International Journal of
Engineering Studies and Technical Approach
ISSN No. 2395-0900

Steady and transient state performance of HVDC transmission system based on hybrid multilevel VSC with ac-side cascaded H-bridge cells

A Siva*, Shaik Hussain Vali ** & P Lakshmi***

****PG Student, Department of EEE, JNTUK-UCEV, Vizianagaram, AP, INDIA***

***** Assistant Professor, Department of EEE, JNTUK-UCEV, Vizianagaram, AP, INDIA***

*****PG Student, Department of EEE, JNTUK-UCEV, Vizianagaram, AP, INDIA***

ABSTRACT

This paper investigates the steady and transient state performance of HVDC transmission system based on a hybrid multilevel voltage source converter with cascaded H-bridge cells on ac-side. The proposed HVDC transmission system offers current limiting capability during dc-side fault. This feature eliminates the need of dc-side circuit breakers in dc power transmission system and filter design by generating higher pulse level. A simplified proposed HVDC transmission steady state model is first developed that can be used for power flow analysis. The transient performance is analyzed by examining the proposed transmission system responses to external AC-side (symmetrical and asymmetrical) and DC-side faults. Additionally, the FFT (Fast Fourier Transform) spectrums for the hybrid multilevel VSC HVDC transmission system outputs are compared and presented to validate the control strategy with existing VSC-based HVDC system.

Key-words: *Modular multilevel converter, pulse width modulation, hybrid multilevel VSC with cascaded H-bridge cells.*

1. INTRODUCTION

The introduction of pulse width modulated voltage source converter technology into high-voltage DC (HVDC) transmission systems has increased their growth and development in many applications[1]. The main benefits of voltage-source-converter high-voltage dc (VSC-HVDC) over the classic line commutated converter based HVDC (LCC-HVDC) are [2]-[9]:

i. Converter inherent reactive power capability.
ii. Independent control of active and reactive power.
iii. Black start capability.
iv. Without need to reverse the DC link voltage polarity, power reversal is achieved instantaneously.
v. Improved ac fault ride-through capability and the unique feature of current-limiting during dc side faults.

In the last decade, VSC-HVDC transmission systems have evolved from simple two-level converters to multilevel converters such as modular converters [10]–[14]. This evolution aimed to increase power-handling capability, improved ac side waveform quality in order to minimize or eliminate ac filters, reduced converter overall cost, reduced voltage stresses on converter transformers and lower semiconductor losses of VSC-HVDC transmission systems to the level comparable to that of conventional HVDC systems based [15]. This paper investigates, a new generation of converter using ac-side cascaded H-bridge cells has started to emerge as an interesting evolution for VSCs. Known as the hybrid multilevel VSC with ac-side cascaded H-bridge cells, this topology contain a large number of full bridge cells, and can thus generate low distortion ac current and no need of ac filters. Furthermore, in case of a dc fault, converter stations 1 and 2 must be able to block current flow between the ac and dc sides during dc fault period. An important feature of the proposed hybrid multilevel H-bridge multi level converter is its dc fault reverse blocking capability, this inherent feature enables the both converter stations are to block the path of the current flow in converter switches. With coordination between the HVDC converter station control functions, the dc fault reverse-blocking capability of the hybrid converter is exploited to achieve the following:

i. During dc fault period eliminate the ac grid contribution with dc system, hence minimizing the risk of converter failure due to uncontrolled over current.
ii. Facilitate controlled recovery without interruption of the VSC-HVDC system from dc-side faults without the need for opening ac-side circuit breakers.
iii. During dc-side faults, improve voltage stability of the ac networks by converter reactive power consumption is reduced.
iv. Simplify dc circuit breaker design due to a reduction in the magnitude and duration of the dc fault current.

2. HYBRID MULTILEVEL VSC WITH AC-SIDE CASCADED H-BRIDGE CELLS

Fig. 1 shows one phase of a hybrid multilevel VSC with n cells per phase. It can generate 4n+1 voltage levels between converter terminal ‘Ca’ and supply midpoint ‘0’. Therefore, with increase in number of H-bridge cells per phase, the gives near pure sinusoidal voltage to the converter transformer as shown in Fig. 1[1], and an effective switching frequency per device of less than 150Hz is possible.

