Performance Evaluation of HVDC Transmission system with the Combination of VSC and H-Bridge cells

K.NAVEENKUMAR
PG Student, EEE, QISCET
ONGOLE, AP, INDIA

B.MOULI CHANDRA P.hd
Assoc. professor, EEE, QISCET
ONGOLE, AP, INDIA

Abstract* — This paper explains the performance of HVDC transmission system based on a hybrid multilevel voltage source converter. The proposed system having current limiting capability during dc-side fault. This characteristic of the system eliminates the requirement of dc-side circuit breakers in dc power transmission system and filter design by generating higher pulse level. A simplified proposed system steady state model is developed that can be used for power flow analysis. The transient performance is analyze by investigative the proposed transmission system responses to external AC-side (symmetrical and asymmetrical) and DC-side faults.

***Keywords*—Hybrid multilevel VSC with cascaded H-bridge cells, pulse width modulation Modular multilevel converter.**

I. 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 INBUILT REACTIVE POWER ABILITY.
ii. INDEPENDENT CONTROL OF ACTIVE AND REACTIVE POWER.
iii. BLACK START CAPABILITY.

In the last few years, the proposed VSC-HVDC transmission systems have evolved from simple two-level converters to multilevel converters such as modular converters [10]–[14]. This development intended to increase power-handling capability, better quality in ac side waveform to reduce or eliminate ac filters, reduced voltage stresses on converter transformers, reduced converter overall cost and minor semiconductor losses of VSC-HVDC transmission systems to the level related to that of conventional HVDC systems based on thyristor current-source converters [15]–[21].

This paper approaches towards a new generation of converter using ac-side cascaded H-bridge cells has started to emerge as an important evolution for VSCs Known as the hybrid multilevel VSC with ac-side cascaded H-bridge cells. This topology contain a big number of full bridge cells, so it can generate low distortion ac current and no need of ac filters. Also, in case of a dc fault, converter stations 1 and 2 must be able to block current flow between both ac and dc sides during dc fault period. And another significant characteristic of this proposed hybrid multilevel H-bridge multi level converter is its dc fault reverse blocking capability. With coordination between the HVDC converter station control functions, the dc fault reverse-blocking capability of the hybrid converter is utilized 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. Simplify dc circuit breaker design due to a reduction in the magnitude and duration of the dc fault current.

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

Fig. 1 shows individual 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'. As a result, with increase in number of H-bridge cells per phase, it gives near pure sinusoidal voltage as shown in Fig. 1[1], and possibility in an effective switching frequency per device of less than 150Hz. The voltage across the H-bridge floating capacitors sum to (1/2) V_{dc} tends to reduced conversion losses in the cells.

These cells are controlled by level-shifted carrier-based multilevel pulse width modulation with 1-KHz switching frequency and the two-level VSC devices operate with 150-Hz switching frequency, so low switching losses and low audible noise are expected. The proposed VSC-HVDC transmission system needs a voltage-balancing scheme that ensures that the voltages across the H-bridge cells are maintained at Vdc/n under steady and transient state conditions, where Vdc is the total dc link voltage. This voltage balancing scheme in hybrid multilevel VSC is realized by turning the H-bridge cell capacitors, and by considering the voltage magnitude of each cell capacitor and phase current polarity. [3], [15]-[20].

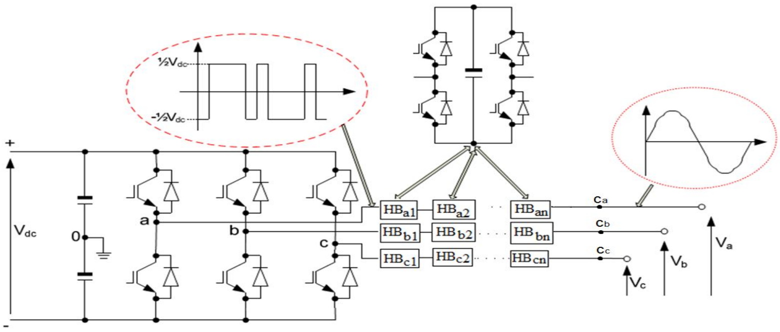


Fig. 1. *Hybrid multilevel VSC with ac-side cascaded H-bridge cells*

An additional PI regulator is used to maintain constant voltage across the H-bridge cells is Vdc/n under all operating conditions as shown in Fig. 3.

