Simulation Analysis of Magnetizing Inrush Current of 500kV Transformer

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Abstract. The 500kV power grid is the most important high-power AC power system in China. The 500kV transformer is responsible for the regular uploading and sending tasks. It is important electrical primary equipment that connects two or even three different voltage levels. Taking a new 500kV transformer in Chongqing as an example, this paper discusses the influencing factors of 500kV transformer inrush current when connected to the grid through PSCAD/EMTDC software, and puts forward feasible measures to suppress the inrush current.

1. Introduction
The 500kV power grid is the most important power transmission system in China, and it undertakes the task of transporting the power generated by the power generation base to the remote substation. Two main transformers are usually set in a 500kV substation. After the new substation is built or main transformer is overhauled, it will always involve the operation of the main transformer no-load grid connection, that is, the closing of the no-load transformer is a routine operation mode of the substation. The no-load closing of the transformer refers to the process of connecting the primary side to the grid when the secondary side is un-loaded. The process of transformer no-load closing is often accompanied with the magnetizing inrush current, as the transformer core material has nonlinear characteristics, during the closing moment; the excessive grid voltage causes the equivalent inductance of the transformer to decrease sharply, so the excitation current is very high. There are plenty of odd harmonics in this current; the main harmonic order is 3, 5 times, it also contains the even harmonics of 2 times. Overcurrent poses a threat to the safety of electrical equipment and staff. Literature [1-3] analyzed the characteristics of transformer excitation inrush current and its potential hazards such as transformer protection disoperation. Literature [4] showed that serious inrush current would lead to bus voltage distortion, base wave voltage drop, and inverter commutation failure. At the present, the suppression of inrush current mainly includes the following methods. In literature [5], inrush current is suppressed by effectively measuring transformer remanence and controlling the initial phase Angle at closing time. In literature [6], the suppression effect of closing resistance on inrush current during transformer air charging is verified. In China, the circuit breaker of 500kV transformer is usually equipped with parallel voltage equalizing capacitor, and there is a capacitive voltage transformer (CVT) connected in parallel on the busbar. The phenomenon of excessive magnetizing inrush current caused by transformer no-load closing has occurred many times [7], causing the voltage oscillation.
In this regard, this paper takes a new 500kV transformer in Chongqing as an example. Through the PSCAD/EMTDC software, the 500kV transformer simulation model with actual parameters is established, and the transformer no-load closing circuit including closing circuit breaker and CVT is set as well. The simulation model discusses the influencing factors of the excitation current of 500kV transformer, and puts forward the feasible pre-control measures of the magnetizing inrush current.

2. Model of 500kV Transformer No-load Closing System

2.1. Introduction of 500kV Substation
The main transformer of TL500kV substation in Chongqing is composed of three single-phase transformers (ODFS-334000/500). The main transformer rated capacity is 334000/334000 /100000kVA, rated voltage is (525/ √3)/(230/ √3 ± 2×2.5%)/36kV, rated frequency is 50Hz[8]. The main transformer’s no-load closing circuit is shown in Figure 1. In the figure, the main capacitor of \( C_{CVT} \) is 5000pF; the capacitance \( C_S \) of the parallel capacitor of the circuit breaker is 2000pF; the other basic parameters of the main transformer are shown in Table 1. The main transformer excitation characteristic curve provided by the manufacturer is shown in Figure 2.

![Figure 1](image1.png)

**Figure 1.** Characteristic curve of transformer excitation

![Figure 2](image2.png)

**Figure 2.** Excitation characteristic curve provided by the manufacturer

| Table 1. Basic parameters of converter transformer |
|--------------------------------------------------|
| Rated capacity/MVA | rated voltage/kV | No-load excitation current /A | Short-circuit impedance/% | No-load loss/% | Short-circuit loss/kW |
|---------------------|------------------|-------------------------------|--------------------------|----------------|----------------------|
| 334                 | 525              | 5.18                          | 15.79                    | 74.55          | 177.35               |

2.2. 500kV transformer simulation modelling

2.2.1. UMEC Transformer Model. The UMEC (unified magnetic equivalent circuit) model is a transformer model that takes the magnetic saturation characteristics of the transformer core into account. The model uses a full interpolation method to describe the magnetic saturation characteristics of the transformer, which can model various core structures. The UMEC transformer model provided by PSCAD/EMTDC has the excitation characteristic curve shown in Figure 3.

