SVC OPERATINAL EXPERIENCES IN THAI NGUYEN SUBSTATION FOR SWITCHING OVERVOLTAGE

VẬN HÀNH SVC Ở TRẠM BIẾN ÁP THÁI NGUYÊN KHI XUẤT HIỆN QUÁ ĐIỆN ÁP ĐÓNG CẮT

Trần Anh Tùng, Trần Thanh Sơn

ABSTRACT

The electricity from China is transferred to Thai Nguyen via a 220kV interconnection transmission line. In the operation, switching overvoltage has been frequently recorded at Thai Nguyen substation when the loads and Static Var Compensator (SVC) are tripped. This phenomenon leads occasionally to the explosion of surge arrester located at the 220 kV side of the autotransformer. Consequently, the suspension of electricity exchange due to surge arrester failure caused the economic losses in the side of Vietnam. This paper represents the simulation of the operation of Thai Nguyen substation using Electromagnetic Transient Program (EMTP). Thus, the simulation results would provide additional useful information for the failure analysis and prevention possible accident in future.

Keywords: *Switching overvoltage, SVC, EMTP-ATP, surge arrester, power system modelling, numerical simulation.*

TÓM TẮT

Điện năng được truyền tải từ Trung Quốc tới Thái Nguyên qua đường dây 220kV. Các quá điện áp đóng cắt thường xuyên xuất hiện trong quá trình vận hành khi bộ bù tĩnh Static Var Compensator (SVC) được cắt ra. Hiện tượng này đã dẫn đến sự cố nổ chống sét van ở phía 220kV của máy biến áp tự ngẫu. Hậu quả là sự gián đoạn trong truyền tải điện do sự cố chống sét van gây ra thiệt hại lớn về kinh tế cho Việt Nam. Bài báo này có mục đích giới thiệu kết quả mô phỏng sự vận hành của trạm biến áp Thái Nguyên sử dụng chương trình quá độ điện từ Electromagnetic Transient Program (EMTP). Các kết quả mô phỏng từ đó có thể cung cấp các thông tin hữu ích cho phân tích và ngăn ngừa các sự cố trong tương lai.

Từ khóa: *Quá điện áp đóng cắt, SVC, EMTP-ATP, chống sét van, mô phỏng hệ thống điện, mô phỏng số.*

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1. INTRODUCTION

Economic growth in Vietnam in recent years demands more investments in power generation. However, to meet the growth rate of energy consumption projected at 16-17 percent per year is absolutely a challenge for the construction of new electricity facilities. So that, imports of electricity from abroad can be an effective solution to overcome the current electricity shortages in Vietnam. The 220kV Malutang (China) - Ha Giang - Thai Nguyen transmission line was thus built and put into operation in 2007, ensuring abundant electricity supply for Thai Nguyen and its surroundings. The imports of power and electricity from China through this transmission line from 2009 to 2013 are reported in Table 1.

Table 1. Electricity bought from China via 220kV Malutang - Ha Giang line

No.	Year	2009	2010	2011	2012	2013
1	Pmax (MW)	220	220	350	290	350
2	Annual import (bil. kWh)	-	2.02	1.87	0.93	1.40

The operation of this transmission line is also required to maintain the least exchange of reactive power between China and Vietnam. Hence, it is necessary to install a Static Var Compensator (SVC) at the receiving end of the line in order to archive voltage stability. The SVC is connected to the 22kV delta winding of the autotransformer at Thai Nguyen substation. The diagram of the 220kV Thai Nguyen substation is illustrated in Figure 1.

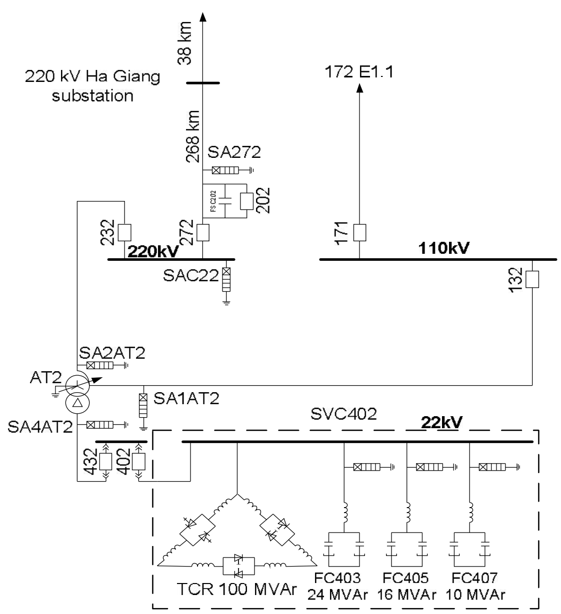

Figure 1. Diagram of Thai Nguyen substation.