III. TEST SYSTEM

Fig.2 shows that a proposed system based on a hybrid multilevel VSC with ac – side cascaded H- bridge cells, and a 600kV HVDC transmission system with both sending and receiving end converters, 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.

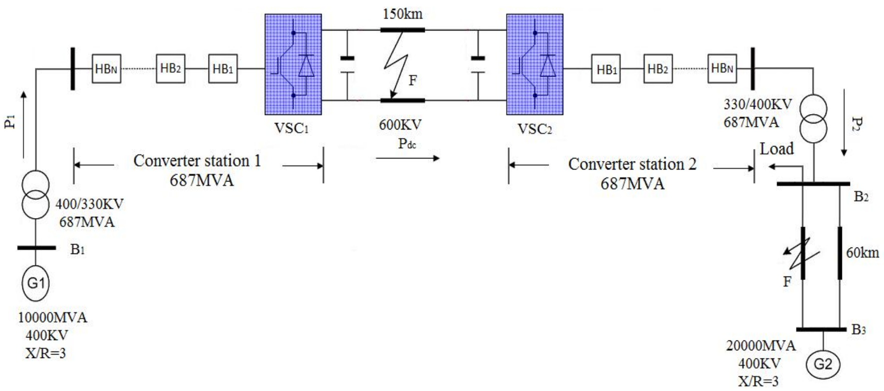


Fig. 2. Proposed HVDC tranmission system

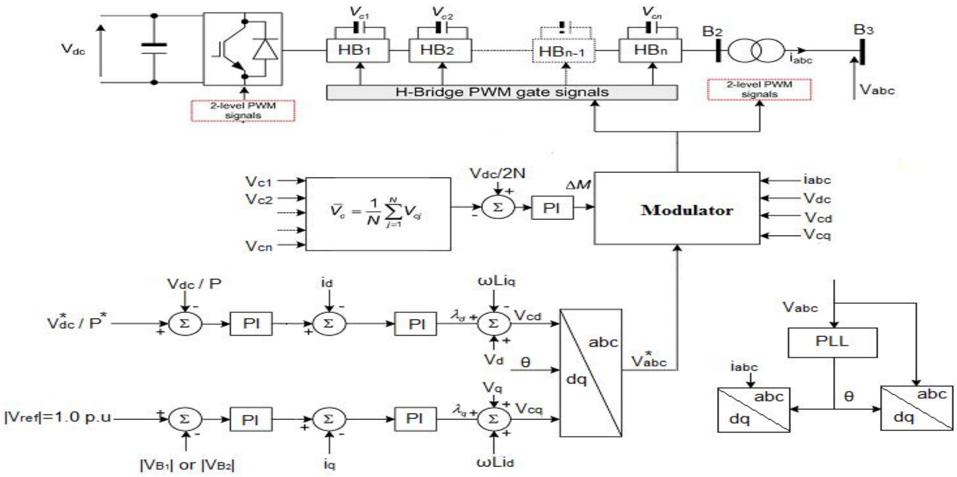


Fig. 3.Control system block diagram of voltage source converters.

