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Analysis of faults on high voltage direct current HVDC transmissions system

***Abstract**. High Voltage Direct Current (HVDC) Transmission with Voltage Source Converters (VSC) is gaining substantial interest from several utilities for various applications as compared to traditional HVDC transmission rely on thyristor technique. The paper presents analysis of three-level VSC-HVDC system during faults on the AC part. The system model is simulated in MATLAB/Simulink, with various faults analysed, such as single line to ground, line to line and double line to ground fault. The results obtained show that the control system respond well to all fault conditions.*

Streszczenie.** Transmisja wysokiego napięcia prądu stałego (HVDC) za pomocą konwerterów źródła napięcia (VSC) zyskuje duże zainteresowanie ze strony kilku zakładów użyteczności publicznej do różnych zastosowań w porównaniu z tradycyjną transmisją HVDC opierającą się na technice tyrystorowej. W artykule przedstawiono analizę trójpoziomowego systemu VSC-HVDC podczas zwarć na części AC. Model systemu jest symulowany w programie MATLAB/Simulink, z analizowanymi różnymi zwarciami, takimi jak zwarcie pojedyncze linia-ziemia, linia-linia i podwójne zwarcie linia-ziemia. Uzyskane wyniki pokazują, że układ sterowania dobrze reaguje na wszystkie stany awaryjne.* (Analiza błędów prądu stałego w systemie przesyłowym wysokiego napięcia HVDC***)

Keywords: HVDC, PWM, IGBT and VSC.
Słowa kluczowe: sieci HVDC, błędy prądu, IGBT.

Introduction

The High voltage direct current (HVDC) transmission system has advanced and gained widespread acceptance. Technical progress is mainly due to high voltage converters and high voltage devices [1-3]. The use of HVDC over the past thirty years has become an available method for transmitting energies in large quantities over long distances. Today HVDC is recognized as effective method for transmitting large power on overhead lines. Since HVDC is such a massive power transmission system, short-term breakdowns might result in complete darkness in the supplied area [4, 5]. In some renewable energy sources, wind energy takes the advantages of HVDC technologies to transmit energy and improve system performance. There are two technologies for HVDC transmission system [6-8] :

1- The Line Commutated Converter (LCC) is a thyristor-based technology.

2- Pulse Width Modulation (PWM) technology is used in the Voltage Source Converter (VSC) technology, which is based on IGBT.

VSC based HVDC systems are the preferred technology for effective network. In addition to lower harmonic generation, this integral allows for rapid and precise control of real and reactive power across both ways. Which improves power goodness and system reliability [9, 10]. The division of converters into two categories must be distinguished by their principle of operation. To function, the first category requires an AC system. Point wave suppression can be investigated using controlled semiconductors such as thyristors, when the AC system voltage drives current to move from phase to phase. As a result, the converter may control the energy exchanged between the AC and DC systems [11]. The second category of converters does not require an AC power source to function. As a result, they are known as self-switching converters. This category can also be separated into converters of current and voltage (CSCs) (VSC), depending on the DC circuit's design. The CSC uses DC current with a reactor, whereas the VSC uses a steady DC voltage given by storage capacity [12]. This work presents analysis of the demeanour of the 3-level VSC-HVDC during failures on the AC side. The selected model is simulated in MATLAB/Simulink, with various faults analysed, such as line-line fault, single-line to ground fault and double-line to ground fault at the AC side of the system.

Design of HVDC System

Figure (1) demonstrates the simulation's HVDC transmission model, which contain the following main components:

1- Transformer: To achieve the best voltage conversion, a type of transformer (wye grounded/delta) has been used. The current winding configuration prevents (filters) the third harmonics produced by the converter. The transformer ratios are at the rectifier side (the transmitter side) 0.915 and 1.1015 from the inverter's side (the receiving side). Because of the converter reactor and transformer leakage reactors, the VSC's output voltage can fluctuate in magnitude and phase from the alternating current system. In addition, the converter's active and reactive power outputs are controlled.

2- AC filer: AC filters are an essential part of the connection model, the filter components are connected in parallel, either the side of the alternating current system or the side of the converter transformer. Due to high arrangement of PWM, the harmonics will be increased. With simplified filter design, the unwanted harmonics caused by switching action will be removed.

