after the equivalent. The verification results show that the dynamic equivalent method proposed in this paper can make the short-circuit capacity of the equivalent system and the origin system approximately equal.

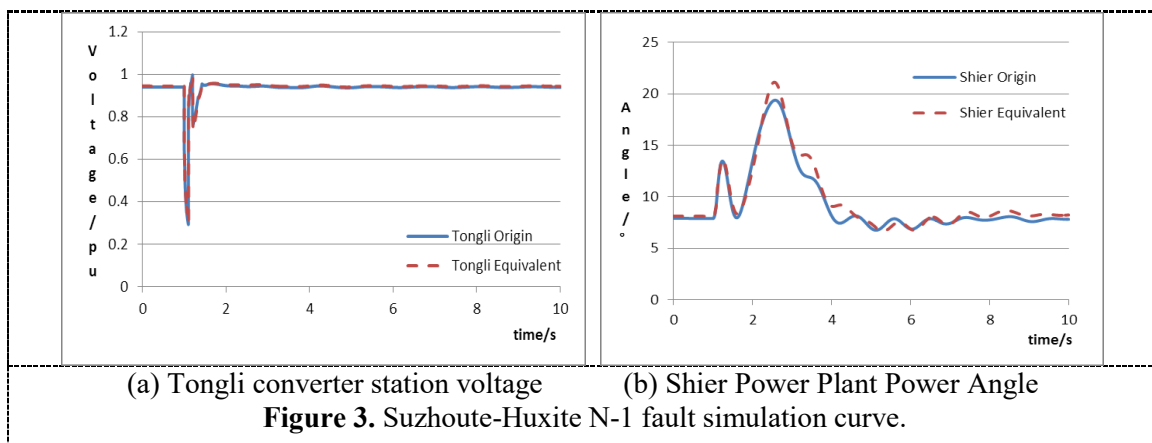
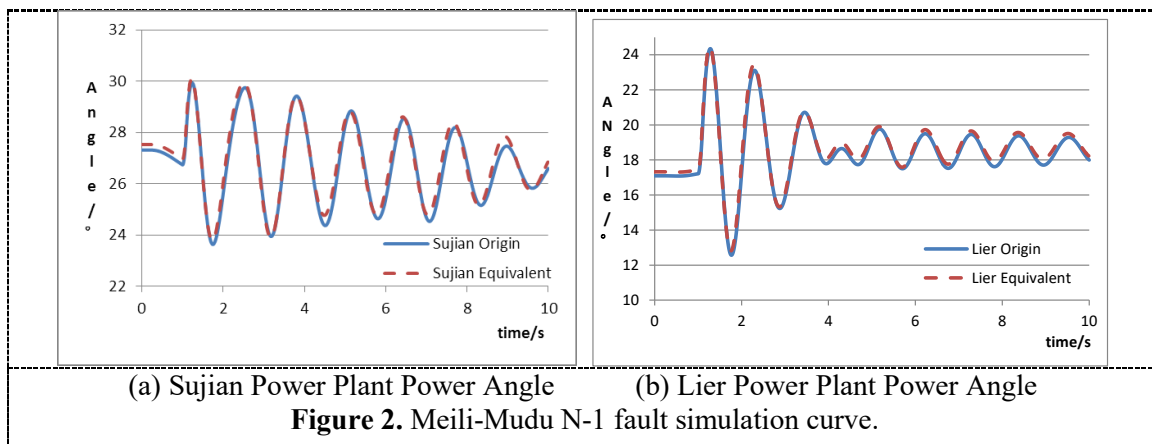
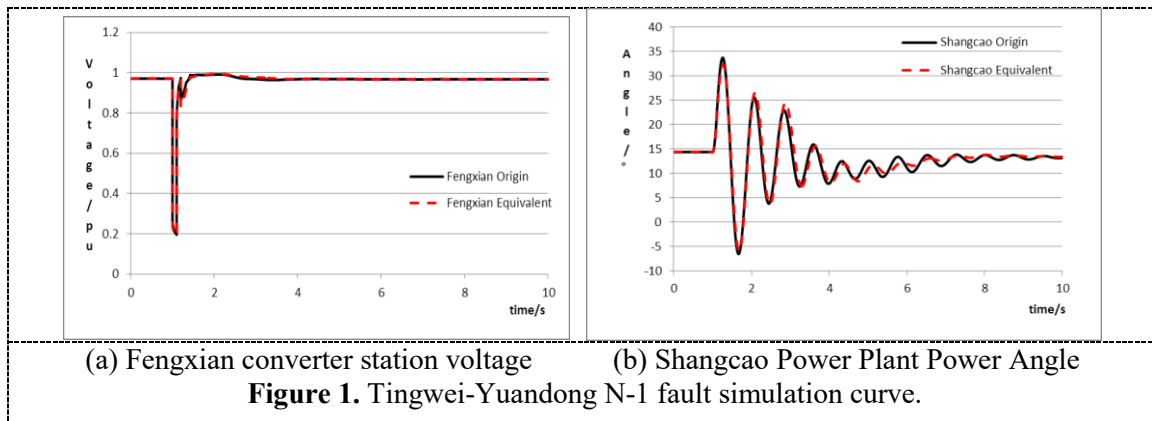
Table 3. Comparison of short-circuit currents before and after equivalence. Unit: kV, MVA

