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HVDC Transmission System with AC Side Contribution Blocking Capability During DC Side Faults Using BBBI Improving Resonance Stability

K.Deepa, S.PalaniKumar

PG Scholar, Department of EEE, Sreenivasa Engineering College, Bommidi, Dharmapuri, Tamilnadu, India

Professor, Sreenivasa Engineering College, Bommidi. Tamilnadu, India

ABSTRACT: Voltage-source converter high-voltage dc (VSC-HVDC) is becoming an attractive solution to deliver renewable energy to main grid which has several advantages compared to conventional HVDC. In general harmonics are generated by switching sequences could be eliminated by ac filters. DC fault current emanates from the contribution of both the ac grid as well as the discharge current of the dc-link capacitor. The discharge current has a large first peak decaying with time. However, there are low-frequency harmonic resonances due to the interaction of the ac grid and VSC controllers are not easy to be filtered out. Harmonic resonances can impact the power quality (PQ) and the power transfer level. Thus harmonic resonances should examine in VSC interfaced ac grids rectifier side and the inverter side. The impedance models for the rectifier ac system and the inverter ac system for a VSC-HVDC system is developed. The voltage is increased to improve the resonance stability. The Time-domain simulation results will be obtained by Mat lab with SimPowerSystems tool kit.

I. INTRODUCTION

In order to reach the goal of climate change mitigation, the interest in renewable energy, recently wind power in particular has been growing fast. The worldwide installed capacity of wind power reached 290 GW. India is the fifth largest installed wind power capacity in the world. The increased penetration of wind power into AC networks has presented more challenges for transmission system operators TSOs to maintain power quality, which has resulted in stricter grid codes.

High-voltage AC transmission links have disadvantages, which may compel a change to DC technology. The break-even distance of HVDC is in the range of 500 to 800 km depending on a number of other factors, like country-specific cost elements, interest rates for project financing, loss evaluation, cost of right of way etc.[4]. HVDC transmission across open sea or into large cities by DC cable may provide the only possible solution.

HVDC Light increases the reliability of power grids, and the technology extends the economical power range of HVDC transmission down to just a few tens of Megawatts (MW). In the upper range, the technology now reaches 1,800 MW and ± 500 kV.

An **HVDC converter** converts electric power from high voltage alternating current (AC) to high-voltage direct current (HVDC), or vice-versa. HVDC is used as an alternative to AC for transmitting electrical energy over long distances or between AC power systems of different frequencies. HVDC converters capable of converting up to two Giga watts (GW) and with voltage ratings of up to 900 kilovolts (kV) have been built and even higher ratings are technically feasible.

In HVDC the DC faults are of Open circuit on DC side, Dc-cable short circuit and Ground faults due to the high discharge current from the dc-link capacitance [5]. A significant decrease in the dc fault current has been analyzed by using BBI-HVDC system during dc-side faults with ac-side blocking capability [1]. The resonance and its effect are not considered.

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In medium to high voltage and certainly in extra high voltage systems the susceptance has a more significant effect in that the first resonance introduced lies in the lower end of the harmonic spectrum and cannot be ignored. The resonance can take the form of parallel resonance between the system capacitance and the system short circuit level impedance as well as series resonance between the system capacitance and the transformer fed lower voltage systems. Multiple resonances within the frequency spectrum can be expected and therefore detailed harmonic impedance studies are quite common for the medium to EHV systems.

Additional harmonic filters and series reactors are required to create an acceptable output waveform at the Point of Common Coupling (PCC) of VSC scheme. The major disadvantage of this technology was its high operating losses. Initial schemes had close to 4% losses, although more recent schemes achieved losses close to 2% per converter station, by using more sophisticated PWM switching techniques. However, in comparison with the losses of LCC technology, the high losses of early VSC schemes were a factor in limiting their application for higher power projects.[9]

The operational losses incurred at each converter station are dependent on the particular scheme design, but are typically around 0.75% of converter rating.[9]

Hence the impedance models for the rectifier ac system and the inverter ac system for a VSC-HVDC system should be developed where the voltage is increased to improve the resonance stability.