3- DC capacitor: This is linked to the VCS terminals, as far as the DC voltage is concerned with minimal ripple, the DC capacitor through the converter terminal may remove this noise and result in steady DC voltage. The capacitor shouldn't be too large when system is interrupted due to turbulence, when the system is disrupted owing to turbulence, this ensures reliable steady-state performance.

4- DC Filter: The third harmonic is controlled in the DC side filters that block the high frequency, which is the primary harmonic found in the anode and cathode voltages. DC harmonics represent zero-sequence harmonics (odd multiple) that are moved to the DC side to maintain balance on this side. The difference between the electrode voltage must be controlled and kept to zero.

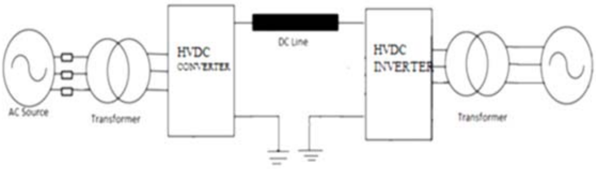


Fig.1. Two terminal HVDC System [6].

VSC Control System

The VSC is connected to the main circuit as shown in Figure (2), the design of the converter 1 and converter 2 is same. The two controllers are separated, there is no connection among them. Every variant had two degrees of freedom, in our state this controller is utilized as follows:

1- Station 1 (rectifier): P&Q
2- Station 2 (inverter): Vdc &Q

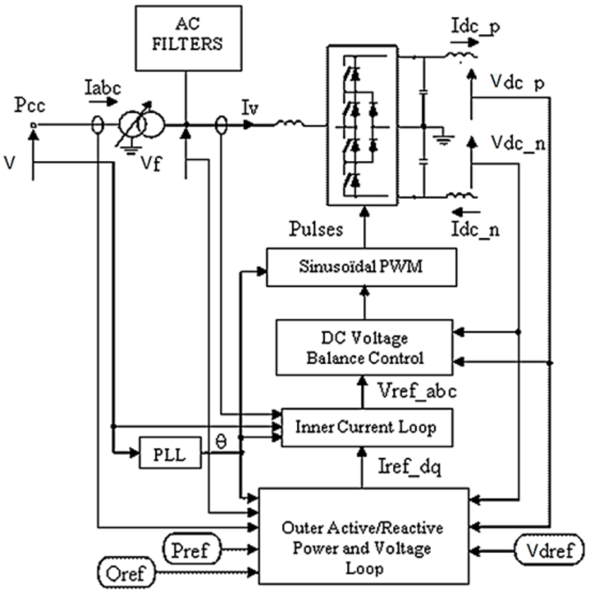


Fig.2. Connection of the main circuit to the VSC control system.

In this model, the control strategy uses the PWM technicality. The rectifier and the inverter give a various control model, in which case the model ought ever to meet the energy equilibrium as shown in equation (1)

$$P_{ac} + P_{dc} + P_{cap} = 0$$

$$P_{ac} + V_{dc}I_{dc} + V_{dc}I_{cap} = 0 \quad (1)$$

where I_{dc} represents DC bus current and I_{cap} is the DC capacitive current.

The AC system must pump enough power (P_{ac}) to charge the DC capacitor until V_{dc} reaches the specific level. The power flow may be controlled via controlling the DC voltage through changing the phase shift, assigned into equation (2). This control mode is specified into the rectifier and Figure (3) illustrates the control strategy for both ends of HVDC system.

$$P_{ac} = \frac{V_{s1}V_{d1}}{X_1}\sin\delta_1 \quad (2)$$

In terms of time, the total power is expressed in equation (3) [13,14].

$$S(t) = V_a(t)i_a(t) + V_b(t)i_b(t) + v_c(t)i_c(t) \quad (3)$$

$$P(t) = \frac{3}{2}\left[v_d(t)i_d(t) + v_q(t)i_q(t)\right] \quad (4)$$

and

$$Q(t) = \frac{3}{2}\left[-v_d(t)i_q(t) + v_q(t)i_d(t)\right] \quad (5)$$

Equation (4, 5) propose that if Vq =0, then the components of real and reactive power are commensurate into id, iq respectively. This feature is vastly used into controlling the three-phase VSC system which connected to the grid, it shows that switching to the periodic coordinate system leads to the possibility of controlling the id, iq independently. Thus, real and reactive power may be sep arately controlled.