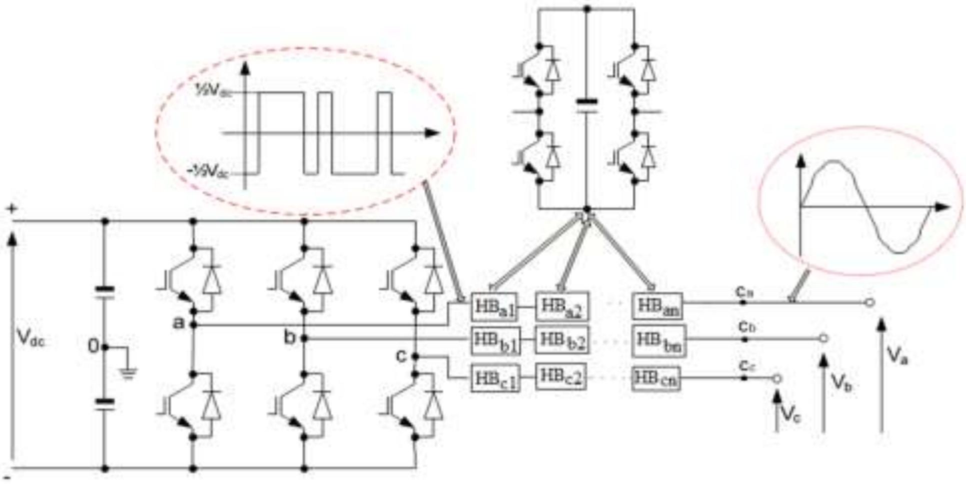


Fig.1. Hybrid multilevel VSC with ac-side cascaded H-bridge cells

The voltage across the H-bridge floating capacitors sum to (1/2)Vdc to minimize the conversion losses in the cells. These cells are controlled level-shifted carrier-based multilevel pulse width modulation with a 1-KHz switching frequency and the two-level VSC devices operate with 150-Hz switching frequency, hence low switching losses and low audible noise are expected. The two-level VSC device that blocks high-voltage controls the fundamental voltage using selective harmonic elimination with one notch per quarter cycle as shown in Fig. 1. The proposed HVDC transmission system requires a voltage-balancing scheme that ensures that the voltages across the H-bridge cells are maintained at Vdc/n under steady and transient state operation, where Vdc is the total dc link voltage. This voltage balancing scheme in hybrid multilevel VSC is realized by rotating the H-bridge cell capacitors, taking into account the voltage magnitude of each cell capacitor and phase current polarity. An additional PI regulator is used to maintain the voltage across the H-bridge cells is Vdc/n under all operating conditions as shown in Fig. 3. Further discussions on the capacitor voltage balancing methods can be found in references [3], [15].

3. SYSTEM OUTLINES

Fig.2 shows that a proposed HVDC transmission system based on a hybrid multilevel VSC with ac – side cascaded H- bridge cells, a 600kV HVDC transmission system with sending and receiving end converters (VSC1 and VSC2), modeled with hybrid multilevel converter with ac-side cascaded H-bridge cells. Converter station 1 and 2 are connected to two AC networks through 687MVA, 330kV/400kV transformers.

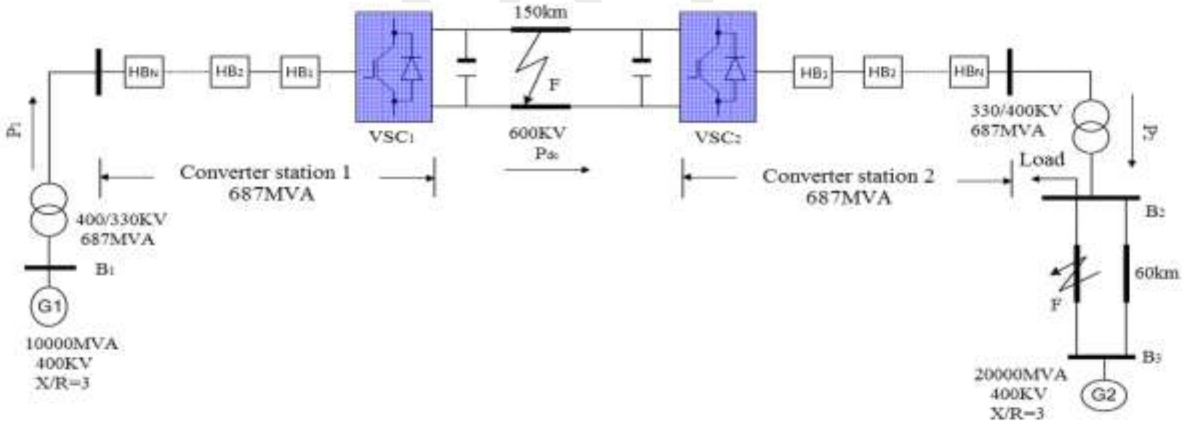


Fig. 2. Proposed HVDC tranmission system

Fig.2 summarizes the control functions of the converter stations 1 and 2. The power flow directions indicated in Fig. 2 are assumed positive.

