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Impact of DC Filters Energies on the Commutation Failure in HVDC CIGRE Benchmark

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Abstract. The present work is devoted to study and simulate of the functioning of monopolar HVDC LCC system of 500 kV in the presence of an AC power grids voltage disturbance. The CIGRE HVDC LCC Benchmark was simulated using MATLAB/Simulink in presence of AC grids voltage variations: first an overvoltage in AC grid 1 and second voltage drop in AC grid 2 have been simulated. All of these simulations are done to evaluate the robustness of the CIGRE HVDC LCC benchmark against AC grids voltage variation, and to investigate the ability of HVDC link function after disappearing of the simulated variation. The results showed that the HVDC LCC system is sensitive to overvoltage higher than 15 % appearing at the rectifier level, and is sensible too to voltage drops with more than 10 % at the invert level. In these conditions, a commutation failure leading to short-circuit was observed, which interrupt the HVDC link operation, and doesn't permit re-establishment of link function after fault disappearing. To find the reason of the commutation failure appearing, the magnetic and electrostatic energies stored in DC filter elements have been measured and analyzed. The analysis show that when the magnetic energy is greater than the electrostatic one, the commutation failure appears.

Keywords. HVDC, power electronics, voltage disturbance, commutation failure, DC filters, capacitors energies

1. Introduction

The High Voltage Direct Current (HVDC) systems have been invented to overcome the limits of the High Voltage Alternating Current limits either in distance, stability, synchronism …., over than 200 HVDC links are operating around the world [1]. This technology is principally based to the use of power electronics converters (rectifier) to transform AC electrical energy absorbed from the first AC grid to DC electrical energy to be transmitted in DC form and converted again to AC form (using inverters) to be injected to the second AC power grid [2].

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Two main types of electronic components are used to distinguish the power converters used in the HVDC systems [3,4]: by using the thyristors in converters called Line Commutated Converter (LCC), or by using IGBT in converters called Voltage Source Converter (VSC).

Many investigations have been published about commutation failure problems in the HVDC systems. Wang et al. [5] have studied the impact of harmonics on the commutation failure in thyristor inverters. Gao et al. [6] have studied the commutation failure in the HVDC LCC system, and the authors have proposed a novel controllable LCC based on combination of semiconductor devices.

In the present investigation, we will study the behaviour of HVDC CIGRE Benchmark [7] in presence of the AC grid voltage disturbance, and this to evaluate the HVDC system robustness against AC voltage disturbance. The voltage disturbances consist in the first AC grid overvoltage increase and the second AC grid voltage drop. The paper is structured as follows: The second section presents the CIGRE Benchmark model studied. The simulation results and discussions are shown in section 3. The last section gives the concluding comments.

2. HVDC CIGRE Benchmark

CIGRE [7] has proposed a monopolar HVDC benchmark as illustrated in figure 1. The used technology is LCC system of 12 pulse converter, the DC voltage is 500 kV and the transmitted power is 1000 MW. Both AC grids are of 50 Hz frequency with 2.5 p.u. Short-Circuit Ratio (SCR).

The DC mean voltage obtained at the rectifier side is given by [1]:

$$V_d = \frac{3\sqrt{2}}{\pi} V_{c1} \cos\alpha - \frac{3}{\pi} X_{c1} I_d \tag{1}$$

With: Vc1 is the first grid phase to phase RMS voltage (in the transformer secondary), α is the rectifier pulse angle, Xc1 is commutation reactance due to inductive effect in the first power grid, and I_d is the mean DC current which is given by [1]:

$$I_d = \frac{V_c}{\sqrt{2}\, X_{c1}} (\cos\alpha + \cos(\alpha + u)) \tag{2}$$

With u is the commutation angle due to the first AC system reactance.

The mean DC voltage at the inverter side is given by [1]:

$$V_d = \frac{3\sqrt{2}}{\pi} V_{c2} \cos\gamma + \frac{3}{\pi} X_{c2} I_d \tag{3}$$

And the mean current for the inverter is [1]:

$$I_d = \frac{V_{c2}}{\sqrt{2}\, X_{c2}} (\cos\gamma + \cos(\gamma + \beta)) \tag{4}$$

With: Vc2 is the second grid phase to phase RMS voltage, γ and β are inverter pulse angle and the commutation angle due to the inductive effect in second power grid.