![Figure 3](image3.png)

**Figure 3.** The UMEC excitation characteristic curve in EMTDC
2.2.2. Model verification  According to the actual parameters of the TL500kV main transformer provided by the manufacturer, the default parameters of the UMEC model are modified. The modified excitation characteristic curve of the UMEC model is shown in Figure 4. The comparison results are shown in Table 2. It can be seen from Table 2 that the modified UMEC model has a high agreement with the actual model, indicating that the UMEC model can be used for the no-load closing research.

Table 2. Comparison of UMEC model and actual transformer excitation characteristics

| Excitation characteristic curve | No-load current |
|---------------------------------|-----------------|
|                                 | 0%  5%  10%  15%  20%  30% |
| Default model                   | 0   1.10  1.15  1.18  1.19  1.21 |
| Actual model                    | 0   1.05  1.09  1.11  1.13  1.18 |

2.3. Substation system model
For the TL500kV transformer no-load closing circuit shown in Figure 1, the simulation takes the CVT detailed model into account. The model parameters are consistent with the actual parameters, that is, the CVT main capacitor is 5000pF, and the 500kV circuit breaker is a double-break circuit breaker, each breaker has a parallel voltage capacitor, which is 2000pF and the system voltage is 525kV.

3. Simulation Analysis of Magnetizing Inrush Current
The simulation system is closed at 0.1s and lasts 0.5s. The following text changes of the CVT, the parallel capacitor of the breaker and the inflection point of the excitation characteristic curve of the transformer to simulate the inrush current. Take the phase A as an example.

3.1. Influence of CVT main capacitor value on magnetizing inrush current
In the transformer closing circuit, the CVT’s original capacitor is 5000pF, now it is changed from 1000pF to 15000pF to simulate the magnetizing inrush current. The peak value of this current under different CVT is shown in Figure 4.

![Figure 4](image.jpg)

*Figure 4.* Peak value of magnetizing inrush current under different $C_{CVT}$

The simulation results show that increasing the capacitance of CVT may lead to an increase in the peak value of the magnetizing inrush current, but the increase is negligible. When $C_{CVT}>6000pF$, continue to increase the CVT main capacitor, which has no significant effect on the peak value of the magnetizing inrush current.

3.2. Influence of parallel capacitance of breaker on magnetizing inrush current
The parallel capacitor value of the circuit breaker was originally 2000pF. Now it is changed from 500pF to 15000pF to simulate the magnetizing inrush current. The main inrush current waveform is shown in Figure 5 and the peak value of the magnetizing inrush current under different capacitances is shown in Table 3.
The above results show that increasing the parallel equalizing capacitance of the circuit breaker, the peak value of the inrush current will increase rapidly and increase approximately linearly.

3.3. Influence of the inflection point of the excitation characteristic curve
The inflection point voltage of the transformer excitation characteristic curve is 1.04 (standard value, the same below). The transformer inflection point voltage is gradually increased from 1.04 to 1.15 at intervals of 0.01, and the inrush current peaks at different inflection point are shown in Figure 6.

