Improvement of Fault Tolerance in HVDC Transmission System based on Hybrid Multilevel VSC

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Abstract— In this paper a different technology of High Voltage dc (HVDC) transmission system created on fusion multilevel voltage source converter (VSC) along with cascaded H-bridge cells on ac side. This paper suggested that HVDC system have capability to regulate both reactive and active power by using VSC systems, ability to protect the converter equipment’s against over voltages and over currents, ability to generate the power without any support from the grid in case of system collapse and the special feature has the ability for current limiting capability in case of dc side faults. In addition to, it offers special features such as larger reactive and active power capability for smaller foot print by using modular multilevel VSC in HVDC converters. This paper evaluates its active evaluation under steady state and network adjustments and finding its response in case of pole to pole dc fault and three phase-ground ac fault. Fuzzy logic controller (FLC) is used to improve the response in case of dc and ac side faults and the simulation results are shown in MATLAB SIMULINK model.

Key words: voltage source converter (VSC), modular multilevel converter, combination of multilevel converter with cascaded H-bridge cells on ac side

I. INTRODUCTION

High Voltage dc transmission (HVDC) is a feasible alternative for transmission of bulk amount of power through longer distances. In the fast years, Voltage Source Converter (VSC) on high voltage dc transmissions systems (HVDC) have grew from two level converters, diode clinched converter and modular multilevel converters [1]-[4]. In VSC-HVDC system has an aspirant to face the encounters to its operational elasticity such as connection for weak ac systems, fast recovery from ac side faults, multi-terminal possibility in HVDC system awareness as active power reversal is realized without any variation in dc link voltage polarity [8].

There are two methods to support the VSC-HVDC transmission system without causing any damage during dc side faults. The first method is fast acting of circuit breakers on dc side and it may able to operate at high voltage and remove dc faults. The first step is derisory, as present VSC-HVDC transmission system can operate voltage 640 KV line to line.

The second method during dc fault period in converter stations is to use reverse blocking capability [1], [4]. During dc fault period, each converter can block the current flow between dc and ac side which allows dc capacitor discharge current on dc side and the high dc fault current declines to zero and to isolate the fault. The main weakness during dc fault period, the active power transfer between dc and ac side reduces to zero.

Fig. 1: Hybrid Multilevel VSC with cascaded H-bridges on ac side

The coordination between the control functions in converter station, the hybrid converter having reverse blocking capability in case of dc side faults is oppressed to achieve the following:

- During faults on dc side, the risk of converter failure is to be minimized due to uncontrolled over current and hence to remove the ac grid involvement in case of dc faults;
- During dc side faults without interruption of VSC-HVDC and without opening circuit breakers on ac side and it can control the recover voltage

II. HYBRID MULTILEVEL VSC WITH SERIES H-BRIDGES ON AC SIDE

Figure 1 shows single phase mixture multilevel VSC having N H-bridges per each phase. Therefore, more cells per arm the converter shows pure sinusoidal voltage at converter transformer as shown in figure 1. It can generate 4N+1 voltage levels between supply midpoint “0” and converter terminal “a”. By using selective harmonic elimination (SHE), it can able to reduce the harmonics in dc and ac side. The H-bridges cells are operated between “M” and “a” in series and act as active power filters to reduce the voltage harmonics produced in the two level converter [5]. It can control by using carrier based level shifted multilevel pulse width modulation with 1-KHZ frequency. The number of H-bridges is reduced to minimize the conversion losses in H-bridge cells such that the capacitor voltage across H-bridge cells is equal to (1/2) Vdc and the waveform is as shown in figure 1. Under all operating conditions, the operation of mixture multilevel VSC requires to maintain voltage balance across H-bridge cells is Vdc/N [4].
An additional fuzzy logic controller (FLC) is used to confirm that the capacitor voltage is maintained at $V_{dc}/N$ as shown in fig. 2(b).

### III. CONTROL OF HVDC SYSTEM USING FUZZY LOGIC CONTROLLER

A HVDC system based on mixture of multilevel VSC with series H-bridges on ac side consists of three layers. Intermediate control layer signifies the controlling the current that controls the reactive power and active power control components over full operating voltage and confines converter station to inject the current into ac network during system disturbances such as dc and ac side faults[8]. Inner control layer signifies the capacitor and modulator voltage balancing to generate the gating signals to the converter switches to maintain the voltage balancing in the H-bridge cells. Outer control layer signifies the reactive power (ac voltage) and active power (dc voltage) controller.