4. PERFORMANCE EVALUATION

This section assesses the steady and transient state performance of the proposed VSC-HVDC system is investigated here. In the steady state, the test network in Fig. 2 is used to assess its power control and voltage support capabilities. To further illustrate the advantages of the hybrid multilevel converter during ac and dc network disturbances, the same test network is subjected to a three-phase(symmetrical) ac-side fault, line-to-line(asymmetrical) ac-side fault and a pole-to-pole dc-side fault at locations depicted in Fig. 2 for a 140-ms duration(7 cycles for 50Hz systems). Converter stations 1 and 2 in Fig. 2 are represented by detailed hybrid VSC models with seven cells per phase, with the controllers in Fig. 3 incorporated.

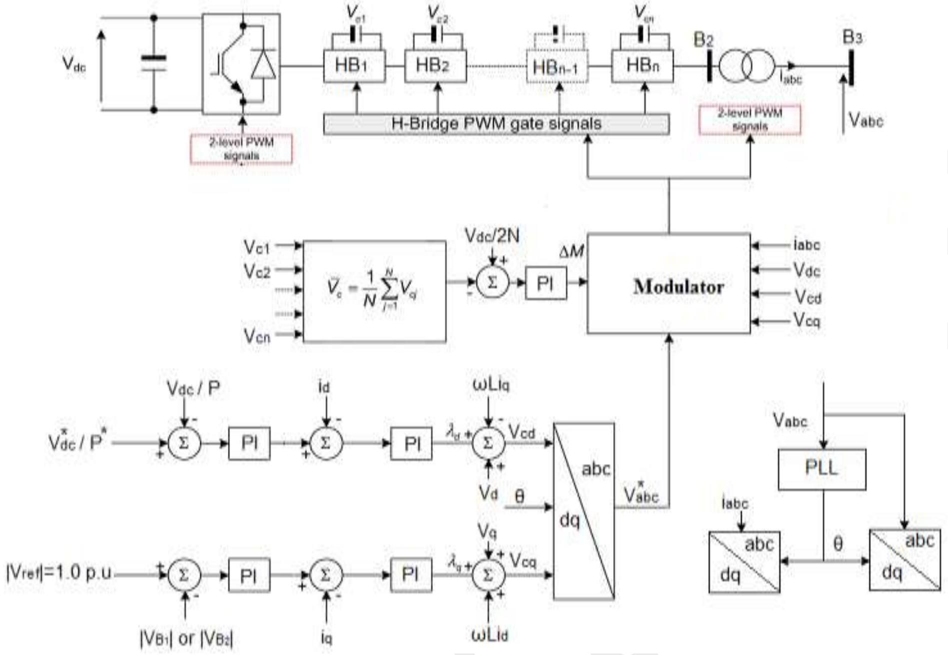
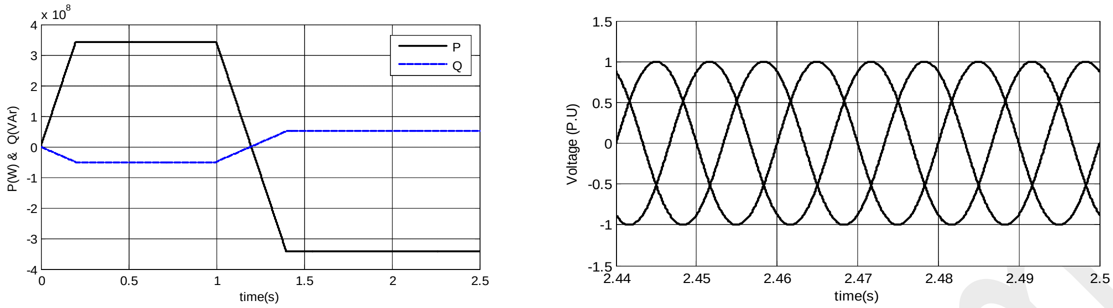


Fig.*3* ***Block diagram summarizes the control system structure of converters VSC1and VSC2***.