Bus name	Voltage level	Origin short-circuit capacity	Equivalent short-circuit capacity	Equivalent/Origin deviation
Huainan	1050	47434	47168	-1%
Nanjing	1050	46666	46448	0%
Shanghai	1050	68923	69514	1%
Suzhou	1050	69981	70573	1%
Zhundong	1050	44558	44204	-1%
Ximeng	1050	45873	46157	1%
Fengxian	525	49939	49742	0%
Fengjing	525	31168	30885	-1%
Huaxin	525	38062	37714	-1%
Meili	525	37700	38309	2%
Shier	525	38896	38382	-1%
Waier	525	45864	45584	-1%
Gulu	525	49231	48918	-1%
Nanqiao	525	44795	44397	-1%
Tingwei	525	55815	55649	0%
Fuyang	525	42907	43675	2%
Pingyao	525	51201	51953	1%

3.4. Transient response verification

The fault of the near-end line of the DC drop point is selected to execute electromechanical transient simulation. Observe the transient response curves of the AC bus, the adjacent main bus voltage and the power angle of the typical large-capacity unit in the origin and equivalent system.

The corresponding simulation curves of the N-1 fault of Tingwei-Yuandong, Meili-Mudu and other AC lines near Shanghai and Jiangsu are shown in Figure 1-3. It can be seen that the dynamic response of the equivalent system before and after the short-circuit fault is consistent with the dynamic response of the origin system which has a good similarity.



4. Conclusion

(1) Applying the dynamic equivalence method based on physical equivalent and using python programming, the equivalent simplification of the planning data of East China Power Grid in 2020 is carried out. The method has the advantages of small calculation amount and simple operation;

(2) Taking the 2020 planning grid data of East China Power Grid as an example, the dynamic equivalent is carried out, and the equivalent effects are compared and verified from three aspects: steady state power flow, short circuit current level and dynamic response characteristics. The results show that the equivalent system is consistent with the mainframe network of the origin system, and the short-circuit capacity is approximately equal. The dynamic response of the equivalent system before and after the fault is consistent with the origin system.

(3) In the selection of the system equivalent scale, when it is necessary to study multiple faults of the AC system, the origin system backbone network should be retained to obtain better dynamic response similarity. If it is specific to a certain fault, simplify the system farther from the point of failure to reduce the size of the equivalent system while ensuring the dynamic equivalence similarity.

References

- [1] Kang Y, Lu S and Chen L 2017 A Reduction Method of Large Power Systems for Electromagnetic *Electric Power Construction* **38** pp 31-38
- [2] Lu S Q 2018 Simulation techniques, stability analyses and optimized control strategies of converter dominated power systems *Zhejiang: Zhejiang University*
- [3] Li J, Chen H and Li D L 2007 A Survey of Research Methods on Power System Dynamic Equivalence *Guangdong Power* **20** pp 1-4
- [4] Niu Q D 2012 Application Research on Dynamic Equivalent of Power System *Shandong: Shandong University*
- [5] Alp E and Yolcu 2011 Determining the most proper number of cluster in fuzzy clustering by using artificial neural networks *Expert Systems with Applications* **38** pp 2248-2252
- [6] Xie X L and Beni G 1991 A validity measure for fuzzy clustering *IEEE Transactions on pattern analysis and machine intelligence* **13** pp 841-847.
- [7] Wu H X 2010 Research on Dynamic Equivalence Method for Electromagnetic Transient Simulation Based on PSS/E *Zhejiang: Zhejiang University*
- [8] Xu J B, Xue Y S, Zhang Q P and Wang D X 2005 Review of Coherent Dynamic Equivalence of Power System *Automation of Electric Power System* **29** pp 91-95
- [9] Ourari M L, Dessaint L A and Do V Q 2006 Dynamic equivalent modeling of large power systems using structure preservation technique *IEEE Transactions on Power Systems* **1** pp 284-1295