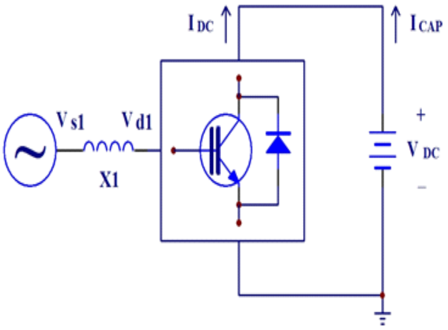


Fig.3. Control Strategy for both terminal HVDC System [10].

Dynamic Execution

The dynamic execution in the transmission system is proved via simulating and monitoring as:

1- Dynamic response into step variations used in the main regulator references, DC voltage and active/reactive power are examples.

2- Recuperating from small and large AC system disturbances.

Matlab/Simulink used to represent and analyse the transmission system as shown in Figure (4) that indicate a schematic exemplification of VSC-HVDC system for length of (175km) between AC system 1 and AC system 2.

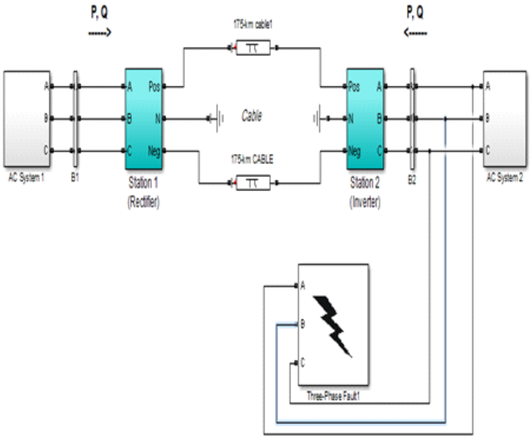


Fig.4. A Schematic exemplification of VSC-HVDC System.

Steady-State and Step Response

The results indicated in figures (5, 6) represent the dynamic responses of VSC-HVDC.

Station 1, which controls an active power converter, is unlocked at t=0.3s, and the power must tardily increase by 3 p.u. . while station 2 converter that control the DC voltage is unlocked at t=0.1s. At approximate t=1.3s steady state is achieved at both stations. In addition, the DC voltage equal to 1.8 p.u. at station 2 and the power of station 1 is equal to 3 p.u. . The reactive power flow is equal -0.1 p.u. in station 1 and a null value in station 2 system that controlled by both converters.

After reaching steady state, a -0.3 p.u. step is applied to the reference active power to converter 1 at t=1.5s, followed by a -0.1 p.u. step to the reference reactive power at t=2s. The dynamic response of the regulators are spotted.

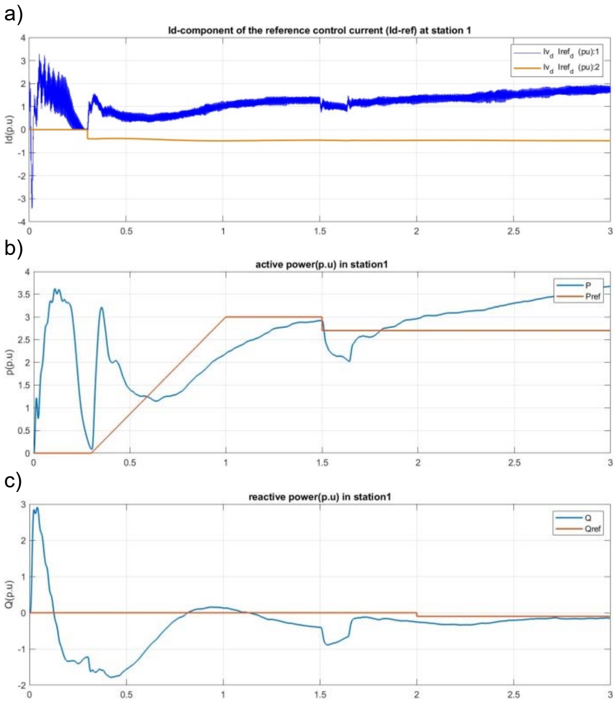


Fig.5. Start up and P&Q step responses in station 1.