The main component of the substation is a 250MVA, 225kV/115kV/23kV autotransformer which receives electricity from China via 268km Ha Giang - Thai Nguyen transmission line. Loads in Thai Nguyen province and its surrounding are then delivered via 110kV line number 172 E1.1 as shown in Figure 1. The normal consummation loads supplied by this line are 90MW and 35MVAr.

To keep the voltage stability of the both sides 220 and 110kV bus bar, SVC at substation can be controlled in a wide range of reactive power from -50MVAR to +50MVAR. As can be seen on Figure 1, this SVC has four reactive branches, TCR of 100MVAR and three filter banks for 3rd, 5th and 7th harmonics with respective capacity of 24MVAR, 16MVAR and 10MVAR. These capacities are nominal values and reactive supply varies with operating conditions. Moreover, a 35Ω Fixed Series Capacitor is also equipped at the receiving end to improve the amount of power transferred on the line. To protect the equipments of substation from overvoltage, surge arresters are used within the system.

In the operation of the substation, the 110kV 172 E1.1 transmission line is sometimes tripped due to the maintenance or operating mode change that causes overvoltage on both 110kV and 220kV sides. In this case, SVC is disconnected shortly before 172 E1.1 tripping according to the operational guideline of Thai Nguyen substation. The switching overvoltage is known as one of the most important factors to be considered in the design of transmission lines and substations. If maximum switching overvoltage exceeds Protection Level, it can lead to the failure of the system. Thus, a lot of switching overvoltage studies have been conducted to ascertain the protection level of transmission lines and insulation coordination procedure [1-3], especially. In our study case, switching overvoltage is considered as the cause of short-circuit by analyzing records from protection relay.

The phase currents and voltages behavior at the receiving end of 220kV Ha Giang - Thai Nguyen transmission line after SVC and 172 E1.1 line tripping were recorded by Siemens 7SA522 relay on 17 June 2015 and are respectively presented in Figure 2 and Figure 3. The voltage ratio is 127000/100, the maximum phase voltages at the receiving end are roughly 100V according to the relay record. From Figure 2 and Figure 3, it is also emphasized that the voltage waveform at the receiving end Thai Nguyen was distorted. This distortion of voltage waveform can be linked to the discharge of 220kV surge arresters due to switching overvoltage. The discharge most likely continued until the phase currents increased sharply as shown in Figure 2. The phase current shows an enormous upturn which corresponds to short-circuit of phase B. This phenomenon is also confirmed by the collapse of phase B voltage as seen in Figure 3. Consequently, the phase B of surge arrester SA2AT2 was exploded due to the overload after 4 minutes of operating under overvoltage. The failure on 17 June 2015 repeated the same failures which occurred in the past. Such transient phenomenon can also cause severe electric field stresses to transformer windings as considered by [2]. Therefore, it is necessary to verify all these hypotheses by simulations in order to have the best understanding on the failure mechanism to prevent the suspension of electricity trading between Vietnam and China in the near future. Based on this approach, all simulations in this study are investigated using EMTP (ATP version). Results of failure case study will be presented and discussed.

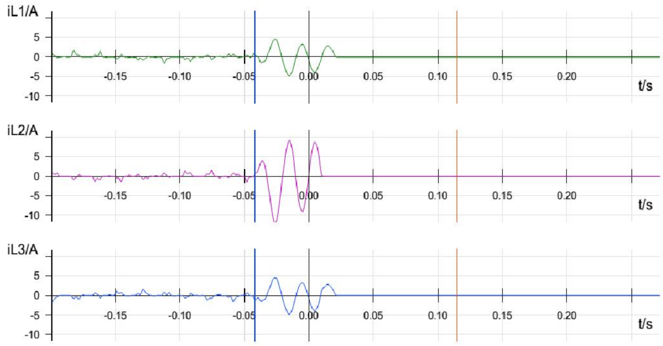

Figure 2. Currents at the receiving end of 220 kV Ha Giang - Thai Nguyen line recorded by Siemens 7SA522 relay on 17 June 2015 after 172 E1.1 line and SVC tripping.

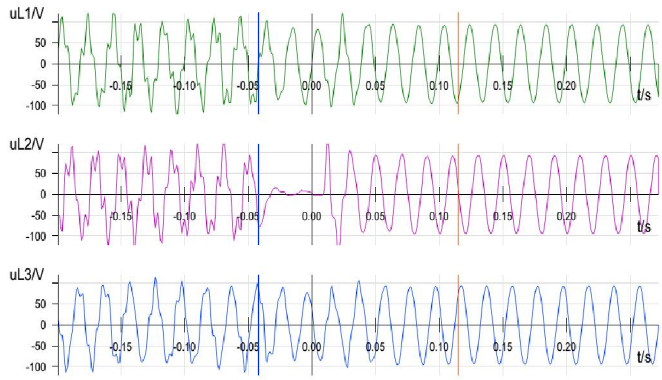

Figure 3. Voltages at the receiving end of 220 kV Ha Giang - Thai Nguyen line recorded by Siemens 7SA522 relay on 17 June 2015 after 172 E1.1 line and SVC tripping.

