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Subsynchronous Oscillation Problem Research in the UHVDC System of a Regional Power Grid in China

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Abstract. Along with the grid structure being more and more complex and the rapid development of the HVDC system, studying the subsynchronous oscillation (SSO) problem on HVDC system has more engineering practice significance. The paper studies subsynchronous oscillations problem of generators near the ±800kV UHVDC converter station, and analyzes the subsynchronous oscillation possibilities through PSCAD/EMTDC simulation. At last, though the researched UHVDC thermal plants have none SSO risk but it needs other measures to make the relevant generators return on normal operation.
Keyword: UHVDC; subsynchronous oscillation (SSO); PSCAD/EMTDC simulation

1 Introduction

As we all know, though China is a big energy country, the energy resources and the development of productive forces have reverse distribution and serious imbalance. Long-distance large-scale electricity transmission becomes inevitable, HVDC technology has vast prospect in China and develops rapidly. Since 1989 Zhoushan HVDC project had been put into operation officially, China has become the first country in the world of largest DC transmission capacity, the highest voltage level, the fastest growing speed [1]. Subsynchronous oscillation belongs to the power system oscillation instability and it's caused by a special kind of electromechanical coupling effect. Subsynchronous oscillation problem caused by HVDC has become an important practical problem [2-6], so study of UHVDC transmission system's SSO question has great significance for power system stability.

2 The researched ±800kV UHVDC project in China

The researched ±800kV UHVDC project is the first UHVDC project which transfers Xinjiang province electric energy outwards and is also the first "wind, solar energy, thermal power "hybrid transmission engineering HVDC project[7]. The project's rated power is 8000MW, rated voltage is±800kV. And the converter station AC bus rated voltage is 500kV, which contacts the 750kV northwest regional power grid through transformers. It includes 8 thermal power units near the rectifier station. The researched UHVDC project was put into operation at the end of 2013, and the rectifier area has 3 power plants. Plant 1 has 2 same generators, Plant 2 has 2 same generators, Plant 3 has 4 same generators of which all generators' rated power is 660MWand their rated voltage is 22kV. The simplified model is shown in Figure 1.

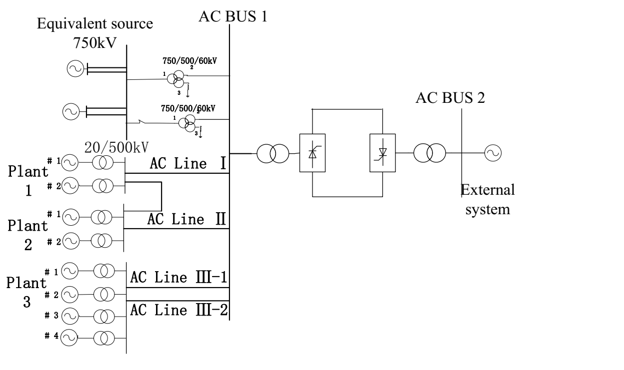

Figure 1. The Researched UHVDC Equivalent Network Diagram

According to the plan data, the electrical distance between thermal power units and the convertor station is relatively short. The negative electrical damping caused by HVDC system may result in SSO problem and seriously may lead to shaft fatigue and damage. The UHVDC has lager rated capacity and may have more serious SSO problem, so it is necessary to conduct study in-depth of the UHVDC's thermal power units.

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3 The time domain simulation analysis of steam turbines near the UHVDC system rectifier station

As shown in Figure 1, under normal operating conditions, the 750kV regional power grid and the rectifier station area units transfer electrical energy to the load center (the external equivalent source) together through the researched UHVDC project. When the UHVDC system is under worse conditions, the thermal units nearby is at island operation, which is isolated with the 750kV regional gird. Unit interaction factor method (UIF) is a screening method which is suitable only for the analysis of DC transmission system on SSO problem. It's always used to analyze simply whether the relevant unit has the SSO problem [8-9]. As the following equation shown:

$$UIF_i = \frac{S_{HVDC}}{S_i}\left(1 - \frac{SC_i}{SC_{TOT}}\right)^2 \qquad (1)$$

S_{HVDC} is the HVDC rated capacity, the unit is *MW*; S_i is the rated capacity of the researched generator *i*, the unit is *MW*; SC_i is the three-phase short-circuit capacity at the HVDC rectifier bus (its unit is *MVA*, and it doesn't conclude the effect of AC filter and the generator *i*); SC_{TOT} is also the three-phase short-circuit capacity at the HVDC rectifier bus, it concludes the effect of generator *i* , but does not contain the AC filter effect as well.