II. CIRCUIT OF THE BUCK BOOST INVERTER

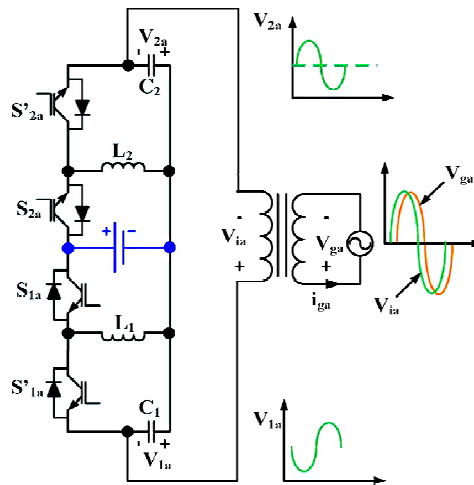


Fig.2.1 One phase of the three-phase BBI

Figs. 1a. A single-stage single-phase BBI shown in fig.3.4 provide dc-to-ac conversion, but also voltage boosting capability. There are two options for three-phase BBI. The first configuration consists of three single-phase BBIs sharing the same dc-link voltage. The other configuration consists of three dc-to-dc buck-boost converters. A comparison between the characteristics of each configuration is done [1].

III. DC-SIDE FAULT AND ITS EFFECT

- Open circuit on d.c. side
- Dc-cable short-circuit and
- Ground faults due to the high discharge current from the dc-link capacitance

During open circuit overvoltage may result if a rectifier is started into an open-circuited d.c. pole or a blocked inverter unless appropriate control action is included in the design. When restart attempt is made into an open-circuited earth electrode line or neutral conductor the current will be forced through a neutral arrester.

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When a d.c. line fault occurs the d.c. voltage for the faulted pole or poles is reduced suddenly to a low level. On the line side of the d.c. reactor, the rate of change of the voltage, dv/dt , is larger than that produced by a commutation failure or by a d.c. bridge fault.

If the d.c. side is resonant at the fundamental frequency, saturation of the converter transformers can occur. This would add to any second harmonic on the primary and cause possible system instability.

Also an a.c. sing-phase-to-earth fault near the rectifier terminal injects large second harmonic voltages on the d.c. side that will remain as long as firing continues.

- Internal fault [1]
- External fault

During the internal fault occurring the voltages of at two ends of the dc line drop sharply

The series inductance of dc transmission line has an effect on the protective relay during the external fault at the inverter side.

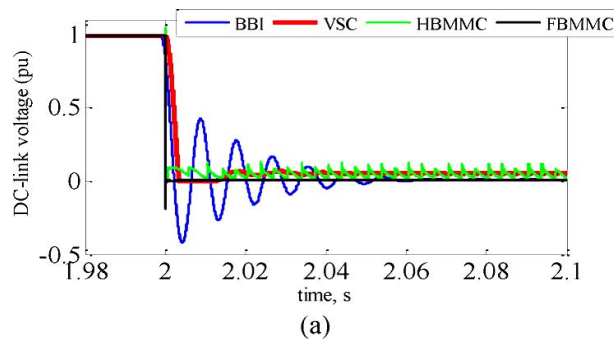


Fig 2.2 Dc-link voltage variation during the dc-side fault for all converter types

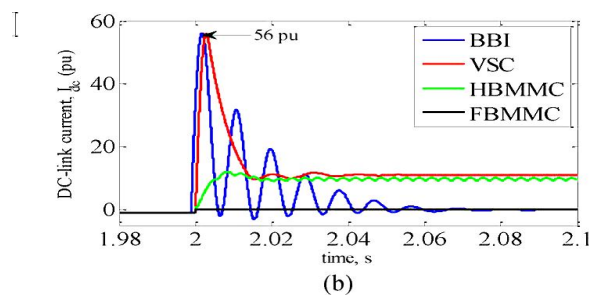


Fig 2.3 Dc-link current variation during the dc-side fault for all converter types

A. Resonance

Resonance occurs when a circuit's inductive reactance and capacitive reactance are balanced. Inductive reactance increases with frequency and capacitive reactance decreases with frequency. If both inductive and capacitive components are in an AC circuit, at one particular frequency their reactance will be equal but opposite. This condition is referred to as resonance, and a circuit that contains these characteristics is called a resonance circuit.