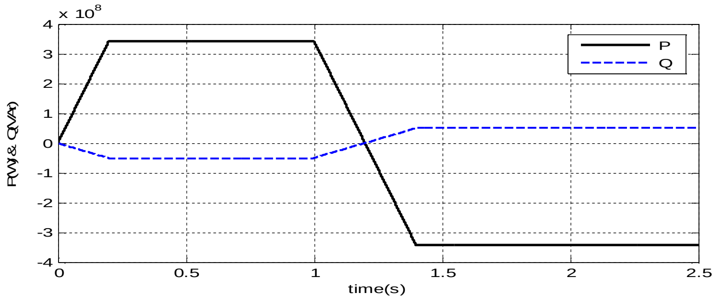
IV. PERFORMANCE EVALUATION

This section evaluates the steady and transient state performance of the proposed system. In the steady state, the test network in Fig. 2 is used to evaluate its power control and voltage support capabilities. Additionally to reveal the advantages of the hybrid multilevel converter during ac and dc network disturbances, the 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.

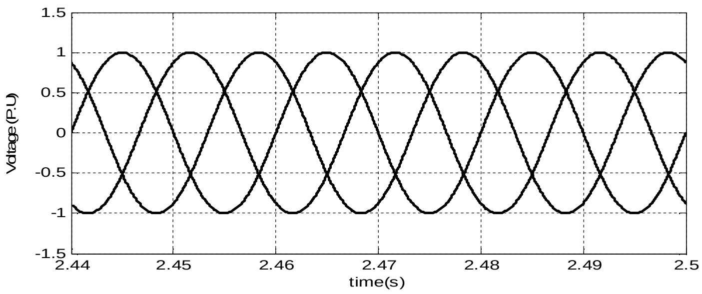
Converter stations 1 and 2 in Fig. 2 are represented by detailed hybrid VSC models with seven cells per phase, with the controllers in Fig. 3 integrated. The proposed hybrid converter with seven H-bridge cells per phase generates 29 voltage levels per phase, which is same as the two-switch modular multilevel converter(M2C) with 28 cells per arm.

A. STEADY STATE OPERATION

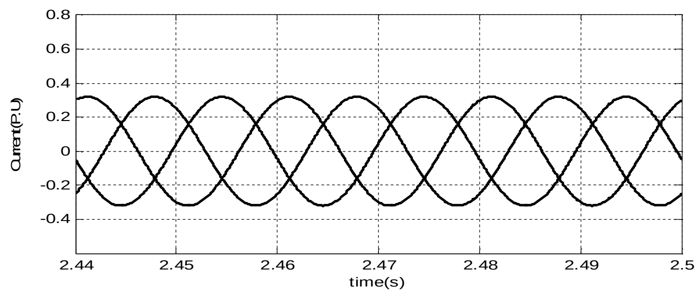
In order to assess performance of the test system in Fig. 2 is simulated in MATLAB/Simulink. In this case Converter station 1 is commanded to increase its output power export from Grid G1 to G2 from 0 to 0.5 pu (343.5 MW) at 2.5 pu/s. At time t =1s it is commanded to reverse the active power flow in 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 shift. The converters are able to adjust their reactive power exchange with bus B1 and bus B2 in order to support the voltage during the whole operating period. The voltage and current waveforms in Fig. 4(b) and (c) respectively reveal 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.