This proposed hybrid converter with seven H-bridge cells per phase generates 29 voltage levels per phase, which is the same as the two-switch modular multilevel converter(M2C) with 28 cells per arm, for the same dc link voltage such that devices in both converters experience the same voltage stresses. The hybrid multilevel converters control active power injection into the dc network and regulate ac voltage magnitudes at points of common coupling bus B1 and bus B2 respectively.

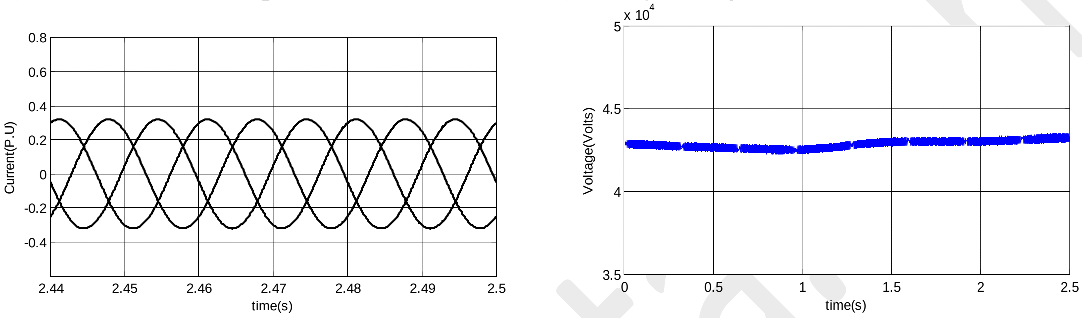
A. Steady state operation

In order to evaluate performance of the test system in Fig. 2 is simulated in Matlab-Simulink. In this case Converter station 1 is commanded to increase its output power export from Grid G1 to G2 from 0 to 0.5 pu (343.5 MW) at 2.5 pu/s. At time t =1s it is commanded to reverse the active power flow in order to import 343.5 MW from grid, at - 2.5 pu/s. At t=2s a load of (120+j90) MVA is introduced to bus B2, this is illustrating the voltage support capability of converter station 2 during network alteration. The converters are able to adjust their reactive power exchange with bus B1 and bus B2 in order to support the voltage during the entire operating period. The voltage and current waveforms in Fig. 4(b) and (c) respectively demonstrate that the use of hybrid multilevel converter capable of eliminating ac filtering equipment in the system, hence reduces overall power losses in the converter stations 1 and 2 as the damping resistances are not required. Based on these results, the proposed VSC-HVDC system is able to meet basic steady-state requirements.



(a) Active and reactive power at bus B1

b) Voltage waveforms at bus B2



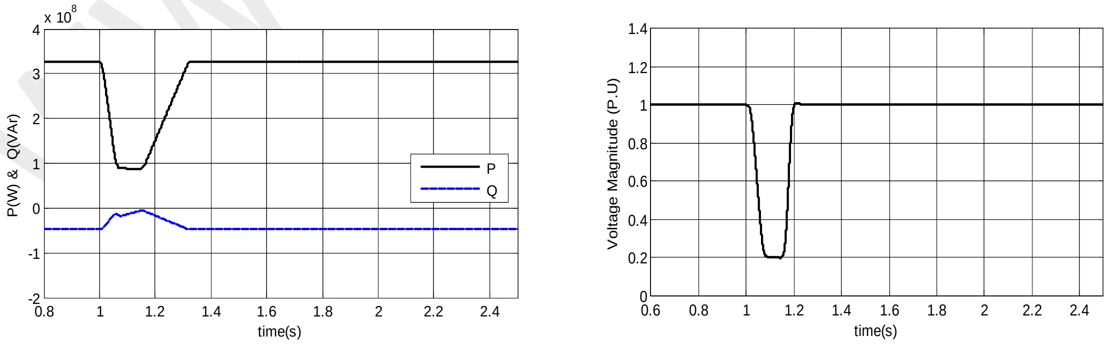
(c) Current waveforms at bus B1

d) Voltage across 21 cell capacitors of the three phases of converter 1

Fig.4 Test network waveforms demonstrating the steady-state operation of proposed HVDC system.