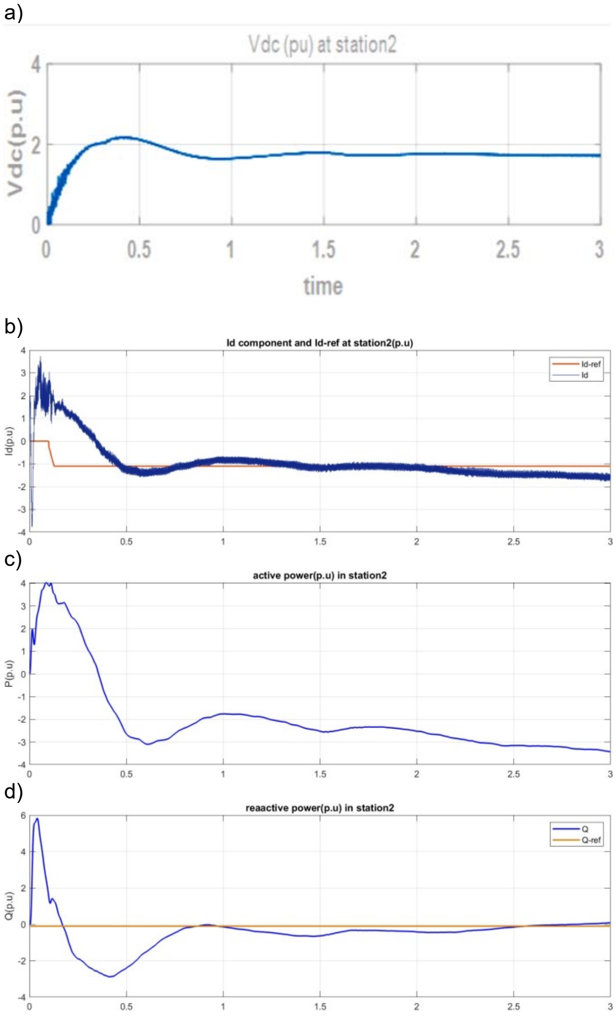


Fig.6. Start up and Vdc step responses in station 2.

Approximately, stability time is equal 0.3s. Similarly, figures including reference control current Id.

AC Side Disturbances to ground

At station 2, a slight and significant disturbance occurs in the normal situation. Three types of faults were tested: -

1- Single Line fault (S.L.G.)
2- Line- Line fault (L.L)
3- Double-Line to ground fault (D.L.G.)

The system retrieval from the disturbances would be fast and stable as explained below.

Single Line to Ground Fault

Figure (7) shows the S.L.G. fault, in which the DC power transferred is decreased by 50% and the DC voltage raised to 2.2 p.u. . As a result of this, the capacitance on the DC side has been overcharged. To sustain the DC voltage within a steady state, station 1's controller controls the active power output. After the fault, the system is retrieval good after 1.3s. The reactive power shows damped fluctuations about 10Hz.

