The Effect of Shunt Reactor on the Switching Overvoltages of 500 kV Transmission Lines : Case of EGAT, BSP-CBG-SNO-CHW Transmission Lines

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Abstract

The analysis of the effect of shunt reactor on the switching overvoltages of 500 kV systems can be done by the EMTP (Electromagnetic Transient Program). The shunt reactor can be used to reduce the switching overvoltage, but for each transmission line, the characteristics and the location are not the same. The study has been done by modeling the three 500 kV transmission lines which have different line parameters and switching overvoltages. The study consists of the steady-state voltage simulation. The main conclusion is that shunt reactor can be used with other devices as surge arrester and closing resistors to reduce switching overvoltage. However, the steady-state voltage may be the main factor to determine the shunt reactor size. The suitable shunt reactor size for each line is recommended.

1. Introduction

The shunt reactors can be used to control the switching overvoltages, but for each transmission lines the size of the shunt reactors will be different because they may have different line parameters due to different physical structures. The study of the effect of shunt reactors on the switching overvoltages in EHV system leads to the selection of proper size of shunt reactor that has a good performance to control the switching overvoltage.

According to the International Electrotechnical Commission (IEC) recommendation, all equipment designed for operating voltages above 300 kV should be tested under switching impulses. With the steady increase in transmission voltage needed to fulfill the increase of the transmitted powers, switching surges have become the governing factor in the design of insulation for the EHV and UHV systems. In the meantime, lightning overvoltage come as a secondary factor in these networks. There are two fundamental reasons for this shift in relative importance from lightning to switching surges as higher transmission voltages are called for:

a. Overvoltage produced on transmission lines by lightning strokes are only slightly dependent on the power system voltages. Their magnitudes relative to the system peak voltage decrease as the latter is increased.

b. The external insulation has its lowest breakdown strength under surges whose fronts fall in the range 50 to 500 μs, which is typical for switching surges.

According to the IEC recommendation, switching overvoltage is the first priority factor to select the insulation level for EHV systems.

2. Switching Overvoltage in Power Systems

Switching overvoltage is one of the internal overvoltages generated by changing the operating conditions of the network. There is a great variety of events that would initiate a switching surge in a power network, such as when a switch in an electric circuit is opened or closed, in both transmission and distribution circuits. The interruption by switching operation of a circuit having inductance and capacitance may result in transient oscillations that can cause overvoltages in the systems. The switching operations of greatest relevance to insulation design can be classified as follows:

1. Switching off an unloaded line, cable or capacitor bank.

2. Energization of transmission lines and cables.

3. Re-energization of transmission line carrying charges trapped by previous line interruptions when high-speed reclosers are used.

4. Load rejection. This is effected by a circuit breaker opening at the far end of the line. This may also be followed by opening the line at the sending end.

5. Switching on and off of equipment. All switching operations involving an element of transmission network will produce a switching surge.

6. Fault initiation and clearing.

3. The Shunt Reactor

Shunt reactor had been employed on power systems to partially compensate the capacitive charging currents of long high voltage AC overhead lines or of high voltage cable systems. The technical advantages include:

1. Control of voltage rise at the ends of long high voltage lines at periods of light load or following load shedding.

2. Prevention of self-excitation of generators on leading-power-factor load.

3. Reduction of overvoltage during a line to ground fault.

4.Reduction of switching overvoltage due to the initial charging of lines.

In a developing network in which the generation of power is far from the load centers, shunt reactors are frequently essential in order to provide voltage control of the very long high voltage AC lines required, particularly during the initial lightly-loaded stage. Similar effects can also arise in high voltage cable systems and relative short lengths can produce problems because of their much higher capacitance per unit length.