In medium to high voltage and certainly in extra high voltage systems the susceptance has a more significant effect in that the first resonance introduced lies in the lower end of the harmonic spectrum and cannot be ignored. The reson-

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ance can take the form of parallel resonance between the system capacitance and the system short circuit level impedance as well as series resonance between the system capacitance and the transformer fed lower voltage systems. Multiple resonances within the frequency spectrum can be expected and therefore detailed harmonic impedance studies are quite common for the medium to EHV systems.

Parallel resonance between the filter impedance and the grid impedance may create unacceptable amplification of harmonic components for which the filters are not tuned. For this reason, an adequate impedance model of the grid for all relevant harmonics is required in order to optimize the filter design.

The selective resonance method represents a reasonable compromise. It takes into consideration the fact that the highest voltage distortion (highest harmonic voltage) occurs with a parallel resonance between filter and AC network. It is unrealistic however, to assume that such a parallel resonance takes place at all frequencies. Normally it is sufficient to consider in the calculation of total distortion and TIF value only two maximum individual distortions from the resonance calculation.

IV. IMPEDANCE BASED STABILITY

Grid-connected inverters are known to become unstable when the grid impedance is high. A grid-connected inverter will remain stable if the ratio between the grid impedance and the inverter output impedance satisfies the Nyquist stability criterion.

An increasingly important concern for grid-connected inverter is the effects of grid impedance on inverter control performance and stability. It is known that high grid impedance can destabilize the inverter current control loop and lead to sustained harmonic resonance or other instability problems.

The essence of the impedance-based stability criterion is to partition the system under study into a source and a load subsystem. The source subsystem is modeled by its Thevenin equivalent circuit consisting of an ideal voltage source (V_s) in series with an output impedance (Z_s), while the load subsystem is modeled by its input impedance (Z_l)

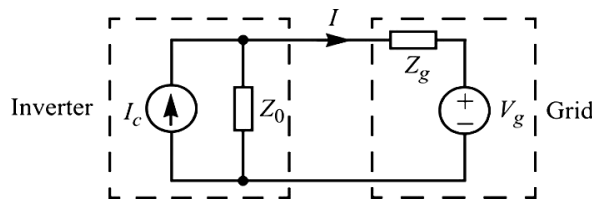


Fig. 2.4 Small-signal representation of an inverter-grid system.

Since almost all power electronic circuits are nonlinear, this linear representation is only valid for small-signal analysis.

4.1. Voltage Source

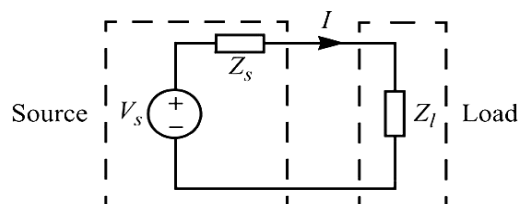


Fig. 2.5 Small-signal representation of a voltage source with load.

With the assumed small-signal model, the current I flowing from the source to the load is

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$$I(s) = \frac{V_s(s)}{Z_l(s) + Z_s(s)} \quad (1)$$

which can be rearranged in the following form:

$$I(s) = \frac{V_s(s)}{Z_l(s)} \cdot \frac{1}{1 + Z_s(s)/Z_l(s)} \quad (2)$$

For system stability analysis, it can be assumed that the source voltage is stable when unloaded and the load current is stable when powered from an ideal source. In that case, both $V_s(s)$ and $1/Z_l(s)$ are stable, such that stability of the current depends on the stability of the second term on the right-hand side of (2)

$$H(s) = \frac{1}{1 + Z_s(s)/Z_l(s)} \quad (3)$$

The impedance-based stability criterion is based on the observation that $H(s)$ resembles the close-loop transfer function of a negative feedback control system where the forward gain is unity and the feedback gain is $Z_s(s)/Z_l(s)$; that is, the ratio of the source output impedance to the load input impedance. By linear control theory, $H(s)$ is stable if and only if $Z_s(s)/Z_l(s)$ satisfies the Nyquist stability criterion.

When applying the impedance-based stability criterion presented above, it is important to recognize that the source is assumed to be a voltage source that is stable when unloaded. Since most practical sources are voltage sources and are stable when unloaded, this assumption tends to be forgotten.

However, grid-connected inverters are usually controlled in the current injection mode and do not behave like a voltage source. Hence, their stability cannot be analyzed by the existing impedance based method.