2. EMTP MODEL REPRESENTATION FOR 220KV THAI NGUYEN SUBSTATION

The EMTP is one of the most widely used programs for simulation of electric power system transients. The program provides accuracy and detail of representation in power system devices including sources, lines, transformer, arresters, etc.

The EMTP is also highly satisfied for simulation of SVC [4-5, 9]. Especially, Transient Analysis of Control System (TACS) allows detailed modeling of the SVC control system so that power system and control system transients can be simulated simultaneously.

The EMTP model representation of Thai Nguyen substation is illustrated in Figure 4.

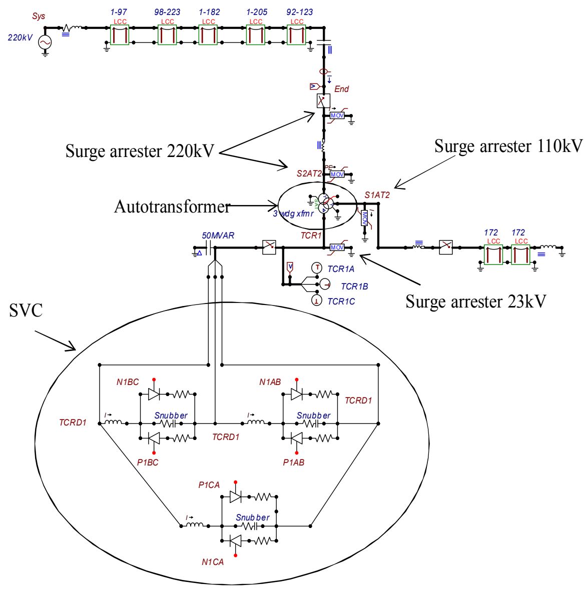

Figure 4. EMTP model representation of Thai Nguyen substation.

2.1. Source, busbar, transmission line and transformer modeling

The source is modeled as an ideal voltage source in series with its impedance. Busbar are represented as cylindrical conductors and modeled by a RL coupled section. For transmission line, several transmission line models are available in ATP-EMTP, such as Bergeron, PI sections, Noda and J-Marti. J-Marti which is currently used in most electromagnetic transient programs, is very efficient and accurate for most simulation cases [7]. The autotransformer is modeled by a saturable transformer model available in ATP-EMTP within parameters from manufacturer.

2.2. SVC modeling

The SVC consists of a Thyristor Controlled Reactor (TCR) and a Fixed Capacitors (FC) Banks. The TCR is a thyristor controlled inductor whose reactance varied in a continuous manner by partial conduction control of thyristor valve [8-9]. In this paper, the 100 MVAR, 22kV TCR circuit is the six-pulse converter connected to the Δ transformer winding (Figure 4). The TCR model includes all GTO valves with the required snubber circuits. The snubber circuit is composed of a RC in series across the thyristor. It is recommended that the minimum RC time constant should be greater the 2-3 times the simulation step size.

2.3. Surge arrester modeling

Metal oxide surge arresters are modeled by MOV element in ATP-EMTP. The surge arrester in failure was SA2AT2 supplied by ABB (type PEXLIM Q192), located at the 220kV side of the autotransformer (see Figure 1). the measured vol-ampere characteristic is shown in Table 2.

Table 2. U-I Characteristic of Pexlim Q192 Surge Arrester

U (kV)	I (A)	U (kV)	I (A)
40	0.00001	315	450
150	0.000025	335	900
210	0.00009	350	1500
230	0.00045	360	2800
240	0.0009	380	5000
250	0.9	400	10000
265	9	440	20000
295	110	500	40000
300	200	630	90000

3. SIMULATION RESULTS

The operation of the system was simulated based on the events on the 17 June 2015. The simulation is limited to 3s to reduce the computation time. The following scenario is simulated:

- SVC is tripped at t = 0.5s;
- The 110kV 172 E1.1 transmission line is tripped at t = 1s;