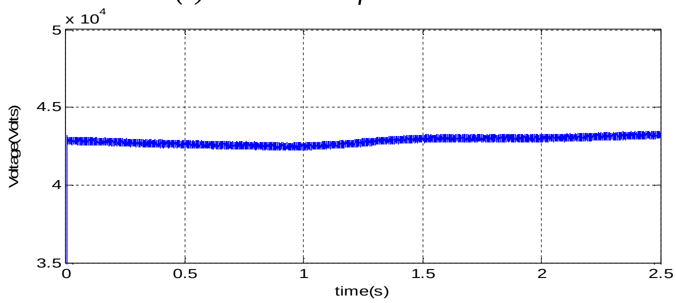
(a) Active and reactive power at bus B1



(b) Voltage waveforms at bus B2



(c) Current waveforms at bus B2



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

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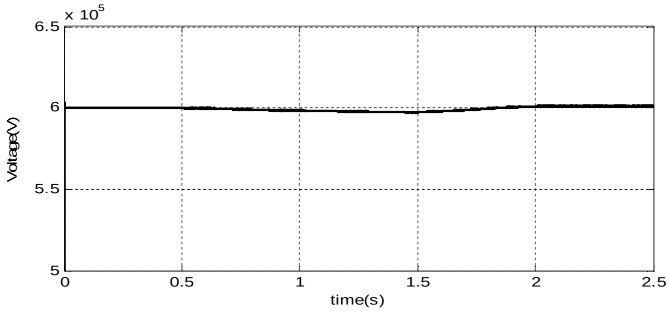
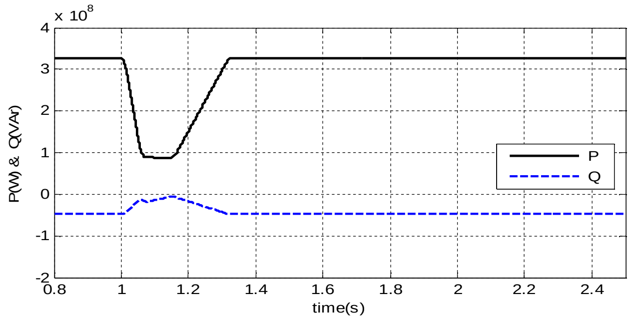


(e) Voltage across the dc link of converter station 2.

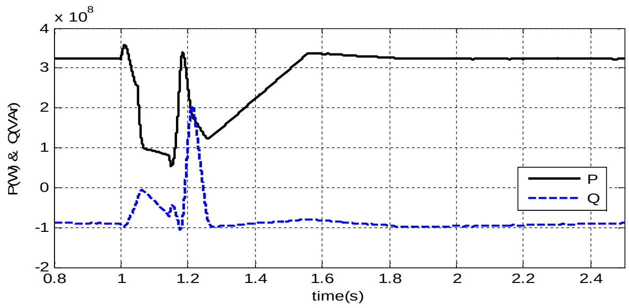
Fig. 4. Test network waveforms demonstrating the steady-state operation of proposed HVDC system.

B. AC NETWORK SYMMETRICAL FAULT

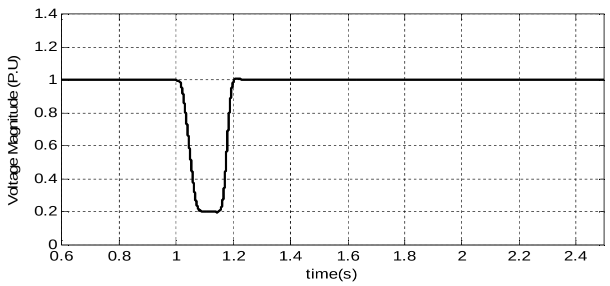
Fig. 4 shows the results obtained when a solid three-phase (symmetrical) fault on the transmission line connecting the converter station 2 to the grid, with fault duration of 140ms as shown in Fig. At t=1s the power command to the converter is reduced to prevent the considerable rise of the main dc link voltage because of the attentive energy in the dc side. After fault is cleared, the active power is increased to normal level as shown in Fig. 5(a). As illustrated that, Coordination of the HVDC system controllers reduces the impact of ac-side faults on the dc side during transient power flow as shown in Fig. 5(f). This confirms that the proposed HVDC system based on the hybrid multilevel VSC does not compromise its ac fault ride-through capability.



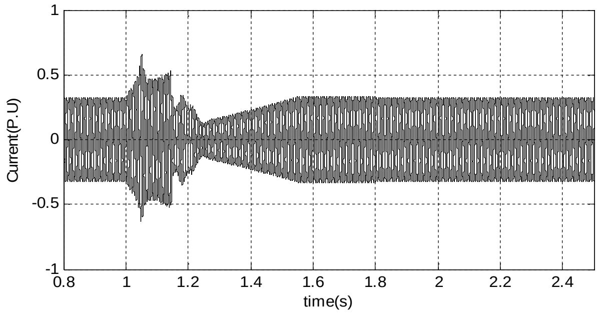
(a) Active and reactive power at bus B1.