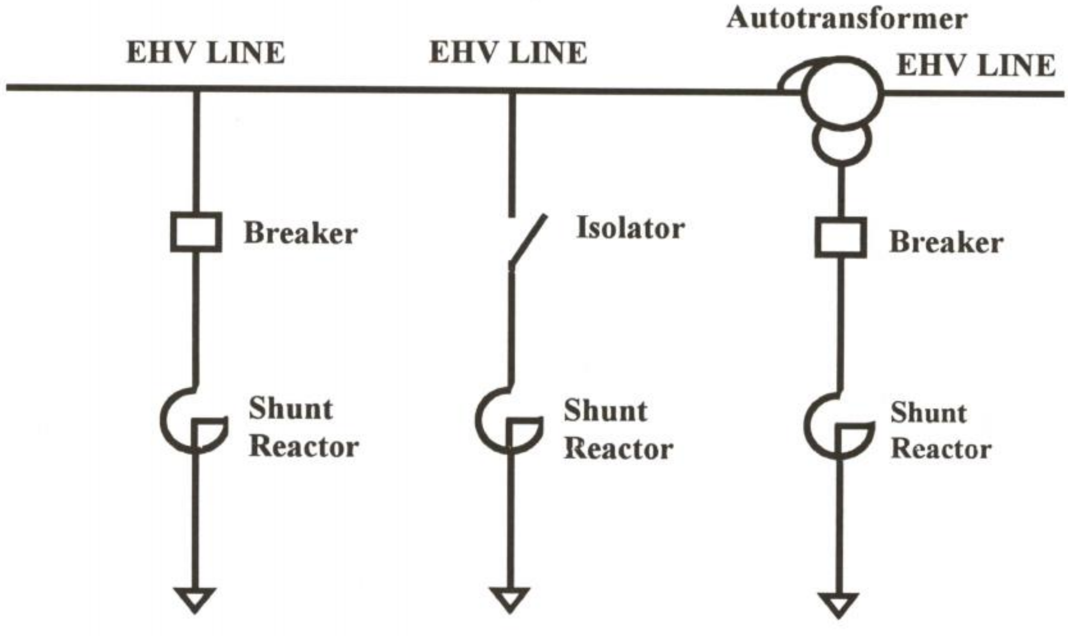

Fig. 1 Methods of Connecting Shunt Reactors to EHV Lines

4. System Modeling and Insulation Level

The major components of 500 kV systems are listed in Table 1. Consider the EGAT' s 500 kV equipment insulation level, the minimum insulation level is 1175 kV. the acceptable maximum switching overvoltage in EGAT' s system is 1175 kV. This is the reference insulation level for result analysis of EGAT 500 kV system.

- Surge arrester: The case of line energization with surge arrester at both end
- L-rec: The case of line energization with shunt reactor at receiving end
- L-send: The case of line energization with shunt reactor at sending end
- L-both: The case of line energization with shunt reactor at both end

Table 1 Equipment modeling of 500 kV transmission line

Item	Equipment	Model
1	Generator	Non-linear elements, Type three phase (X)-matrix
2	Three phase step-up transformer	Lumped linear elements, short circuit impedance
3	Circuit breaker	Lumped linear elements for pre-insertion resistors, Ordinary switches
4	Surge arrester	Non-linear elements, type metal oxide arrester
5	Transmission line	Distributed parameter, completely transposed
6	Single phase subtransmission transformer	Lumped linear elements (short circuit impedance)
7	Shunt reactor	Lumped linear elements
8	Load	Lumped linear elements

5. The Calculation Results

Fig. 2 is the line diagram for the simulation calculations. The simulation calculations have been done for many cases such as:

- No device: The case of line energization without any protection device.
- R-350: The case of line energization with closing resistor 350 Ω.
- R-520: The case of line energization with closing resistor 520 Ω.
- Arrester and reactor: The case of line energization with both surge arrester and shunt reactor
- No-load energization and steady-state voltage with different shunt reactor size
- Simulation of different line lengths
- Simulation of different loads such as no-load, 50-, 100-MW load, 100-MVAr load
- Simulation of line de-energization

Each calculation includes many different phase angles to find the maximum value.

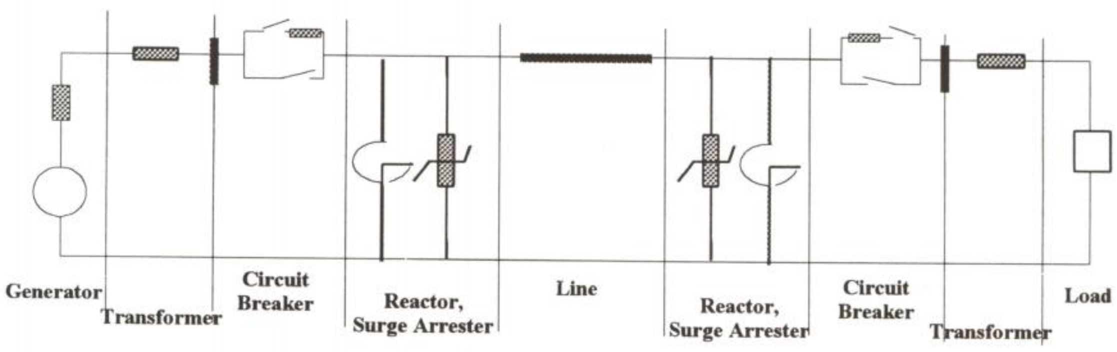

Fig. 2 The diagram of simulation calculation

5.1 Fig. 3 and 4 are the sample results of switching overvoltages of the short length (33-km) no-load 500-kV transmission line. The results show that the highest switching overvoltage will occur at the receiving end bus without protection device. The maximum switching overvoltages for each conditions are:

1. No-load line energization switching overvoltage is 849 kV.

2. Transformer at the receiving end bus, no-load line energization switching overvoltage is 849 kV.

3. For 100-MW load line energization switching overvoltage is 588 kV.

4. For 50-MW load line energization switching overvoltage is 694 kV.

5. For 100-MVAr inductive load, line energization switching overvoltage is 767 kV.

6. For 100-MVAr capacitive load, line energization switching overvoltage is 947 kV.

7. For 100-MVAr inductive load, line de-energization switching overvoltage is 400 kV.

8. For 100-MVAr capacitive load, line de-energization switching overvoltage is 510 kV.

The results can be summarized as follow:

1. Line energization.

1.1 For the case of no protection devices, the line energization switching overvoltage is the most severe. The maximum peak value is 947 kV for 100-MVAr capacitive load, 849 kV for no-load and 767 kV for 100-MVAr inductive load. These are lower than SWIL 1175 kV. Thus, all equipment has sufficient insulation level.

1.2 Inserted resistor (520 Ω) is the most efficient switching overvoltage control device compared with other overvoltage protection devices.

1.3 The effect of shunt reactor is the smallest. Switching overvoltages are nearly the same for different location of shunt reactor.

2. Line de-energization switching overvoltage is not severe when comparing with the energization case.

3. The shunt reactor size varies inversely with the percent compensation for the switching overvoltages. This is the same as the steady-state voltage.

4. The transformer at the receiving end is one of the factors that increases the switching overvoltage. With the capacitive load, such as shunt capacitor bank the switching overvoltage is most severe. The real power increase can reduce switching overvoltage.

5. For the EGAT 500-kV system, surge arresters are installed at both ends of the line. That is enough for switching overvoltage control in 33-km length transmission line. The shunt reactor size should not be determined by the switching surges, because all results indicate that the switching overvoltages are within the maximum limit. The steady-state voltages under no-load are less than 1.05 pu. So that 33-km transmission line needs not shunt reactor.

5.2 Fig. 5 and 6 are the sample results of switching overvoltage of the medium length (95 km) 500-kV transmission line. All results show that the highest switching overvoltage will occur at the receiving end bus without any protection device. The maximum switching overvoltages for each conditions are:

1. No-load line energization switching overvoltage is 896 kV.

2. Transformer at the receiving end bus, no-load line energization switching overvoltage is 896 kV.

3. For 100 MW load, line energization switching overvoltage is 666 kV.

4. For 50 MW load, line energization switching overvoltage is 735 kV.

5. For 100 MVAr inductive load, line energization switching overvoltage is 802 kV.

6. For 100 MVAr capacitive load,

line energization switching overvoltage is 1076 kV.

7. For 100 MVAr inductive load, line de-energization switching overvoltage is 430 kV.

8. For 100 MVAr capacitive load, line de-energization switching overvoltage is 568 kV.

The results can be summarized as follows:
Line energization : For the case of without no device, the line energization switching overvoltage is the most severe. The maximum value is 1076 kV for 100-MVAr capacitive load, 896 kV for no-load and 802 kV for 100 MVAr inductive load. All these values are lower than SWIL 1175-kV. Thus, all equipment has sufficient insulation level.

The remaining is similar to 5.1 except the following:

For the EGAT' s 500-kV system, surge arresters are installed at both ends of the line. That is enough for switching overvoltage control in 95-km transmission line. The shunt reactor size should not be determined by the switching surges, because all results indicate that the switching overvoltages are within the maximum limit. The steady-state voltages is most important and under no-load they are less than 1.05 pu. so that the compensation should be 60 % or 62 MVAr. Since the size is not big, only one shunt reactor at receiving end is sufficient.