Figure 5. Simulation waveform of magnetizing inrush current under different $C_S$

Table 3. Magnetizing inrush current peak under different $C_S$

| $C_S$ /pF | Peak value of magnetizing inrush current /kA |
|-----------|--------------------------------------------|
| 500       | 1.0466                                    |
| 1000      | 1.0849                                    |
| 1500      | 1.1236                                    |
| 2000      | 1.1640                                    |
| 3000      | 1.2549                                    |
| 5000      | 1.4587                                    |
| 8000      | 1.7663                                    |
| 10000     | 1.9596                                    |

Figure 6. Peak Magnetizing inrush current under different inflection point voltage
The simulation result shows that after the inflection point increasing to 1.06, the peak value of inrush current does not change significantly; when the voltage is continuously increased to 1.07, the peak value of the magnetizing inrush current decreases slightly. When the inflection voltage is raised to 1.10 and higher, the peak value decreases, that is, increase the excitation point voltage means that the saturation condition is hard to satisfy. If the saturation condition is not reached, the excitation current increases linearly with the applied voltage, which does not form magnetizing inrush current. Therefore, as the inflection point voltage increases, the magnetizing inrush current is hard to form.

4. Inhibition measures for magnetizing inrush current
According to the theory and simulation analysis about influence factors of magnetizing inrush current above, the pre-control measures are proposed as followed.

a. Decreasing the value of CVT’s capacitor appropriately can reduce the peak value of magnetizing inrush current, but when the value is too large, the inrush current does not change significantly.

b. Reducing the value of parallel capacitor of the circuit breaker can effectively suppress the occurrence of magnetizing inrush current. After reducing the circuit breaker capacitance to 500pF, there is almost no magnetizing inrush current occurring.

c. Increase the saturation voltage of the core. By increasing the inflection point of the excitation characteristic curve, the core is not saturated or just enters the saturation stage when the transformer is closed. The peak value of the magnetizing inrush current is greatly reduced.

5. Conclusion
This paper is aimed at the phenomenon of magnetizing inrush current in Chongqing TL500kV transformer, The influence of the parallel capacitance value of 500kV breaker circuit breaker, the CVT main capacitor value and the inflection point voltage of the transformer excitation characteristic on the peak value of the inrush current are analysed. Based on the influencing factors above, the measures to suppress the inrush current are proposed, such as reducing the main capacitance of the CVT, reducing the parallel capacitance of the breaker, and changing excitation characteristics, can effectively avoid the occurrence of the inrush current.

References
[1] HAO Zhiguo, ZHANG Baohui, Chu Yunlong, Research on suppression technology of transformer inrush current excitation inrush[J], High Voltage Apparatus, 2005(02): 81-84.
[2] LI Zhenqiang, GU Dingxie, DAI Min. Analysis and suppression method of resonant overvoltage and magnetizing inrush current for UHV no-load transformers[J], High Voltage Engineering, 2012, 38 (02):387-392.
[3] RAO yufei, ZHANG penghui, LI chenghao. Influence mechanism and evaluation method of excitation inrush current on phase conversion failure of HVDC transmission system [J]. Power System Protection and Control.2019,47(13):54-61
[4] LI Xiaohua,ZHANG Dongyi,WU Lizhu. Analysis of the special characteristics of the inrush current of converter transformer[J].Power Grid Technology.,2017,41(12):3869-3875.
[5] CHEN chuanjiang, FANG chunen, ZENG junlong. Study on phase selection and closing of no-load transformers with residual magnetism [J]. Power System Protection and Control, 2018,46(16):82-88.
[6] WANG Yan,HUANG Fucheng,ZHAO Shuzhen. Simulation Analysis of Transformer Magnetizing Inrush Current Considering Ferromagnetic Hysteresis[J]. Automation of Electric Power Systems,2009,33(15):78-83.
[7] YANG Tongyun, LI Xiaohua, DAI Yangyu. Analysis on Magnetizing Inrush Current Characteristic of Converter Transformer and Its Suppression[J]. Power grids and clean energy,2017,33(01):64-70+78.
[8] CHANG Yong, Analysis on Energizing Inrush Current of No-Load Converter Transformer in 500 kV Gaoling Back-to-Back Converter Station [J]. Power System Technology,