4.8.2. Current Source

To develop an impedance-based stability criterion for current source systems, we start from a small-signal model similar to that used in the voltage-source case. However, instead of using a Thevenin equivalent circuit, we represent the current source by a Norton equivalent circuit, in the form of a current source (I_s) in parallel with an output admittance (Y_s). The load is represented by its input admittance, Y_l (see Fig.4.10). With this small-signal representation, the voltage across the load is

$$V(s) = \frac{I_s(s)}{Y_l(s) + Y_s(s)} \quad (4)$$

which can be rearranged as follows:

$$V(s) = \frac{I_s(s)}{Y_l(s)} \cdot \frac{1}{1 + Y_s(s)/Y_l(s)} \quad (5)$$

Similar to the voltage-source case, the current source can be assumed stable when unloaded (that is, when the load is a short circuit such that its admittance is infinite), and the load is stable when powered from an ideal current source. Under these assumptions, both $I_s(s)$ and $1/Y_l(s)$ are stable, such that the stability of $V(s)$ depends on the stability of the second term on the right-hand side of (5).

Note again that this term resembles the close-loop transfer function of a negative feedback control system where the forward gain is unity and the feedback gain is $Y_s(s)/Y_l(s)$.

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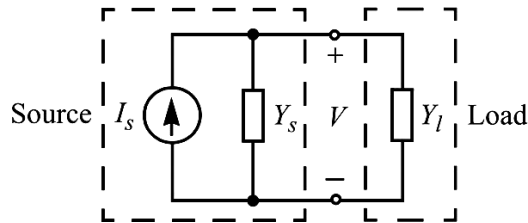


Fig. 2.6 Small-signal representation of a current source with load.

Therefore, a current-source system is stable if:

- 1) The current source itself is stable when unloaded, i.e., when the load is a short-circuit.
- 2) The load is stable when supplied by an ideal current source.
- 3) The ratio of the source output admittance to the load input admittance satisfies the Nyquist criterion.

Note that admittances instead of impedances are used in (5) in order to highlight its duality to (2). The analysis can also be carried out based on the source output impedance (Z_s) and load input impedance (Z_l), in which case (5) becomes

$$V(s) = I_s(s) Z_l(s) \cdot \frac{1}{1 + Z_l(s)/Z_s(s)} \quad (6)$$

and stability of the interconnected system requires the ratio of the load input impedance to the source output impedance meet the Nyquist stability criterion.

Comparing (6) to (2), one can see that stability requirements for current-source systems are opposite to that for voltage source systems: A current source should have high (ideally infinite) output impedance, while a voltage source should have low (ideally zero) output impedance in order to ensure stable operation with a wide range of loads; and a current-source system is more stable when the load impedance is low, while a voltage-source system is more stable when the load impedance is high.

Given that Thevenin and Norton equivalent circuits can be used exchangeably in circuit analysis, it is necessary to make a distinction between current source and voltage-source systems. Based on (3), stability of the system would require the ratio of the source output impedance to the load input impedance, not the inverse as appeared in (6), to satisfy the Nyquist stability criterion.

In the Grid connected system always the load impedance will be high hence Voltage-source system used.

V. PROPOSED CONTROL SCHEME

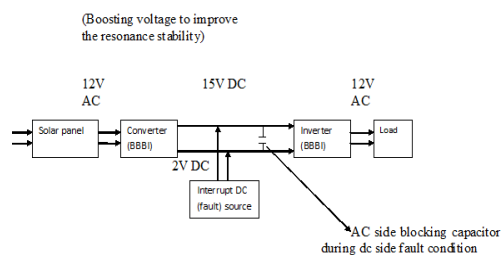


Fig.5.1 Block Diagram of the proposed system

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The DC Power is obtained from the Solar panel and the converter is used to boost the voltage for improving the resonance stability by means of BBI the interrupted voltage of fault current is injected with additional source for nasalization. The blocking capacitor is used to block the fault current. Again the DC is converted into AC by means of BBI which is given to the load.

Here the nasalization is done (i) under load and unloaded condition; (ii) Fault and without fault condition.