5.3 Fig.7 and 8 are the results of switching overvoltages of the long length (285 km) 500-kV transmission line. All results show that the highest switching overvoltage will occur at the receiving end bus without protection device. The maximum switching overvoltages for each conditions are:

1. No-load line energization switching overvoltage is 1340-kV.

2. Transformer at the receiving end bus, no-load line energization switching overvoltage is 1340 kV.

3. For 100 MW load, line 974-kV.

4. For 50 MW load, line energization switching overvoltage is 1133 kV.

5. For 100 MVAr inductive load, line energization switching overvoltage is 1128 kV.

6. For 100 MVAr capacitive load, line energization switching overvoltage is 1757 kV.

7. For 100 MVAr inductive load, line de-energization switching overvoltage is 577 kV.

8. For 100 MVAr capacitive load, line de-energization switching overvoltage is 913 kV.

The results can be summarized as follows:

1. Line energization

1.1 For the case of no protection devices, the line energization switching overvoltage is the most severe. The peak value is 1757 kV for 100 MVAr capacitive load, which is higher than SWIL 1175 kV. When the inserted resistors (both 350 and 520 ohms) are used, the overvoltage is still higher than SWIL 1175 kV. The best method for overvoltage controls is the combination of three devices (surge arresters, closing resistance and shunt reactor) and the peak value can be reduced to 707 kV (At 80 % compensation and 520 Ω inserted resistor) which is less than 1175 kV.

1.2 Surge arrester is the most efficient switching overvoltage control device compared with other overvoltage protection devices, particularly in the longer line.

2. Line de-energization switching overvoltage is not severe compared with the energization case.

3. For the different shunt reactor size, the switching overvoltage is varies inversely with the percent compensation and this is the same for the steady state voltage.

4. The transformer at the receiving end is one of the factors increasing the switching overvoltage. With the capacitive load such as shunt capacitor bank the switching overvoltage is the most severe.

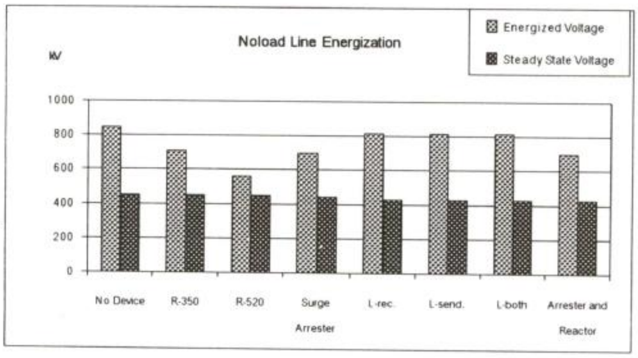

Fig. 3 The voltage magnitude at receiving end bus, the case of no-load 33 km line energization

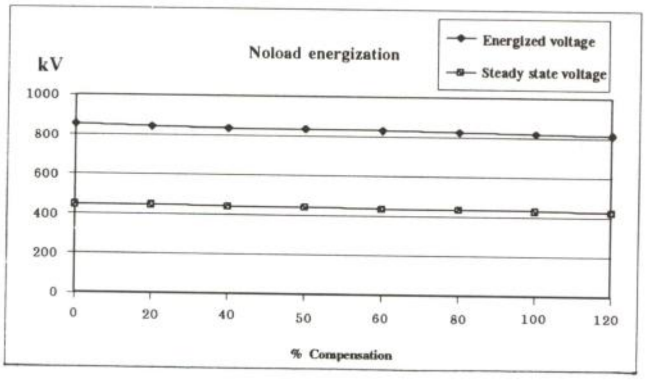

Fig.4 No-load line energization and steady-state voltage with different shunt reactor sizes (33 km line)

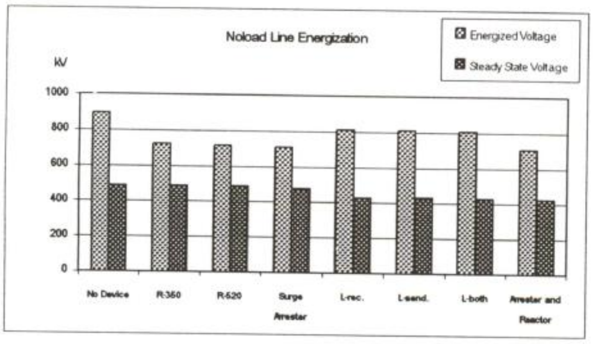

Fig. 5 The voltage magnitude at receiving end bus, the case of no-load 95 km line energization