#### A. Fuzzy Logic Controller Design:

Fuzzy logic is a logical system based on multivalve logic. The fuzzy logic controller design is as shown in figure. 3(a).

#### B. Fuzzy Inference System:

It converts given inputs into outputs by using fuzzy logic. It can be used in different fields such as expert system, classification of data, computer vision.

#### C. Fis Editor:

In the FIS editor consists of two fuzzy inputs which converts fuzzy outputs. FIS editor is called as fuzzy inference. If already loaded to build the system by typing fuzzy IM. Automatically it can save time and follow quickly. After loading the file IM .fis into FIS editor and launches the FIS editor.

#### D. Membership Function:

Membership function represents a fuzzy set and the value lies in the range [0 1].The applications of Membership Function is to measure accurately, decision making. Membership Function represents the degree of truth and extension of evaluation. The membership Function used in “IMPROVEMENT OF FAULT TOLERANT IN HVDC SYSTEM BY USING MULTILEVEL VSC” is “Triangular Membership Function”. Comparison is easy in case of Triangular Membership Function because it is easy to know by using fuzzy rules. In case of faults, Triangular Membership Function is more suitable to compares the values for the given inputs.

#### E. Rule Editor:

Based on fuzzy rules the membership function allows building a graph. Here the inputs are taken as Zero (Z), Negative Big (NB), Positive Big (PB), Negative Medium (NM), Positive Medium (PM), Negative Small (NS), Positive Small (PS). Based on given inputs the outputs can generate to build the waveform. The fuzzy rule table is shown in fig 3.1.
By using the change in Error and Error, it can generate the waveform by using Membership Function. The Membership Function values lies in the range [0 1].

<table>
<thead>
<tr>
<th>Converters 1 and 2</th>
<th>Values</th>
</tr>
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<tbody>
<tr>
<td>Maximum active power capability</td>
<td>600MW</td>
</tr>
<tr>
<td>Power ratings</td>
<td>687MVA</td>
</tr>
<tr>
<td>Two-level dc link voltage</td>
<td>600KV</td>
</tr>
<tr>
<td>Maximum reactive power capability</td>
<td>335MVAr</td>
</tr>
<tr>
<td>H-bridge cell capacitance</td>
<td>3mF</td>
</tr>
<tr>
<td>H-bridge switching frequency</td>
<td>1kHz</td>
</tr>
<tr>
<td>H-bridge dc link voltage</td>
<td>42.86kV</td>
</tr>
<tr>
<td>Two-level dc link capacitance</td>
<td>0.00015F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Converter 2 controllers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current controller: $K_i$</td>
</tr>
<tr>
<td>Current controller: $K_p$</td>
</tr>
<tr>
<td>DC voltage controller: $K_{iv}$</td>
</tr>
<tr>
<td>DC voltage controller: $K_{pv}$</td>
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<td>AC voltage controller: $K_{iv}$</td>
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</tr>
<tr>
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<tr>
<td>AC voltage controller: $K_{pv}$</td>
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Table I: Parameters of Converter Station

<table>
<thead>
<tr>
<th>Parameters on lines (based on lumped π model)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>ac line series capacitance</td>
<td>12.74nF/km</td>
</tr>
<tr>
<td>ac line series impedance</td>
<td>(0.0127+0.2933)Ω/km</td>
</tr>
<tr>
<td>dc line series inductance</td>
<td>0.159mH/km</td>
</tr>
<tr>
<td>dc transmission distance</td>
<td>74km</td>
</tr>
<tr>
<td>dc line series capacitance</td>
<td>0.231µF/km</td>
</tr>
<tr>
<td>dc line series resistance</td>
<td>13.9mΩ/km</td>
</tr>
<tr>
<td>ac line length</td>
<td>60km</td>
</tr>
</tbody>
</table>

Table III: Parameters of Transmission System

The values of the HVDC line parameters and the controller values are seen in the following tables.

IV. PERFORMANCE EVALUATION

The feasibility of the proposed system uses hybrid multilevel VSC with series H-bridges on ac side is explored, to importance the active show under any modification of the network. Under stable state the test network is shown in fig. 4. To explain the advantages of hybrid multilevel converters in case of ac and dc side faults. In the test network consists of three phases to ground fault on ac side in converter-2 with duration 140ms pole to pole dc fault on dc side with duration of 140ms. Each converter station having three phases and each phase connects with seven H-bridge cells in order to attain adequate simulation times without comparing outcome precision.

Hybrid multilevel converter with seven H-bridges per each phase to creates 29 voltage levels for each phase. Each H-bridge consists of 28 cells per arm with two switch modular multilevel converter having same voltage stresses and dc link voltage in both the converters. The converters are used to control active power, dc link voltage exchange and the results are seen in MATLAB Simulink model.

