inverter is v (t) = v1 (t) + v2 (t). By opening and closing the switches of H1 appropriately, the output voltage v1 can be made equal to −Vdc, 0, or Vdc while the output voltage of H2 can be made equal to −Vdc/2, 0, or Vdc/2 by opening and closing its switches appropriately.

3. Hybrid Multilevel VSC with AC-Side Cascaded H-Bridge Cells

The Fig.1 shows single- phase of a hybrid multilevel VSC with N H-Bridge cells per phase. It can able to generate 4N+1 level at converter terminal “a” relative to supply midpoint “0”. Therefore, with a large number of cells per phase, the converter will produce a pure sinusoidal voltage to the converter transformer.

The H-bridge cells between “M” and “a” are operated as a series active filter to attenuate the harmonics in voltage produced by two level converter bridge. In order to minimize the conversion losses in the H-bridge cells, the number of cells is reduced such that the voltage across the H-bridge floating capacitor sum to Vdc/ 2. As a result of using less number of H-bridge cells, a small converter station is required than that of modular multilevel converter. Here a seven cell topology is used which will capable to provide 29 level voltage at converter terminal. The effective switching frequency per device is only less than 150 Hz. However the operation of hybrid multilevel VSC requires a voltage balancing scheme which ensures that the voltage across the H-bridge cells are maintained at Vdc/N under all operating conditions, where the Vdc is the total dc link voltage.

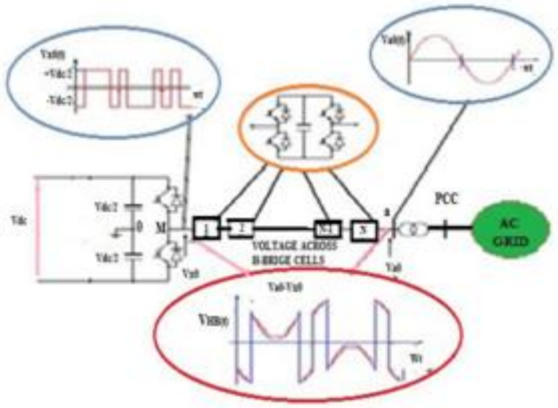

Figure 1: Single phase representation of a hybrid multilevel VSC with N H-Bridge cells per phase

The dc fault reverse-blocking capability of the proposed HVDC system is achieved by inhibiting the gate signals to the converter switches, therefore no direct path exists between the ac and dc side through freewheel diodes, and cell capacitor voltages will oppose any current flow from one side to another. Consequently, with no current flows, there is no active and reactive power exchange between ac and dc side during dc-side faults. This dc fault aspect means transformer coupled H-bridges cannot be used. The ac grid contribution to dc-side fault current is eliminated, reducing the risk of converter failure due to increased current stresses in the switching devices during dc-side faults. From the grid standpoint, the dc fault reverse-blocking capability of the proposed HVDC system may improve ac network voltage stability, as the reactive power demand at converter stations during dc-side faults is significantly reduced. The ac networks see the nodes where the converter stations are connected as open circuit nodes during the entire dc fault period. However, operation of the hybrid multilevel VSC requires a voltage-balancing scheme that ensures that the voltages across the H-bridge cells are maintained V_{dc}/N at under all operating conditions, where is the total dc link voltage. The H-bridge cells voltage balancing scheme is realized by rotating the H-bridge cell capacitors, taking into account the voltage magnitude of each cell capacitor and phase current polarity.

4. Controlling Technique

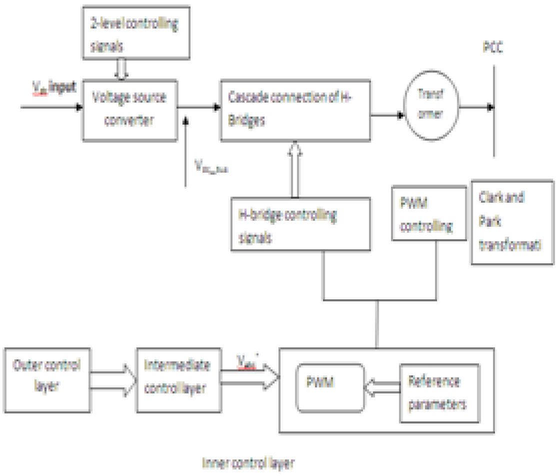

Figure 2: Schematic diagram summarizing the control layer of the hybrid multilevel converter with ac side cascaded H-bridge cells

A HVDC transmission system based on a hybrid multilevel VSC with ac-side cascaded H-bridge cells requires three control system layers. The inner control layer represents the modulator and capacitor voltage-balancing mechanism that generates the gating signals for the converter switches and maintains voltage balance of the H-bridge cell capacitors. The intermediate control layer represents the current controller that regulates the active and reactive current components over the full operating range and restraints converter station current injection into ac network during network disturbances such as ac and dc side faults. The outer control layer is the dc voltage (or active power) and ac voltage (or reactive power) controller that provide set points to the current controllers. The inner controller has only been discussed to a level appropriate to power systems engineers. The intermediate and outer control layers are presented in detail to give the reader a sense of HVDC control system complexity. The current, power, and dc link voltage controller gains are selected using root locus analysis, based on the applicable transfer functions. Some of the controller gains obtained using root locus analysis give good performance in steady state but failed to provide acceptable network disturbance performance. Therefore, the simulation final gains used are adjusted in the time domain to provide satisfactory performance over a wide operating range, including ac and dc side faults.