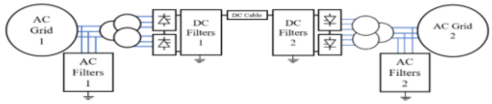

Figure 1. CIGRE HVDC benchmark simulated.

The reactive power consumed by the rectifier depends to the active transmitted power P and of course to the rectifier's pulse angle. This power is given by [1]:

$$Q = P \tan(\alpha) \tag{5}$$

For the inverter, the same relation is used with replacing the angle α by γ.

The reactive power consumed by converters is generated by capacitor and the AC filters.

All of these parameters have been implemented in the simulation realized under MATLAB/Simulink.

3. Simulation Results and Discussion

The HVDC CIGRE Benchmark will be simulated under AC grid voltage variation. For this, two cases are simulated: the first one consists of the first grid voltage variation, and the second one with variation of the second grid voltage variation.

We simulate the overvoltage impact for the first AC grid (Source), and the second AC grid voltage decrease (load). In these simulations, the converter pulses angles are maintained without any variations, and this to evaluate the performance of the CIGRE HVDC benchmark to resist against AC grid voltage variations which may be generated. Several variations are considered.

The voltage will be varied five times from its nominal value to another value with a step value of 0.04, 0.08, 0.12, 0.16 and 0.2 respectively: for the first grid the AC grid voltage will be increased with the precedent steps, and for the second AC grid the voltage will be decreased. The AC grids voltage profiles variations are illustrated in figure 2.

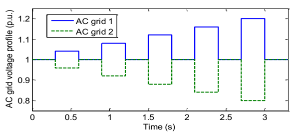

Figure 2. AC grids voltages profiles considered for our simulation.

3.1. Impact of the AC Grid 1 Overvoltage

For the first step, we will evaluate the impact of voltage increase in the first AC grid: we will increase the first AC grid voltage with four steps : +4%; +8%; +12%; +16% and +20%. The voltage will be increased for 0.3 seconds, and after that will be changed to its nominal value, and this to evaluate the possibility of HVDC LCC resistance against voltage variation with big steps. The results for the simulation with AC grid 1 voltage variations for the parameters of both AC grids and DC one are illustrated in the figure 3.

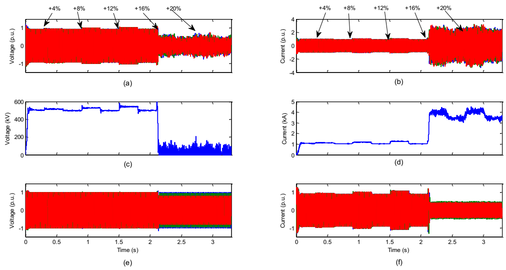

Figure 3. Impact of AC grid 1 voltage variation on the CIGRE HVDC benchmark: (a)&(b) AC grid 1 voltage and current; (c) &(d) DC side voltage and current, (e)&(f) AC grid 2 voltage and current.

We observe that for the voltage increases in the AC grid 1 with 4, 8 and 12 % that the HVDC system is not really damaged by the voltage variation, and the system re-establish its initial conditions when the AC grid 1 overvoltage disappears. When the voltage of AC grid 1 has been increased with 16% and 20 %, a short circuit is observed in DC side and AC grid 1, with voltage & current deformation observed in AC grid 2, and this may be due to the commutation failure in the converters.

To investigate the reason of this commutation failure, we have measured during the simulation the stored energy in the smoothing reactor and in the capacitors by using the relations (6) and (7) respectively [1]:

$$W_L = \frac{1}{2} L\, i^2 \tag{6}$$

$$W_C = \frac{1}{2} C\, u^2 \tag{7}$$

Where i is the current in passing through the smoothing reactor (DC current in our case), and u is the voltage applied to each capacitor.

The energies in the DC filters elements installed in rectifier side and inverter side are illustrated in figures 4(a) and (b) respectively.

We observe in the nominal case, the energy stored in the capacitors is greater than the energy in the smoothing reactors, and this in both sides. When the voltage has been increased with the steps +4%, +8% and +12 % we have observed that the inductor energy increase, but it still lower than the capacitors energy.