Fig. 4: Test network of HVDC system based on hybrid multilevel VSC with series H-bridges on ac side

A. Four Quadrant Operation And Voltage Support Capability:

To determine the voltage support and four quadrant operation ability of current VSC- HVDC system, converter station 1 is commanded to increase its output power export to $G_2$ from $G_1$ at 2.5pu/s is 343.5 MW (0 to 0.5pu). At t=1 sec it is commanded to import 343.5 MW from grid $G_2$ in order to reverse the active power flow at -2.5pu/s. A load of 120+j90 MVA is given to PCC2 at t=2 sec, explains the voltage ability during network modification in converter station 2.

During the operating period, the converters are able to vary the reactive power exchange when the load is introduced at t=2 sec in PCC2 in order to improve the voltage. Under steady state conditions, VSC-HVDC is able to achieve the challenges in case of voltage and current.

B. Waveforms for Steady State Condition In Hvdc System With Fuzzy Logic Controller (FLC):
C. Faults In Ac Network:

Present day HVDC system has the capability of ride through during ac fault such as three-phase to ground with duration 140ms is seen in the test network as shown in the fig. 3. In the fault period the power command in converter 1 is reduces in quantity of decrease in voltage magnitude, it can be achieved by sensing voltage in PCC2. In order to minimize the dc link voltage increase in two level converters due to stuck energy in dc side, because power is not transferred as voltage collapses at PCC2. At t=1 sec three phase to fault is occurred, in order to increase the voltage from 0 to 343.5 MW (0.5 pu) from G1 to G2. Fig. 4(a) represents the reactive power and active power conversations in PCC1. Converter 1 matches the active power to increase the voltage from 0 to 343.5 and has the ability to transfer the power in order to decrease the converter 2 dc link voltage collapse. At t=1 sec the three-phases to ground fault in ac side and clears the ac fault at t=1.14 sec. If the fault is cleared in the system, the converters have the ability to recover the voltage and the waveforms in HVDC system with three-phase to ground ac fault in case of fuzzy controller.

D. Waveforms For Three-Phase To Ground Ac-Fault By Using Flc:

Fig. 3(a): waveform for reactive and active power for converter 1

Fig. 3(b): waveform for reactive and active power for converter 2

Fig. 3(c): waveform for voltage in converter 2

Fig. 3(d): waveform for current in converter 1

Fig. 3(e): waveform for voltage across 21 h-bridges in converter 1

Fig. 3(f): waveforms for dc link voltage for converter 2

Fig. 4(a): waveform for reactive and active power in converter 1

Fig. 4(b): waveform for reactive and active power in converter 2

Fig. 4(c): waveform of current in converter 2 exchanges at PCC2

Fig. 4(d): waveform for converter 2 dc link voltage
Fig. 4(e): waveform for voltage across h-bridge cell capacitance in converter 2

E. Faults In Dc Network:

During dc side fault in VSC-HVDC, it has the ability to limit the current of hybrid multilevel VSC with cascaded H-bridge cells on ac side will be discussed here. The dc fault such as pole to pole dc fault with duration 140ms is as shown in fig. 3. The fault occurs at t=1 sec and clears at t=1.14 sec. After the fault is cleared the converters are able to recover the voltage with long duration in case of dc fault. In case of dc fault the converters are blocked at both ac ends and no current flow between ac and dc side. During dc fault period, the active power and reactive power must be decreases to zero, hence no current flows in the converter switches 1 and 2. Hence large surge in reactive and active power transfers between G1 and G2.

F. Waveforms Of Dc Pole To Pole Fault by Using Flc:

Fig. 5(a): waveform for reactive and active power for converter 1

Fig. 5(b): waveform for reactive and active power for converter 2

Fig. 5(c): waveform for current exchanges in converter 1 at G1

Fig. 5(d): waveform for current exchanges in converter2 at G2

Fig. 5(e): waveform for converter 2 dc link voltage

Fig 5(f): waveform for voltage across h-bridge cells in converter2.

V. CONCLUSION

The main advantages of implementing of new VSC-HVDC system based on hybrid multilevel converter with series h-bridges on ac side using fuzzy logic controller are:
- Fast recovery in case of ac faults.
- Black start capability.
- Voltage support capability, four quadrant operations which play a major role in connection of weak ac systems.
- Overall performance is better and to improve the steady state response.
- It has the essential feature of reverse blocking capability in case of dc side faults.

REFERENCES