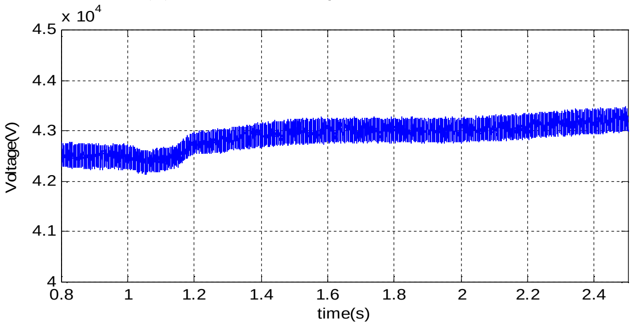
(b) Active and reactive power converter 2 injects into Bus 2



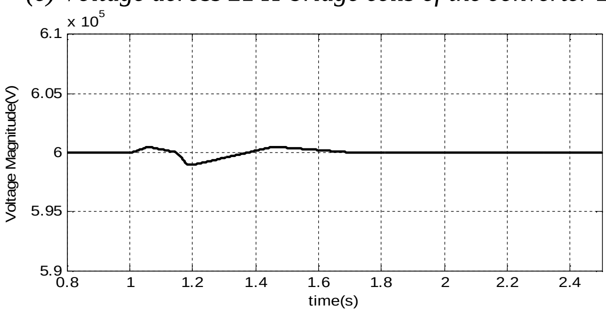
(c) Voltage magnitude at bus B2



(d) Current waveforms converter 2



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

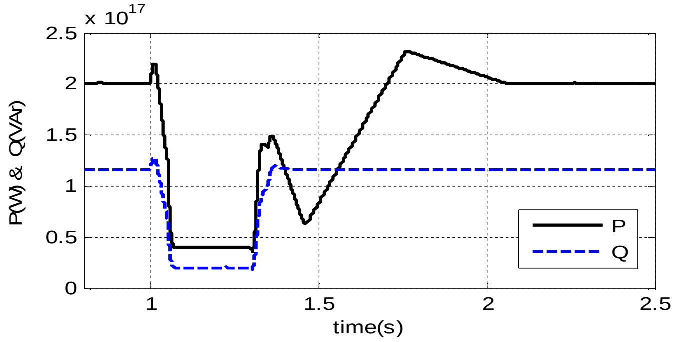


(f) Converter 2 dc link voltage

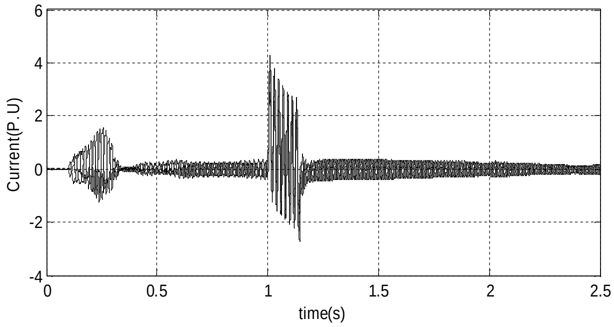
Fig. 5.Waveforms demonstrating ac fault (symmetrical) ride-through capability of HVDC transmission systems.