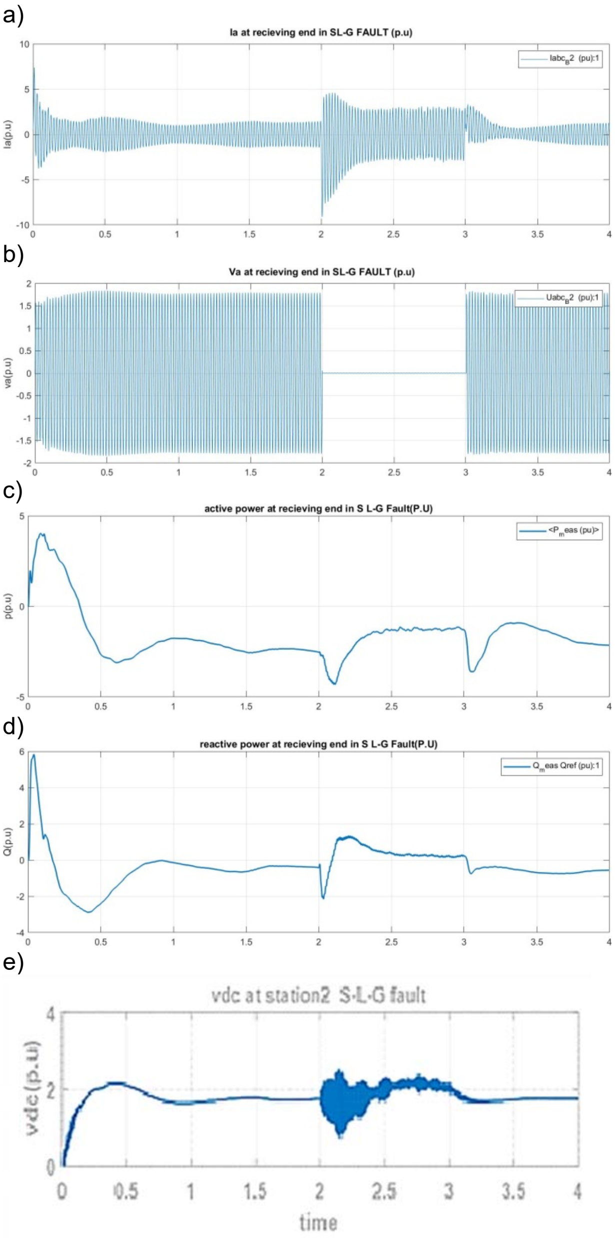


Fig.7. Single line to ground fault results.

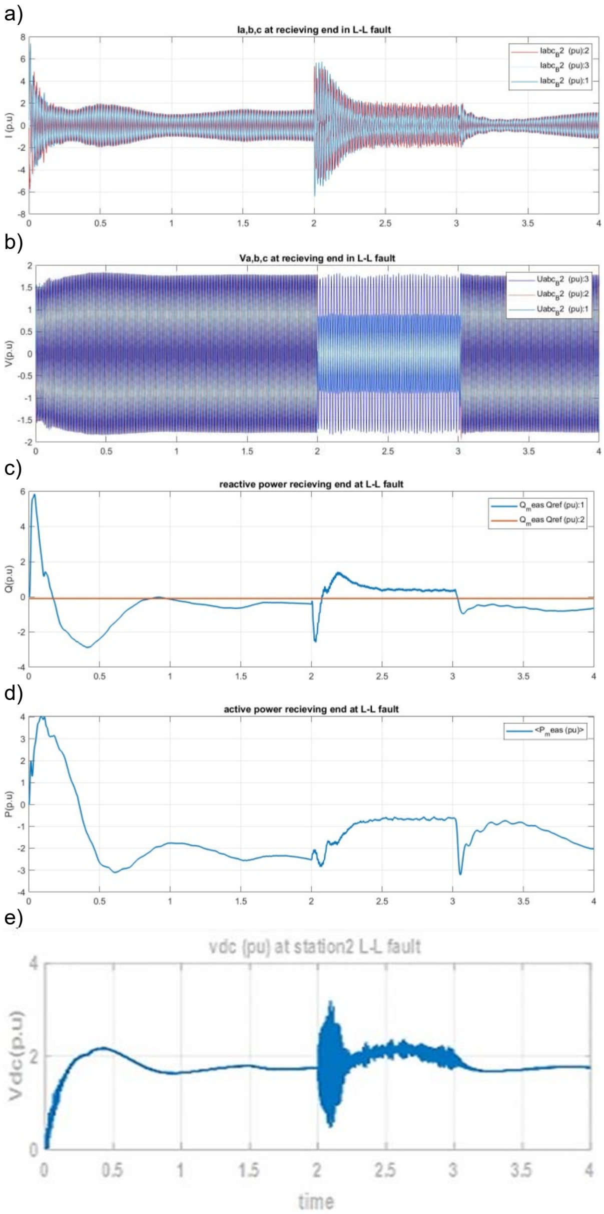
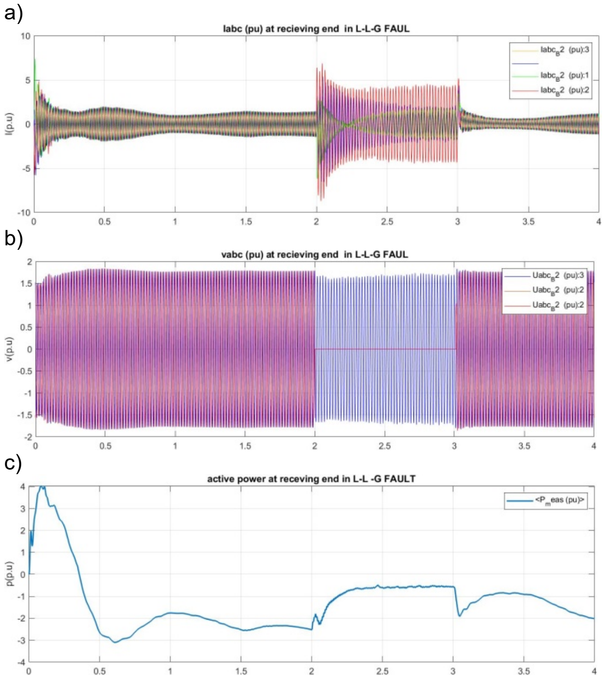