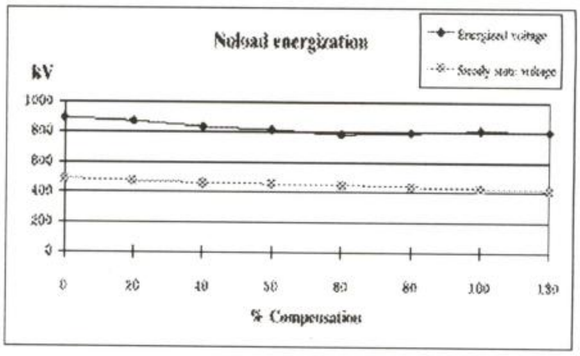

Fig. 6 No-load line energization and steady state voltage with different shunt reactor size (95 km line)

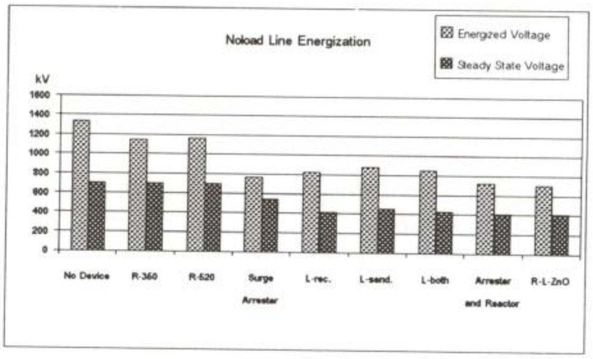

Fig. 7 The voltage magnitude at receiving end bus, the case of no-load 285 km line energization

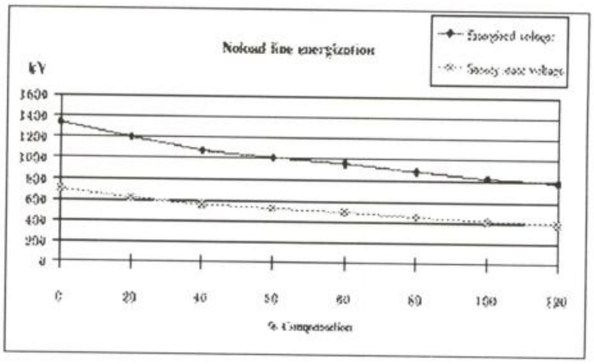

Fig. 8 No-load line energization and steady-stat voltage with different shunt reactor sizes (285 km line)

energization switching overvoltage is But real power can reduce the switching overvoltage. The shunt reactor can control switching overvoltage efficiently in the longer transmission line.

5. For the EGAT' s 500-kV system, surge arresters are installed at both ends of the line and the circuit breaker are equipped with closing resisters. The size of shunt reactor in the system is mainly determined by the steady-state voltage. The system maximum steady-state no-load voltage is 1.05 pu. the compensation should be 80 % or 249 MVAr. This value is very high, therefore shunt reactors should be installed at both sides of the line.

6. Conclusions

From the results above, the following conclusions are drawn. The most severe switching surge will occur when

1. Line energized with capacitive load
2. Line energized without overvoltage control device

The effect of shunt reactor on switching overvoltage reduction will be more efficient for the longer line than the shorter line.

The short-length transmission line needs no shunt reactors, the medium-length transmission line needs about 60 % compensation and the long-length transmission line need 80 % compensation.

Shunt reactor can reduce switching overvoltages but it is not the main factor to determine the installation. However, the steady state voltage is the main factor, and it is also the main factor to determine the shunt reactor sizing. The location of shunt reactor is slightly effect to control the switching overvoltage.

There are many factors to determine the shunt reactor location.

Steady state voltage. With shunt reactors at both end, the steady-state voltage will be better distributed.

Reactor size. Because the slight difference of switching overvoltages for each case of different locations, the shunt reactor size could be the main factor for location consideration. For example, for 285-km line, the total compensation is 249 MVAr. This is very large, so that it should be divided into two units for better voltage distribution and easy transportation. For the 95-km case, only 62-MVAr is needed. A single unit at the receiving end is more suitable with better voltage distribution than at sending end.

For the 33-km or short length transmission line the surge arresters are installed at both ends, the ZnO surge arresters are enough for switching overvoltage control.

For the 95-km or medium-length transmission the surge arresters are normally installed at both ends, the ZnO surge arrester is enough for switching overvoltage control. However, the switching overvoltage is rather high, shunt reactor or closing resistor areis useful to control the switching overvoltages.

For the 285 km or long length transmission line, the switching overvoltage is the most severe. Therefore, more protection devices, such as: surge arrester, inserted resistor and shunt reactor are necessary.

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