When UIF_i <0.1, we can think that the interaction is not obvious between researched units and the DC transmission system. The risk of subsynchronous oscillation in this unit is relatively small. On the contrary, when UIF_i >0.1, the researched unit has SSO risk, some other precise methods can be used to analysis later on. According to the UIF method, it can conclude the following Table1 and Table 2:

Table1. Each unit UIF coefficient with the 750kV equivalent source

Plant 1 Unit amount	Plant 2 Unit amount	Plant 3 Unit amount	Plant1 UIF	Plant 2 UIF	Plant 3 UIF
2	0	0	0.029	-	-
2	2	0	0.035	0.030	-
4	2	0	0.031	0.031	-
4	2	2	0.029	0.028	0.027

Table2. Each unit UIF coefficient without the 750kV equivalent source

Plant 1 Unit amount	Plant 2 Unit amount	Plant 3 Unit amount	Plant 1 UIF	Plant 2 UIF	Plant3 3 UIF
2	0	0	0.295	-	-
2	2	0	0.153	0.182	-
4	2	0	0.116	0.118	-
4	2	2	0.094	0.093	0.099

It can be concluded from the above two tables that when the UHVDC system has 750kV equivalent source , each unit's UIF coefficient at different conditions is less than 0.1which means no SSO problem; when the UHVDC system has none 750kV equivalent source, each unit's UIF coefficient of the first 3 conditions is more than 0.1,which indicates SSO problem probably. But the UIF method is only a rough way to estimate SSO, so it needs detailed time domain simulation.

3.1 PSCAD/EMTDC simulation with 750kV equivalent source

When the 750kV equivalent grid is associated with UHVDC transmission project, we can establish the simulation model in accordance with Figure 1 with the PSCAD/EMTDC software which is specifically used for the analysis of power system transient software. And the simulation conditions are set as Table 1. What's more, the fault type is A phase grounding; fault location is at the AC Line Ⅲ-2; fault time is at the t=20s, and the whole fault time is 0.05s, and then the fault is removed.

The result founds that at each condition, the physical quantities of each unit would converge after the fault at last . It means that each unit has strong electrical damping at each shafting modal frequency, and the SSO probability is little. At each condition, the physical quantity of units in Plant 1(Figure 2. and Figure 3.) and Plant 2(Figure 4. and Figure 5.) converge easily. Note that each figure below is under 8 machines' condition.

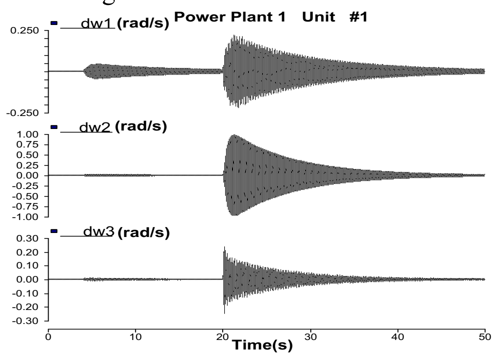

Figure 2. Power plant 1 -unit #1 each modal shaft speed deviation when having the 750kV equivalent source

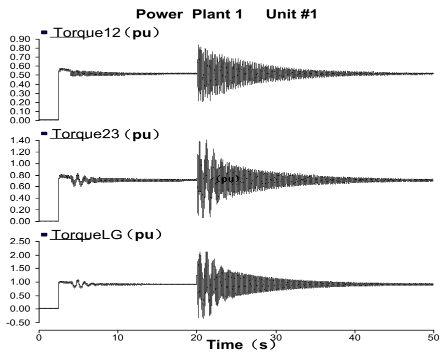

Figure 3. Power plant 1 -unit #1 torque change between each mass when having the 750kV equivalent source

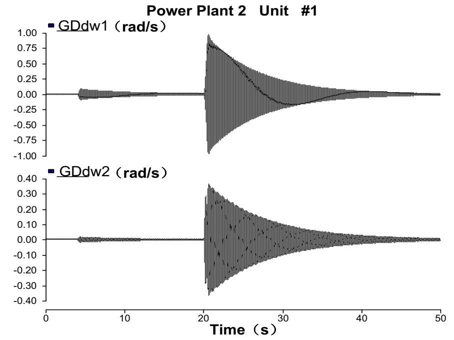

Figure 4. Power plant 2 -unit #1 each modal shaft speed deviation when having the 750kV equivalent source

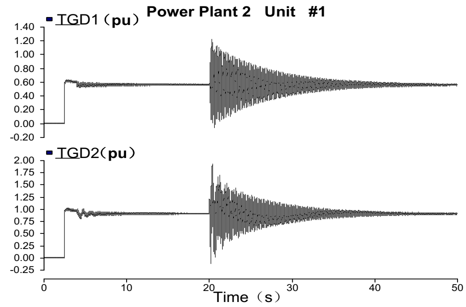

Figure 5. Power plant 2 -unit #1 torque change between each mass when having the 750kV equivalent source

But Plant 3's physical quantities have different trend, as shown in the following Figure 6~7.- unit #1 shaft speed deviation and the torsional torque(As units in the power plant have the same parameters, we choose the unit #1's figures under 8 machines' condition in the system for the example).