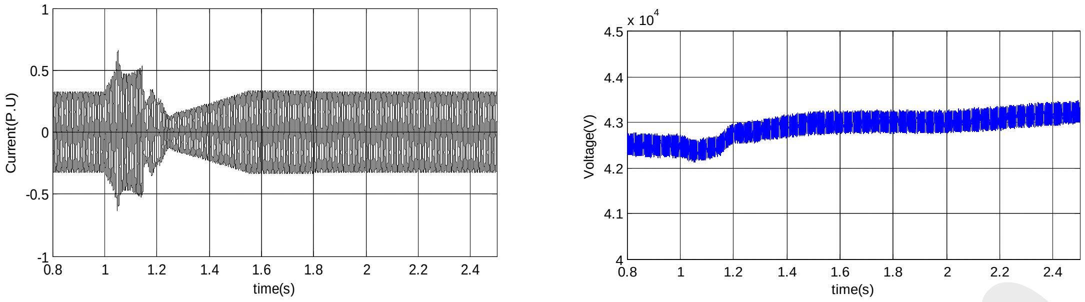
B. AC network symmetrical fault

Fig. 4 shows the results obtained when the test system is subjected to a solid three-phase (symmetrical) fault on one of the transmission line connecting the converter station 2 to the grid, with fault duration of 140ms as shown in Fig. At t=1s the active power command to the inverter is reduced to prevent the considerable rise of the main dc link voltage because of the trapped energy in the dc side. At t=1.14s the fault cleared, the active power is increased at bus B1 by slope of +2.5 pu/s and at bus B2 as shown in Fig. 5(a).



(a) Active and reactive power at bus B1.

(b) Voltage magnitude at bus B2.



(c) Current waveforms converter 2

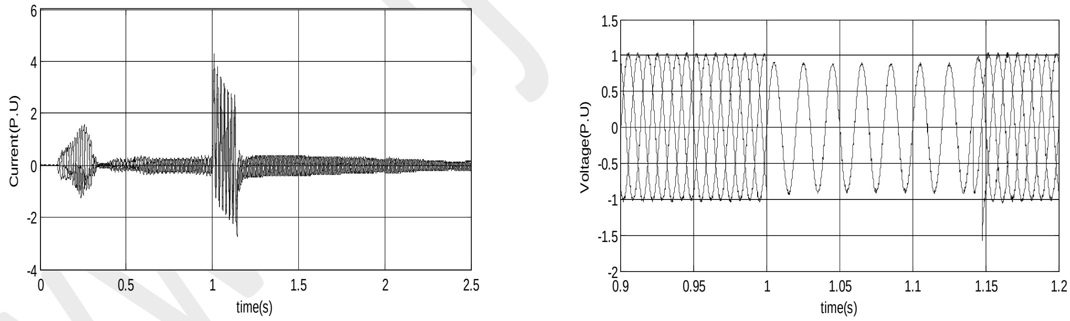
(d) Voltage across 21 H-bridge cells of the converter 2.

Fig.5. Waveforms demonstrating ac fault (symmetrical) ride-through capability of HVDC transmission systems.

As illustrated that, Coordination of the HVDC system controllers minimizes the impact of ac-side faults on the transient power flow on the dc side as shown in Fig. 5(e). This confirms that the proposed HVDC system based on the hybrid multilevel VSC does not compromise its ac fault ride-through capability.

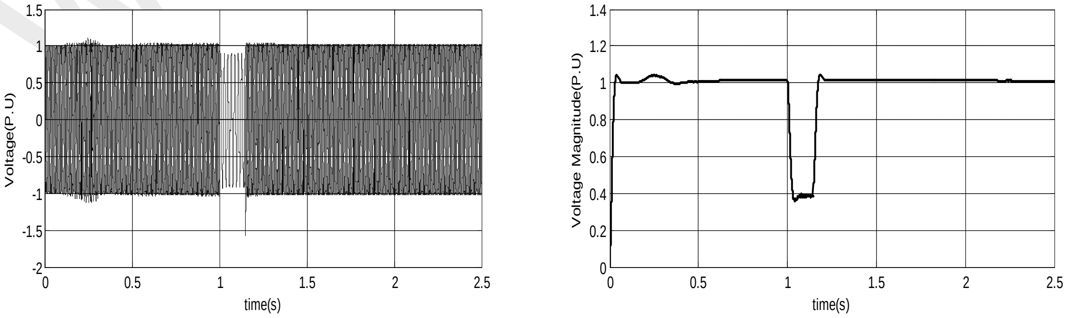
C. AC Network asymmetrical fault

Fig. 6 shows the results obtained when the test system is subjected to a line-to-line (asymmetrical) fault on one of the transmission line connecting the converter station 2 to the grid, with fault duration of 140ms as shown in Fig.2. At t=1s the active power command to the inverter is reduced to prevent the considerable rise of the main dc link voltage because of the trapped energy in the dc side. At t=1.14s the fault cleared. The voltage magnitude at bus B1 remains unaffected, hence confirming the hybrid VSC does not compromising the HVDC transmission system's decoupling future.