C. AC NETWORK ASYMMETRICAL FAULT

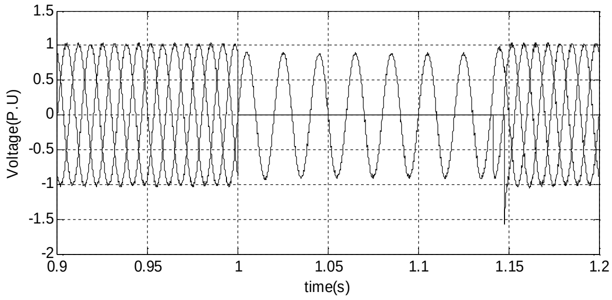
Fig. 6 shows the results obtained during a line-to-line (asymmetrical) fault on the transmission line connecting the converter station 2 to the grid, with fault duration of 140ms as shown in Fig.2. At t=1s the active power command to the converter1is reduced to prevent the considerable rise of the main dc link voltage because of the trapped energy in the dc side. After the fault is cleared the voltage magnitude at bus B1 reaches to normal state, hence confirming the hybrid VSC does not compromising the HVDC transmission system's decoupling feature and ac fault ride-through capability.



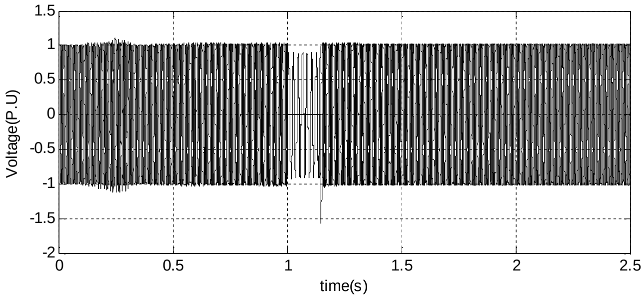
(a)Active and reactive power converter 2 injects into bus B2



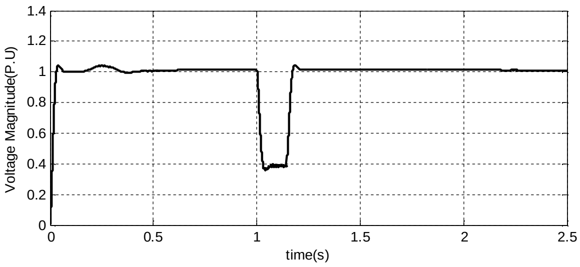
(a) Current waveform at bus B2



(b)zoomed version of Voltage waveforms at bus B2



(c) Voltage waveforms at bus B2

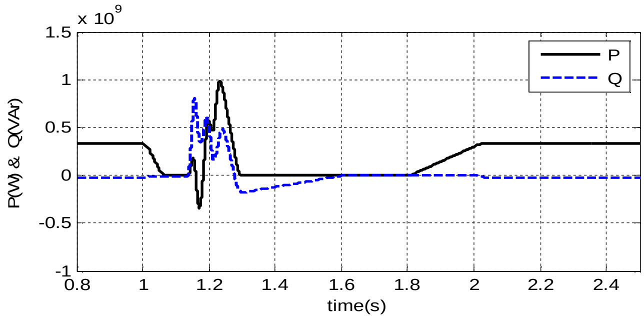


(d) Voltage magnitude at bus B2

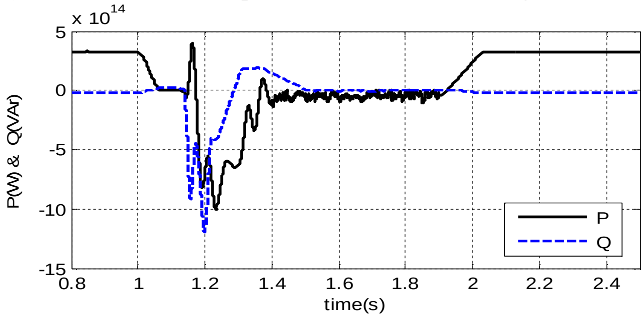
Fig. 6.Waveforms demonstrating ac fault (asymmetrical) ride-through capability of HVDC transmission systems.

