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SIMULATION OF VOLTAGE SOURCE CONVERTER-BASED HVDC TRANSMISSION SYSTEM, WITH 200MVA (+/-100KV), USING SPWM TECHNIQUE

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ABSTRACT

A 200 MVA (+/- 100 kV DC) forced-commutated Voltage-Sourced Converter (VSC) interconnection is used to transmit power from a 230 kV, 2000 MVA, 50 Hz system to another identical AC system. The rectifier and the inverter are three-level Neutral Point Clamped (NPC) VSC converters using close IGBT/Diodes. The Sinusoidal Pulse Width Modulation (SPWM) switching uses a single-phase triangular carrier wave with a frequency of 27 times fundamental frequency (1350 Hz).. The 40 Mvar shunt AC filters are 27th and 54th high-pass tuned around the two dominating harmonics. The discrete control system generates the three sinusoidal modulating signals that are the reference value of the bridge phase voltages. The amplitude and phase of the modulating signals can be calculated to the reactive and real AC power flow at the PCC, or the reactive power flow at the PCC and the pole to pole DC voltage. It would also be possible to control the AC voltage amplitude at the PCC.

KEYWORDS: HVDC, Voltage Source Converter (VSC), IGBT, SPWM, Control Design

INTRODUCTION

The conventional AC/DC converter, which is used in an HVDC transmission system, back-to back AC system link and frequency converter station, is a line commutated converter using thyristor valve. This converter type shows some characteristics as follows;

Converter consumes large amounts of reactive power Commutation margin angle of inverter station decreases when AC voltage drops or DC current increases Low order harmonics is relatively large.

In the above indicates that large capacity of shunt compensation and filters are needed. Commutation margin angle serious difficulty in inverter operation and induces commutation failure in the worst case. Self-commutated converters will solves or mitigates these problems because of the high potential of such a converter there are some studies of self-commutated converter installation to an HVDC system. They conclude that though a self-commutated converter has high performance. But loss at the converter, over-current protection of' the valve and its cost must be taken into account. Capacitor Commutated Converter (CCC) has similar circuit topology to the conventional line commutated converter (LCC) which is consisted of thyristor bridges. The difference between them is whether converter has series capacitor per phase,

Which is named commutation capacitor (CC) between converter transformer and thyristor bridge. By using this thyristor bridge we cannot control over the output voltage, active power and reactive power output because thyristor is not a self commutated converter that means it cannot turn off by using the pulses. For this we are using IGBT diodes in place of thyristors and these controlled by using sinusoidal pulse width modulation technique as carrier frequency to the input of voltage source converter and we control over the output generated: The overview of the project describes about forced-commutated Voltage-Sourced Converter (VSC) interconnection is used to transmit power from one system to another identical AC system by using sinusoidal PWM technique. The second chapter discusses about Voltage source converter and it based on IGBT technology, 12 Pulse converter and HVDC converter stations. The third chapter deals about the various PWM techniques like single pulse, Multiple-pulse-width, Sinusoidal pulse-width. In the final chapter the conclusions and the future scope of the project included.

VOLTAGE-SOURCE CONVERTER

In VSC HVDC, Pulse Width Modulation (PWM) is used for generation of the fundamental voltage. Using PWM, the magnitude and phase of the voltage can be controlled freely and almost instantaneously within certain limits. This allows independent and very fast control of active and reactive power flows. PWM VSC is therefore a close to ideal component in the transmission network. From a system point of view, it acts as a zero inertia motor or generator that can control active and reactive power almost instantaneously. Furthermore, it does not contribute to the short circuit power, as the AC current can be controlled.

This Paper illustrates modeling of a forced-commutated Thyristor based 12-pulse HVDC transmission link. The objectives of this project are to demonstrate the use of Sim Power Systems blocks in the simulation of a HVDC transmission link based on three-level Neutral Point Clamped (NPC) Perturbations are applied to examine the system dynamic performance .

VSC Based HVDC System

The VSC-HVDC is a new DC transmission system technology. The valves are built by IGBTs and PWM is used to create the desired voltage waveform. With PWM it is possible to create any waveform, any phase angle and magnitude of the fundamental frequency component. This high controllability allows for a wide range of applications.