(a) Current waveform at bus B2

(b) zoomed version of Voltage waveforms at bus B2



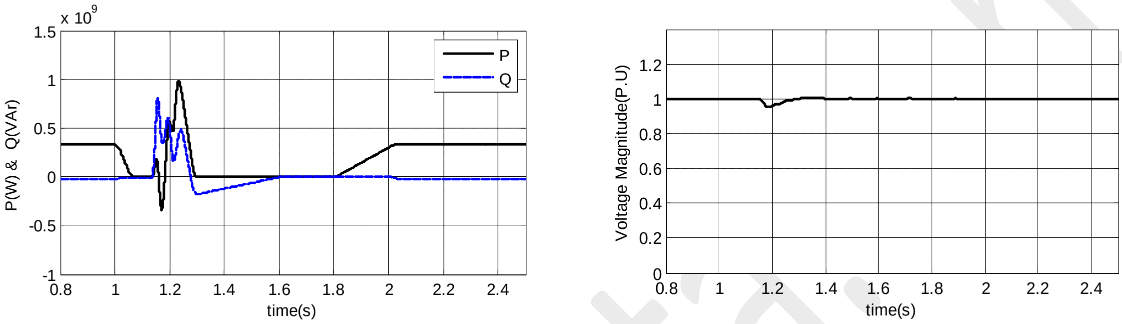
(*c) Voltage waveforms at bus B2*

d) Voltage magnitude at bus B2

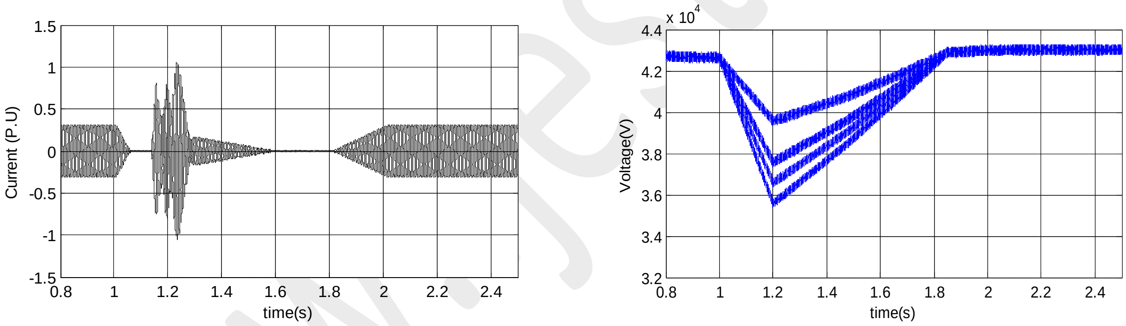
Fig.6 Waveforms demonstrating ac fault (asymmetrical) ride-through capability of HVDC transmission systems.

D. HVDC network pole-to-pole fault

This section assesses the viability of proposed HVDC system with inherent dc reverse blocking capability dc side fault. This is tested by subjecting to a solid pole-to-pole dc fault at the middle of the dc line connecting converter station 1 and 2, with a fault duration 140ms. During the dc-side fault period, the active power commands from control systems to the converter station 1 and 2 are reduced to zero and this facilitates uninterruptable system recovery, hence this eliminates a grid contribution to the dc fault.



a) Active and reactive power converter 1 exchanges with bus B1 b) Voltage magnitude at bus B2



(c) Current waveforms converter 1 exchange with grid at bus B2. d) Voltage across the H-bridge cell capacitors of converter 1

Fig.7 Waveforms demonstrating dc fault ride-through capability of HVDC transmission systems.

Fig. 7 shows the results obtained from proposed HVDC system when the test network is subjected to a temporary fault. In Fig. 6(a), Observe there is no current flow in the switches of converter station 1 and 2, hence zero active and reactive power exchange between the converter stations and ac grids during the dc side fault period. However, after the fault is cleared a large surge is observed in active and reactive power when the gating signals to converters 1 and 2 are restored, in order to restart the system. As shown in Fig. 7(c) due to reactive power consumption during HVDC system start-up, the current surge experienced by both converter stations 1 and 2 causes noticeable voltage dipping at bus B1 and bus B2. This result confirms the no need of dc circuit breakers to isolate temporary dc side faults that use HVDC converters with current limiting capability.

5. FFT ANALYSIS

The FFT analysis is performed for the outputs at the inverter end of the HVDC system to finally analyze the effect of the insertion of the filters into the system. The VSC HVDC Systems is simulated with the help of ―MATLAB.