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TABLE II
CONVERTER TRANSFORMER PARAMETERS

Transformers 1 and 2	
Power rating	687MA
Voltage ratio	330kV/400kV
Per unit impedance	(0.0008+j0.32)

TABLE III
TRANSMISSION SYSTEMS PARAMETERS

Lines parameters (based on lumped π model)	
ac line length	60km
ac line series impedance	(0.0127+j0.2933)Ω/km
ac line shunt capacitance	12.74nF/km
dc transmission distance	75km
dc line series resistance	13.9mΩ/km
dc line series inductance	0.159mH/km
dc line shunt capacitance	0.231μF/km

5. AC Faults

During the fault period the power command to converter 1 is reduced in proportion to the reduction in the ac voltage magnitude (this is achieved by sensing PCC2 voltage). This is to minimize the two-level converter dc link voltage rise because of the trapped energy in the dc side, since power cannot be transferred as the voltage at PCC2 collapses.

Here in this topology an additional PI regulator is used to ensure that the cell capacitors are maintained at Vdc/N. Hence by considering voltage magnitude of each cell capacitor and phase current polarity, the H-bridge cells voltage balancing scheme can be realized in rotating the H-bridge cell capacitors.

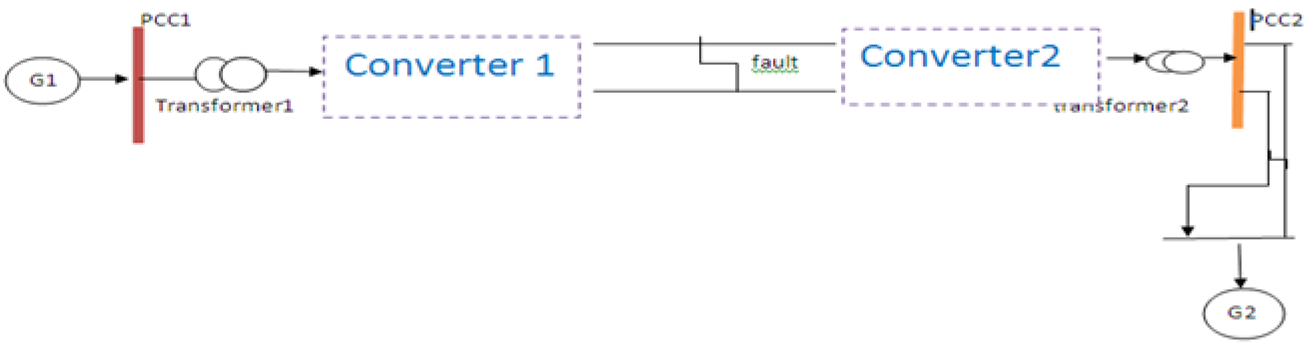

Figure 3: Test network used to illustrate the viability of the hybrid multilevel voltage source converter HVDC systems

6. DC Faults

The inherent current-limiting capability of the hybrid multilevel VSC with ac-side cascaded H-bridge cells that permits the VSC-HVDC system to ride-through dc-side faults will be demonstrated here. The test network is subjected to a 140 ms solid pole-to-pole dc-side fault at the location indicated .During the dc-side fault period, active power exchange between the two grids and is reduced to zero. This facilitates uninterruptable system recovery from the temporary dc fault with minimal inrush current, since the power paths between the converter's ac and dc sides are blocked (by inhibiting all converter gate signals) to eliminate a grid contribution to the dc fault.

This contribution creates a noticeable reduction in the cell capacitor voltages during system restart. The cell capacitors of converter 2 that regulate dc link voltage, experience a larger voltage dip than converter 1, which regulates active power. However, the reduction in H-bridge cell capacitor voltages is minimized if large capacitance is used.