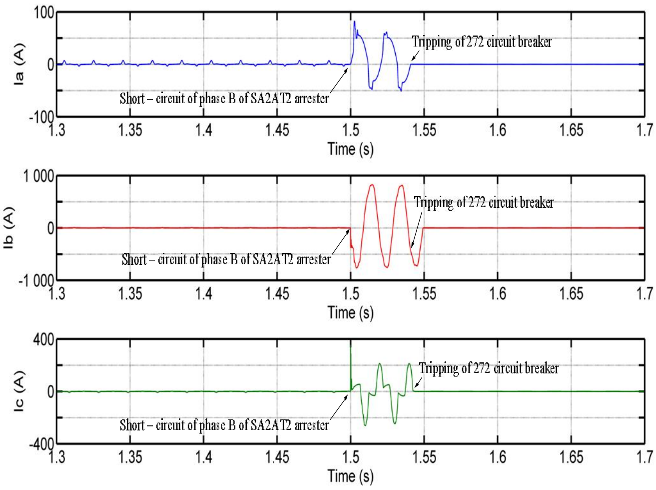

Figure 5. Currents at the receiving end of 220kV line, simulated in disturbed state

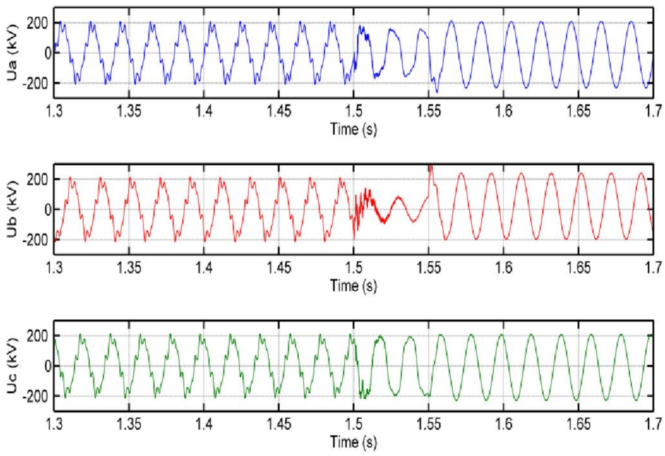

Figure 6. Voltages at the receiving end of 220kV line, simulated in disturbed state

- Phase B of SA2AT2 arrester is short-circuited at t = 1.5s in order to simulate the failure of this arrester;
- The 220kV circuit breaker number 272 is tripped at t = 1.54s.

The simulated phase currents at the receiving end of 220kV Ha Giang - Thai Nguyen transmission line are presented in Figure 5.

The waveform of simulated currents is similar to the measured currents (see Figure 2). Their value are small before t = 1.5s, corresponding to magnetization current of the autotransformer after SVC and load tripping. The currents increase sharply when the phase B of SA2AT2 arrester is in short circuit at t = 1.5s. After that, these currents become null after the 220kV circuit breaker is tripped. It must be noted that the difference of magnitude between simulated currents is due to the direct short-circuit of the phase B of SA2AT2 arrester to ground. In fact, the short-circuit could take place after the phase B of SA2AT2 arrester was gradually damaged by thermal instability related to switching overvoltage.

To verify the effects of overvoltage in the system, the simulated phase voltage at the receiving end of the 220kV line are shown in Figure 6. From this figure, it is important to note that the simulated voltages behave the same waveform with the measured voltage signal from 7SA522 relay (see Figure 3). Moreover, the overvoltage is observed with the amplitude of 200kV under no load condition. The distortion of the voltage waveform is recognized as well. The phenomenon is probably due to the discharge of arresters when the voltage exceeds their discharge threshold. Consequently, the overvoltage is limited to the residual voltage of these arresters.

For that reason, these simulation results helped us underscore the failure and some recommendations would be proposed to the operator of the Thai Nguyen substation:

- Voltage of phase B at the receiving end of 220kV Ha Giang - Thai Nguyen line in the no load condition can be maxium because of the effect of phase disposition. With higher overvoltage level applied, the phase B of SA2AT2 arrester becomes thermal instability more easily.

- Replace or add more arrester is not reasonable solution. This could improve the thermal stability of arrester but the overvoltage problem will be not solved. Arrester with higher thermal energy absorption capability can only extend time to failure. Moreover, arresters with higher U_C (max continuous operation voltage) lead to dangerous residual voltage level for transformer in case of lightning overvoltage.

- The proposed solution is to install a shunt reactor at the receiving end of 220kV Ha Giang - Thai Nguyen. The solution will help suppress switching overvoltage at the 220kV side of Thai Nguyen substation when SVC and 110kV line tripping occur.

4. CONCLUSION

220kV Malutang - Ha Giang - Thai Nguyen transmission line provides energy solution for Thai Nguyen province and its surrounding. However, the switching overvoltage is often reported in the operation when load is tripped. This lead to the failure of arrester located at the 220kV side of the autotransformer in Thai Nguyen substation. Therefore, the aims of our work are to highlight the failure by using ATP-EMTP simulation. The obtained results helped us analyze the cause then give some recommendation to the operator of the Thai Nguyen substation. The installation of shunt reactor at the receiving end of 220kV Ha Giang – Thai Nguyen line is finally proposed in order to suppress the switching overvoltage.

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