A. Ac side protection during DC side fault condition using blocking capacitor

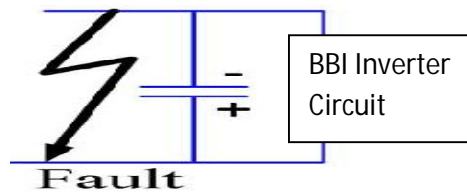


Fig.5.2 Block Diagram with blocking capacitor

Selection of Capacitor:

Capacitor is selected to obtain acceptable voltage ripple at rated conditions. The capacitor voltage ripple is given by

$$\Delta V = \frac{D_{max} \cdot n \cdot \hat{I}_{gph}}{2C_{f_{smax}}} \quad (7)$$

B.Improving Resonance stability:

Voltage is improved by Buck Boost inverter there by increasing voltage stability which refers in equation (1) and (2)

B. Control Strategy

The simulation diagram for the buck boost converter is coded and the shown.

TABLE (1)
PROTOTYPE SPECIFICATION

SCR	TDA 2003
DIODE	IN 4007
CAPACITOR	1000 μ F 63V
SOLAR PANEL	STEP DOWN
TRANSFORMER	21V

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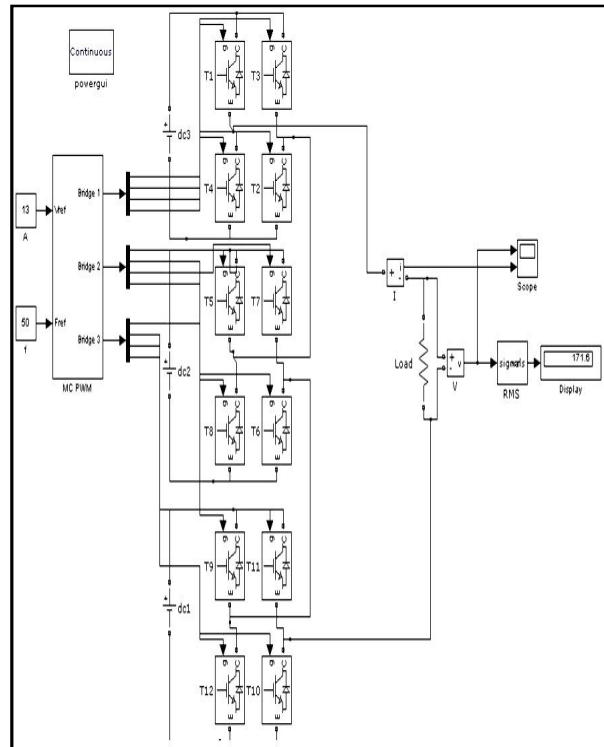


Fig 5.3.Simulation diagram

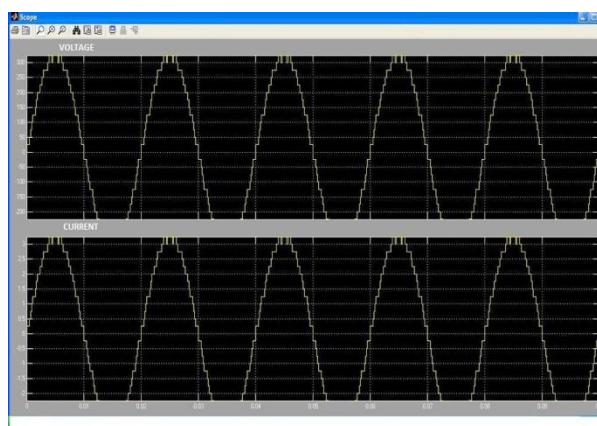


Fig 5.4.Simulation result output voltage

V.CONCLUSION

This paper proposes a BBI-HVDC system with blocking capability of ac-side fault current contribution during dc-side faults improving resonance stability. The main advantages of the proposed BBI system are as follows: 1) AC fault ride through capability; 2) complete blocking capability between the ac grid and dc-side faults via blocking the IGBT gate signals; that is, by employing a BBI topology, the semiconductor devices are protected against dc fault currents. This feature is highly desirable especially in multi terminal HVDC systems. 3) no common mode voltages; 4) very low output stresses; 5) voltage balancing is not needed as in the MMC and hybrid VSC; and 6) BBI has no circulating current; 7) provides independent active and reactive power control in both directions. The impacting factors on stability are

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the feed forward filter structure, line length, and power transfer levels will be identified. The resonance instability will be detected using outer control loop and phase locked loop. The simulation results illustrate the promising performance of the BBI-HVDC configuration under dc-side faults.

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