Fig.8. Line to Line fault results.



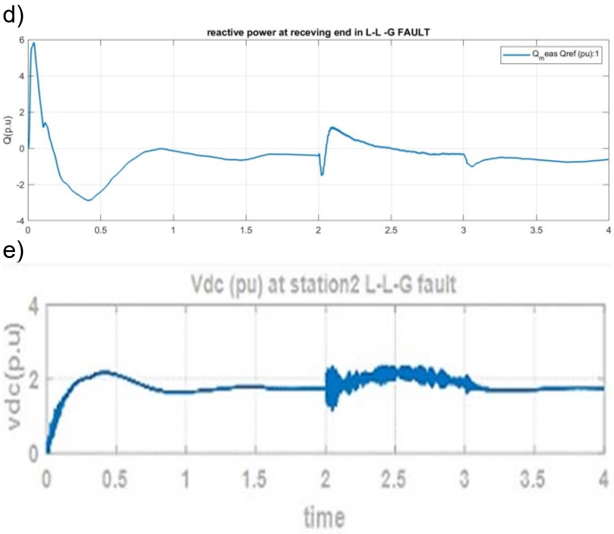


Fig.9. Double Line to ground fault results

Line-Line fault

The L.L. fault is depicted in Figure (8). It's important to note that the transferred DC power is decreased by 90% and the DC voltage raised toward (3 p.u.). The capacitance on the DC side has been overcharged as a result. As part of the active power control (at station 1), a special function called "DC Voltage Control Exceeds" attempts to keep the DC voltage within a certain range at all times. After 1.3 seconds, the system has been restored to full functionality. The reactive power shows damped fluctuations at 10 Hz.

Double-Line to Ground Fault

Figure (9) show the D.L.G. fault, It is worth noting that the L.L fault reduces the transmitted DC power by 90% while increasing the DC voltage to (2.3 p.u.). The capacitance on the DC side is being overcharged. The active power control (in station 1) has a function (DC Voltage Control Exceeds) that seeks to keep the DC voltage constant. After the fault, the system is retrieval good after 1.3s. In the reactive power, note the damped oscillations at 10Hz.

Conclusions

This paper presents the stable condition and dynamic performance of VSC in HVDC transmission systems over progressive variations of active and reactive powers. These analyses are performed under balance and unbalanced faults conditions. In each state, the suggested control strategy was found to satisfy dynamic responses of the suggested system. By simulation, it has been shown that VSC-HVDC can achieve fast response control of the bi-directional power transfer. It may also be noted that for S.L.G faults, the DC power transmitted is decreased by 50% while the DC voltage tend to rise. Also, during L.L. and D.L.G. faults, the DC power transmitted is decreased by 90% when the DC voltage rises. The system is fully recovered after the fault, within 1.3 s.

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