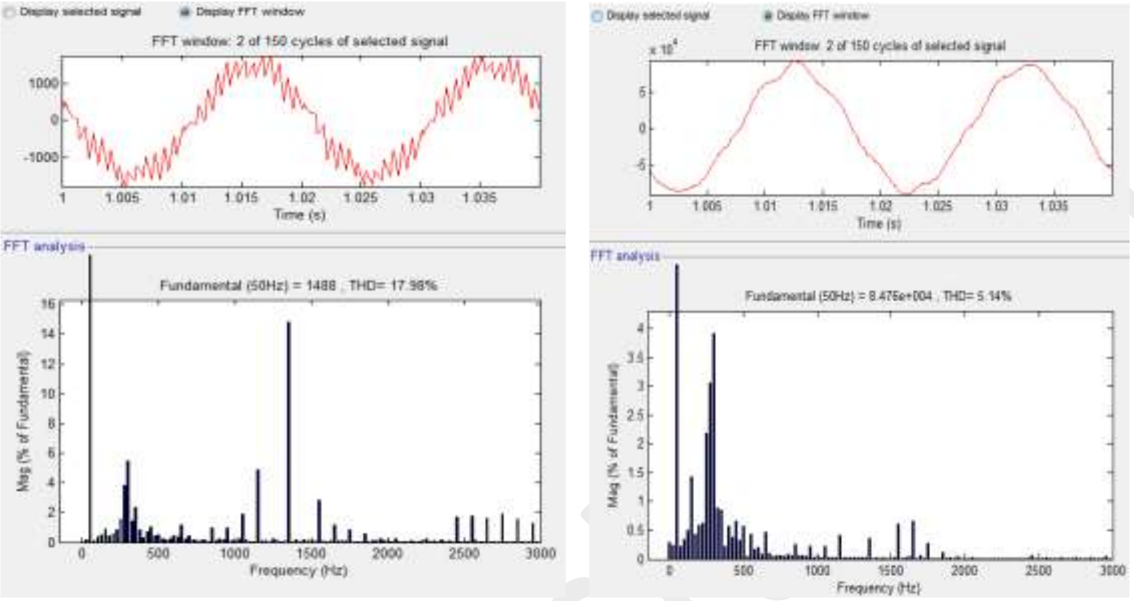


Fig. 8.Harmonic spectrum of phase voltage & phase current of existing VSC HVDC system at bus B2.

Simulation is carried out to observe the improvement in the phase voltage THD and phase current THD for proposed VSC HVDC System with existing normal VSC HVDC system. Following quantities have been observed:

i. Phase current and Phase voltage waveform for proposed VSC HVDC System inverter side.
ii. Phase current and Phase voltage waveform for existing VSC HVDC System inverter side.

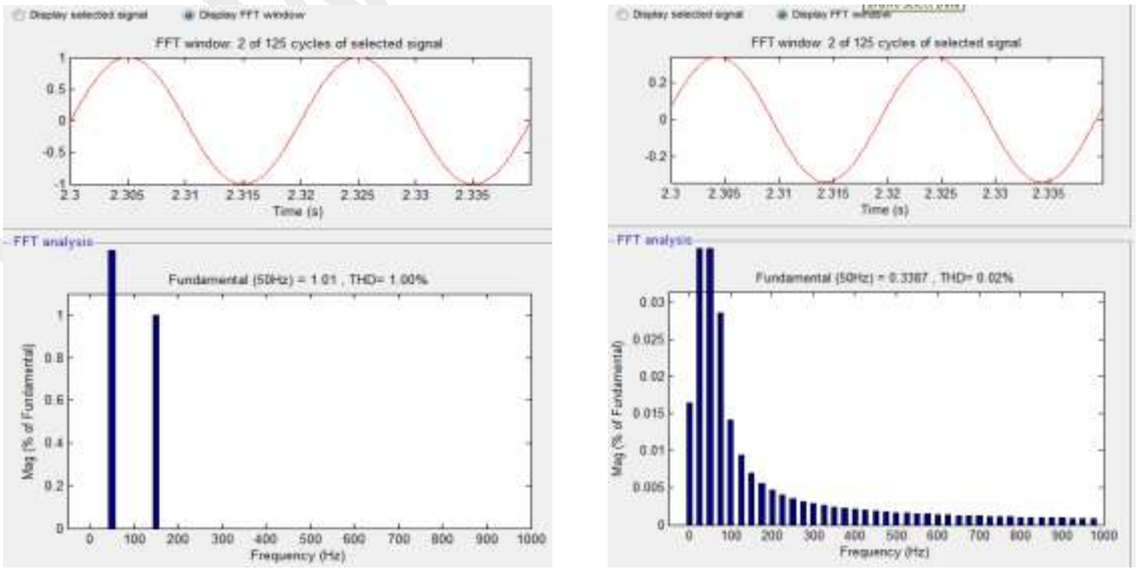


Fig.9 Harmonic spectrum of phase voltage & phase current of proposed VSC HVDC system at bus B2.