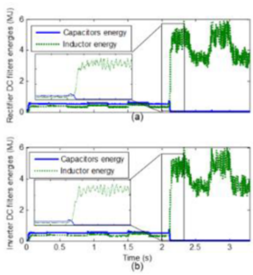

Figure 4. DC filter elements stored energy during the voltage increase in AC grid 1:(a) the rectifier side, (b) the inverter side.

When the voltage has been increased with 16 and 20%, we have observed that the magnetic energy has been increased with a great value exceeding the capacitors energies, and with this increase the capacitors energies drop to zero, and this for the two sides of the HVDC system.

3.2. Impact of the AC Grid 2 Voltage Drop

After studying the overvoltage in AC grid 1 impact on the HVDC link, we study the impact of the impact of voltage sags in the AC grid 2. Here, we will evaluate the impact of voltage drop in the second AC grid: we will decrease the second AC grid voltage with four steps: -4%; -8%; -12%; -16% and -20%. The voltage will be decreased each time for 0.3 seconds as done for the previous simulation, and after that will be re-established to its nominal value. The simulation results consisting in AC and DC grids parameters are presented in figure 5.

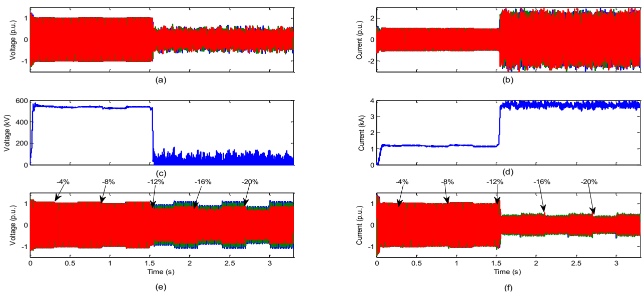

Figure 5. AC grid 2 voltage drop impact on the CIGRÉ HVDC benchmark : (a)&(b) AC grid 1 voltage and current ; (c) &(d) DC side voltage and current, (e)&(f) AC grid 2 voltage and current.

The results illustrates that the slight voltage drop don't interrupt the HVDC link work, but with voltages drops more than 10 % a commutation failure is observed in the HVDC link; a short circuit is observed in the AC grid 1 and in DC side, with wave distortion in the AC grid 2 parameters. This commutation failure may be due to the excessive increase of energy in the smoothing reactors (figure 6), without re-establishment to its initial value.

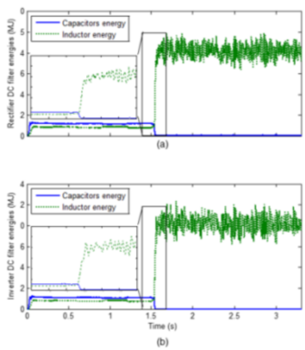

Figure 6. DC filter elements stored energy during the voltage drop in AC grid 2 :(a) the rectifier side, (b) the inverter side.

As has been observed before, when the smoothing reactor energy is lower than the capacitors energies, the HVDC link function is maintained.

For the present case, when the voltage has been decreased with 12, 16 and 20%, the magnetic energy in the smoothing reactors have increased with great value exceeding the capacitive has been increased with a great value exceeding the capacitors energies, and with this increase the capacitors energies drop to zero, and this for the two sides of the HVDC system.

4. Conclusion

This paper has presented to study the behaviour of CIGRE HVDC LCC Benchmark when subjected to AC grid voltage variations and this to evaluate the robustness of the HVDC function.

In the case of AC grid 1 overvoltage: when the voltage has increased with relatively small values (4 to 12%), the capacitors are charged gradually to reach the new DC voltage level. But when the voltage has been increased with great value, the capacitors have required a considerable current to be charged and reach the DC voltage level, but this current have passed by the smoothing reactor, which have increased its energy and becomes greater than the capacitors one, and in this case the capacitor voltage have dropped because of commutation failure, and a short-circuit have appeared.

In the case of AC grid voltage drop: when the voltage has decreased with weak values (4 to 8%), the capacitors are discharged gradually to reach the new DC voltage level fit the AC grid one. But when the decrease is considerable, the capacitors are discharged through the smoothing reactors with important current magnitudes, which increase its energy and becomes greater than the capacitors one. So, the DC voltage drops because of commutation failure, and a short-circuit have appeared.

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