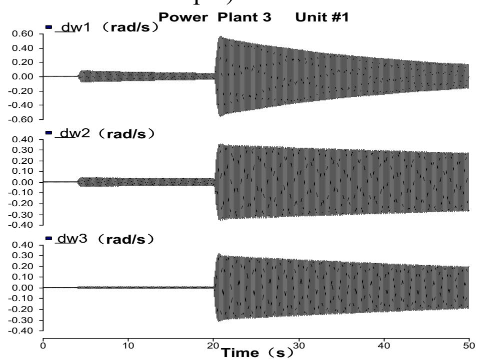

Figure 6. Power plant 3 -unit #1 each modal shaft speed deviation when having the 750kV equivalent source

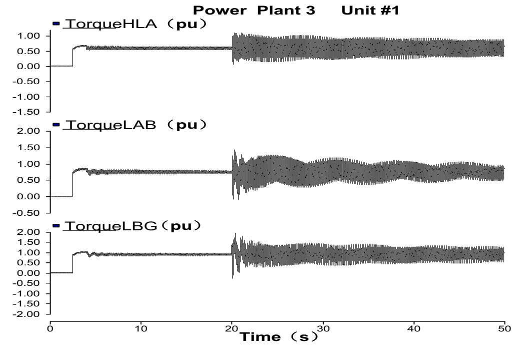

Figure 7. Power plant 3 -unit #1 torque change between each mass when having the 750kV equivalent source

The time domain simulation results show that, in the UHVDC system with 750kV equivalent source condition, whether the power plant 1, plant 2 or plant 3 has no torsional vibration divergence phenomenon, namely the system having none SSO danger which is consistent with the judge result using by UIF method. Though the power plant 3 has no subsynchronous oscillation phenomenon, but each modal component converges much more slowly than power plant 1 and power plant 2. And this phenomenon is also harmful for the whole power system.

3.2 PSCAD/EMTDC simulation without 750kV equivalent source

When the 750kV equivalent network is removed from the researched UHVDC system, the system's thermal power units near the converter station are at the islanding operation status. And the fault is same as that shown above. When the units' amount is 2, 4, 6, each generator's UIF is more than 0.1, which means that the generator and DC transmission system have closer electrical coupling, and the SSO problem is more obvious. When all plants units are put into operation, that's to say, the whole generators' number is 8, it can be found that, each unit UIF is less than 0.1, but close to 0.1. As the UIF method itself is a kind of rough way to estimate system SSO risk, so for this condition, it also needs PSCAD/EMTDC time domain simulation of SSO in detail.

Therefore, we can establish the UHVDC transmission system islanding model with the PSCAD software, and set up different simulation conditions in accordance with Table 2. Simulation results show that under various conditions, power plant 1, 2, 3 don't have SSO phenomenon. Then it can be found that physical quantities of power plant 1 and power plant 2's units also converge quickly under different conditions. Unit #1's shaft speed deviation of each modal frequency and the torsional torque between each mass in power plant 3 are shown in Figure 8 and Figure 9 below (take the 8 machines' condition for the example):

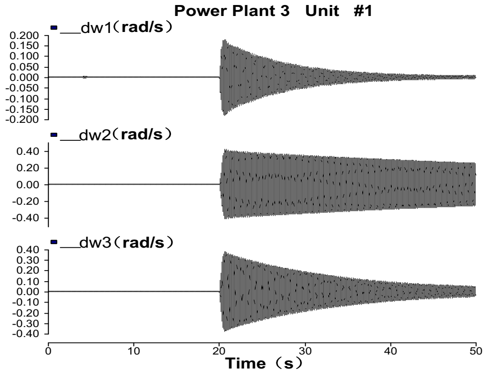

Figure 8. Power plant 3-unit #1 each modal shaft speed deviation at which not having the 750kV equivalent source

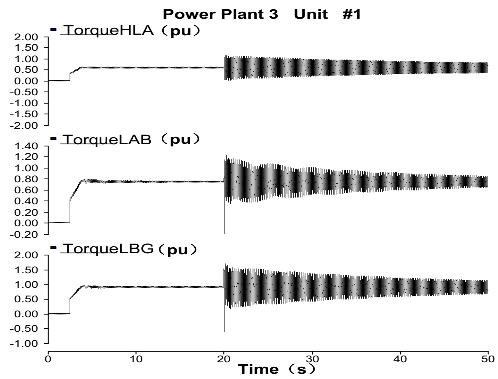

Figure 9. Power plant 3 -unit #1 torque change between each mass at which not having the 750kV equivalent source

Under the islanding operation, after the fault, although each physical quantity of power plant 3 units doesn't have the divergent phenomenon, the convergence speed is very slow especially the modal 2 speed deviation *dw2*, which is significantly lower than the other plants' generator. Power plant 3 should be taken as the important object in later SSO research.

4 Conclusions

From the PSCAD/EMTDC time domain simulation and analysis above, we can conclude that:
(1) The researched UHVDC thermal plants all have none SSO risk and none generator shafting torsional vibration divergence phenomenon whether the system have or not the 750kV equivalent source.
(2) Although power plant 3 don't have SSO phenomenon, but the modal components convergence speed is very slow.

(3) It's necessary to design subsynchronous damping controller (SSDC) for units in power plant 3 which can enhance the relevant system electrical damping and can make the generator return to normal operation as soon as possible.

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