7. Simulation Analysis

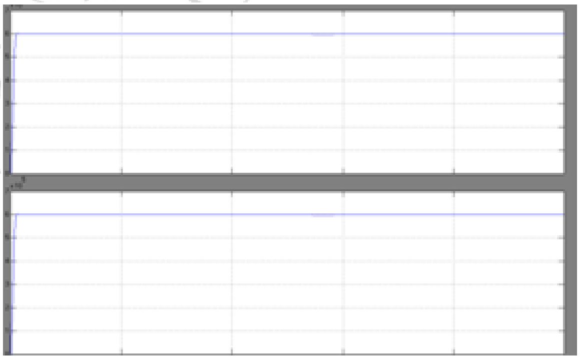

Figure 4: DC link voltages

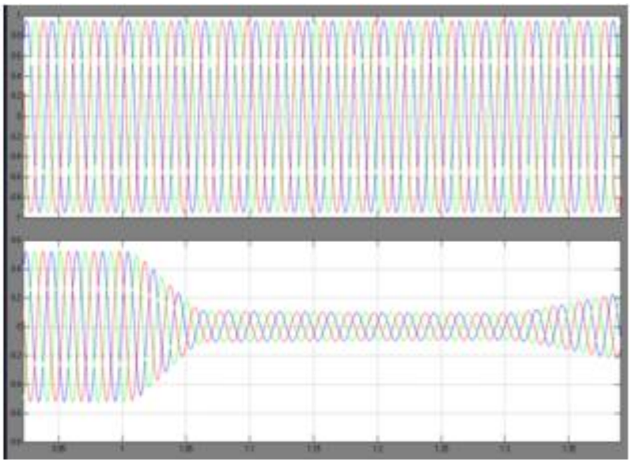

Figure 5: Voltage and current waveforms at PCC1

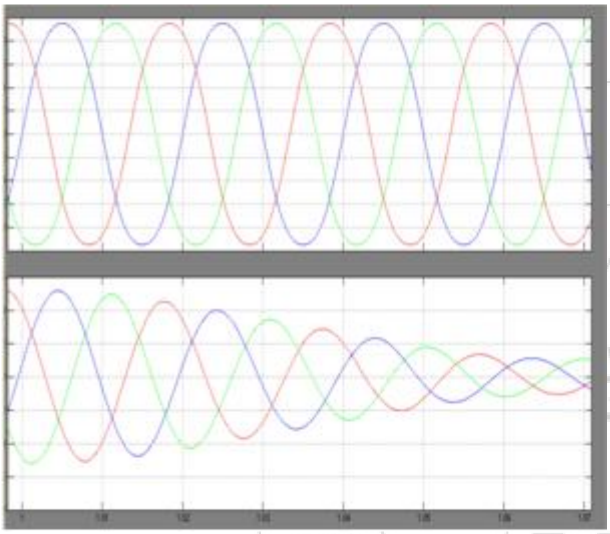

Figure 6: Voltage and current waveforms at PCC2

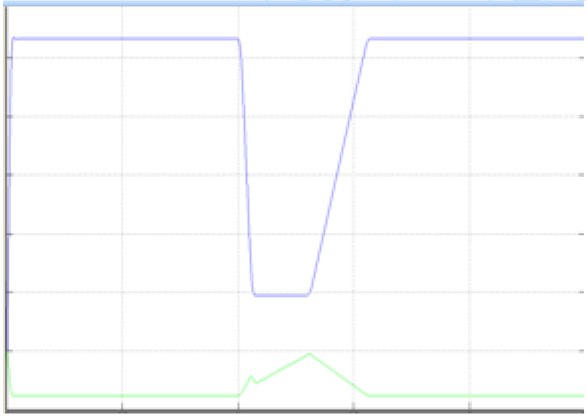

Figure 7: Active and reactive powers of PCC1

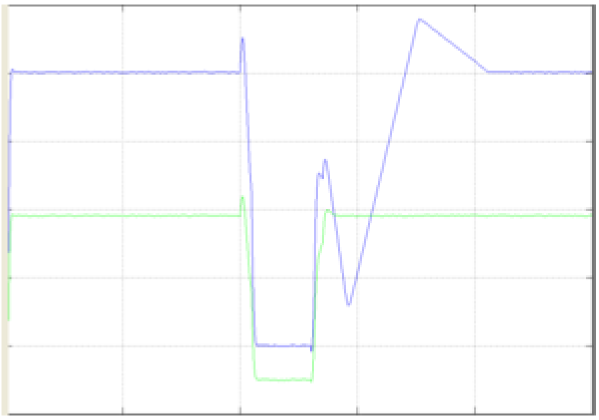

Figure 8: Active and reactive powers of PCC2

8. Conclusion

This paper presented a new generation VSC-HVDC transmission system based on a hybrid multilevel converter with ac-side cascaded H-bridge cells. The main advantages of the proposed HVDC system are:

- Potential small footprint and lower semiconductor losses compared to present HVDC systems.
- Low filtering requirements on the ac sides and presents high-quality voltage to the converter transformer.
- Does not compromise the advantages of VSC-HVDC systems such as four-quadrant operation; voltage support capability; and black-start capability, which is vital for connection of weak ac networks with no generation and wind farms.
- Modular design and converter fault management (inclusion of redundant cells in each phase may allow the system to operate normally during failure of a few H-bridge cells; whence a cell bypass mechanism is required).
- Resilient to ac side faults (symmetrical and asymmetrical).
- Inherent dc fault reverse blocking capability that allows converter stations to block the power paths between the ac and dc sides during dc side faults (active power between ac and dc sides, and reactive power exchange between a converter station and ac networks), hence eliminating any grid contribution to the dc fault current

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ISSN (Online): 2319-7064

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