D. HVDC NETWORK POLE-TO-POLE FAULT

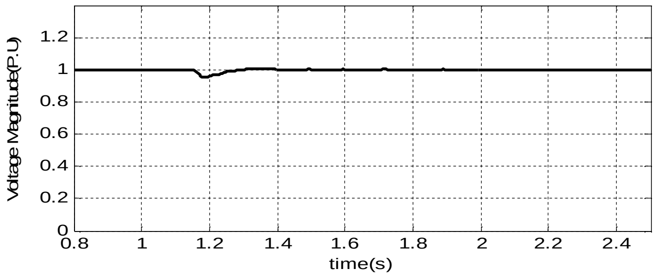
This section reveals the feasibility of proposed HVDC system with inherent dc reverse blocking capability during dc side fault. In this the test network subjected to a solid pole-to-pole dc fault at the middle of the dc line of 600kv connecting converter station 1 and 2, with a fault duration 140ms. 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 make possibility of uninterruptable system recovery, hence this eliminates a grid contribution to the dc fault. Fig. 7 shows the results obtained from proposed HVDC system when the test network is subjected to a temporary fault. In Fig. 7(a), we can 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. But, 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(d) 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 surge current discharge through converter side capacitor. This result confirms the no need of dc circuit breakers to isolate temporary dc side faults.



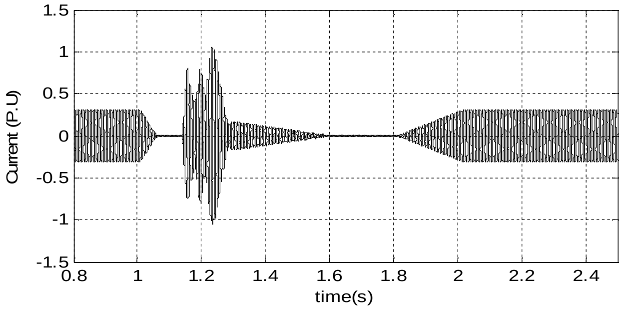
(a) Active and reactive power converter 1 exchanges with bus B1



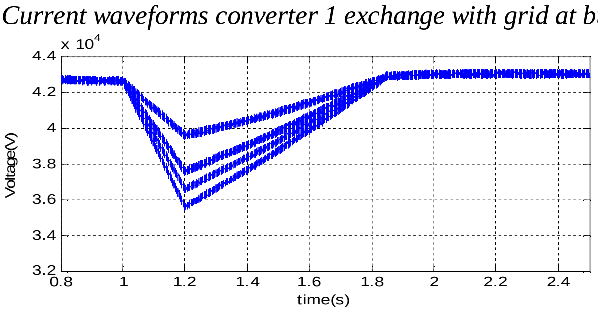
(b)Active and reactive power converter 2exchanges with bus B2



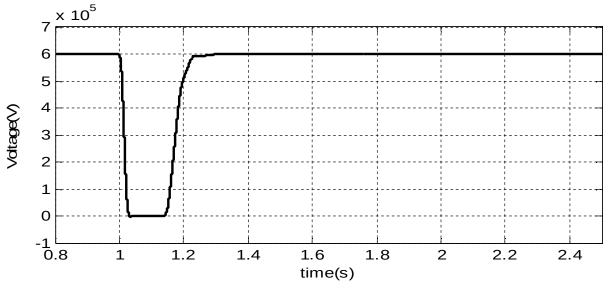
(c) Voltage magnitude at bus B2



(d) Current waveforms converter 1 exchange with grid at bus B2.



(e) Voltage across the H-bridge cell capacitors of converter 1.



(f) Converter 2 dc link voltage

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

V. CONCLUSION

This paper examined the steady-state and transient performance of a HVDC transmission system based on Hybrid two level with ac-side cascaded H-bridge cells converter topology. The results shown that the proposed HVDC system is does not give any concession to the advantages of existing VSC-HVDC systems such as four-quadrant operation, black start capability and voltage support capability besides it provides inherent dc fault reverse blocking capability and resilient to ac side faults features.

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