6. CONCLUSION

This paper investigated the steady-state and transient performance of a new generation HVDC transmission system based on Hybrid Multi level with ac-side cascaded H-bridge cells converter topology. The results of the investigation have shown that with hybrid multilevel converter an HVDC system is does not compromise the advantages of existing VSC-HVDC systems such as four-quadrant operation, black start capability and voltage support capability. In addition to existing VSC-HVDC system, proposed HVDC system provides inherent dc fault reverse blocking capability and resilient to ac side faults features.FFT analysis shows that, voltage harmonics and current harmonics is reduced hence proposed HVDC system converter topology generate less harmonics, hence low filtering requirement on the ac sides and present high- quality voltage to the converter station transformer by generating higher pulse level.

REFERENCES

i. V.G. Agelidis et al., “Recent Advances in High-Voltage Direct-Current Power Transmission Systems,” IEEE Conference on Industrial Technology,, Mumbai, 15-17 Dec. 2006, pp. 206-213.

ii. Grain. P. A, O. Anaya-Lara, G. Burt and J. McDonald, “Multi-terminal DC Transmission System Based on Modular Multilevel Converter,” 44th University Power Engineering Conference, Glasgow-UK, 1-4 Sept 2009.

iii. N. Flourentzou, V.G. Agelidis and G. D. Demetriades, “VSC-Based HVDC Power Transmission Systems: An Overview,” IEEE Trans. Power Electronics, Vol. 24, No. 3, March 2009, pp. 592-602.

iv. E. Dirk et al., “Prospects of HVDC&FACTS for Bulk Power Transmission and System Security,” paper available online at SIEMENS website ww.usa.siemens.com.

v. J. Pan et al., “AC Grid with Embedded VSC-HVDC for Secure and Efficient Power Delivery, IEEE Energy 2030 Conference, 17-18 Nov. 2008, pp. 1-6.

vi. E. Santacana et al., “Power to be efficient: transmission and Distribution Technologies are the Key to Increased Energy Efficiency,” ABB Review Feb. 2007.

vii. M. P. Bahrman and B. K. Johnson, “The ABCs of HVDC Transmission Technologies: An Overview of High Voltage Direct Current Systems and Applications,” IEEE Power and Energy Magazine, March/April 2007, pp. 32-44.

viii. A. Gunnar et al., “HVDC Light DC Transmission based on Voltage Source Converters,” ABB review 1998, available online at ABB website.

ix. B. Markus, “The Case for Advanced Power Technologies,” ABB review 2003, available online at ABB website.

x. Y. Zhanget al., “Voltage source converter in high voltage applications: Multilevel versus two-level converters,” inProc. 9th IET Int. Conf. AC and DC Power Transmission, London, U.K., 2010, pp. 1–5.

xi. G.P.Adamet al., “Modular multilevel inverter: Pulse width modulation and capacitor balancing technique,” IET Power Electron., vol. 3, pp. 702–715, 2010.

xii. V. Naumanenet al., “Mitigation of high -originated motor overvoltages in multilevel inverter drives,”IET Power Electron., vol. 3, pp. 681–689, 2010.

xiii. H. Abu-Rub et al., “Medium-voltage multilevel converters: State of the art, challenges, and requirements in industrial applications, ”IEEE Trans. Ind. Electron., vol. 57, no. 8, pp. 2581–2596, Aug. 2010.

xiv. G. P. Adamet al., “Modular multilevel converter for medium-voltage applications,” inProc. IEEE Int. Conf. Electr. Mach. Drives Conf.,2011, pp. 1013–1018.

xv. G. P. Adam, S. J. Finney, A. M. Massoud, and B. W. Williams, “Capacitor balance issues of the diode-clamped multilevel inverter operated in a quasi-two-state mode,”IEEE Trans. Ind. Electron.,vol.55,no.8,pp. 3088–3099, Aug. 2008.