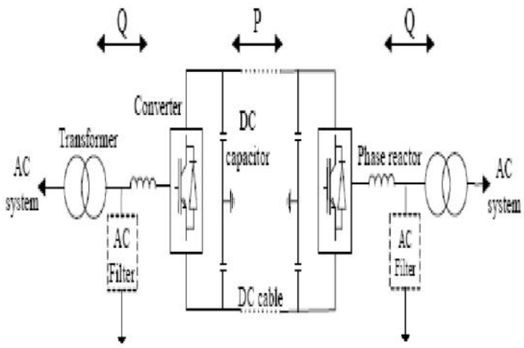

Figure 1: VSC HVDC

VOLTAGE SOURCE CONVERTER BASED ON IGBT TECHNOLOGY

The modular low voltage power electronic platform is called Power Pak. It is a power electronics building block (PEBB) with three integrated Insulated Gate Bipolar Transistor (IGBT) modules. Each IGBT module consists of six switches forming three phase legs. Various configurations are possible. For example three individual three-phase bridges on one PEBB, one three phase bridge plus chopper(s) etc. The Power Pak is easily adaptable for different applications.

The IGBT modules used are one Power Pak as it is used for the SVR. It consists of one three-phase bridge (the three terminals at the right hand side), which provides the input to the DC link (one IGBT module is used for it) and one output in form of one single phase H-bridge (the two terminals to the left) acting as the booster converter. For the latter two IGBT modules are used with three paralleled phase legs per output terminal. By paralleling such PEBBs adaptation to various ratings is possible.

GTO/IGBT (Thyristor Based HVDC)

Normal thyristors (silicon controlled rectifiers) are not fully controllable switches (a "fully controllable switch" can be turned on and off at will.) Thyristors can only be turned ON and cannot be turned OFF. Thyristors are switched ON by a gate signal, but even after the gate signal is de-asserted (removed), the thyristor remains in the ON-state until any turn-off condition occurs (which can be the application of a reverse voltage to the terminals, or when the current flowing through (forward current) falls below a certain threshold value known as the holding current.) Thus, a thyristor behaves like a normal semiconductor diode after it is turned on or "fired.

12-Pulse Converters

The basic design for practically all HVDC converters is the 12-pulse double bridge converter which is shown in Figure below. The converter consists of two 6-pulse bridge converters connected in series on the DC side. One of them is connected to the AC side by a YY-transformer, the other by a YD transformer. The AC currents from each 6-pulse converter will then be phase shifted 30°. This will reduce the harmonic content in the total current drawn from the grid, and leave only the characteristic harmonics of order 12 m±1, m=1,2,3..., or the 11th, 13th, 23rd, 25th etc. harmonic. The non-characteristic harmonics will still be present, but considerably reduced. Thus the need for filtering is substantially reduced, compared to 6-pulse converters.

The 12-pulse converter is usually built up of 12 thyristor valves. Each valve consists of the necessary number of thyristors in series to withstand the required blocking voltage with sufficient margin. Normally there is only one string of thyristors in each valve, no parallel connection. Four valves are built together in series to form a quadruple valve and three quadruple valves, together with converter transformer, controls and protection equipment, constitute a converter. The converter transformers are usually three winding transformers with the windings in YYD N-connection. There can be one three-phase or three single phase transformers, according to local circumstances. In order to optimize the relationship between AC- and DC voltage the converter transformers are equipped with tap changers.

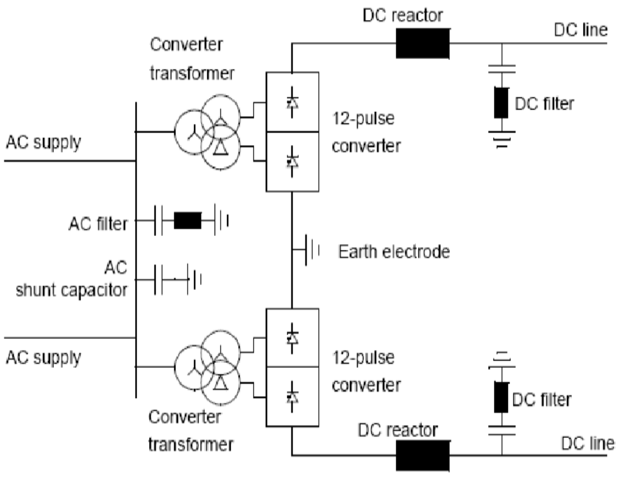

Figure 2: Main Elements of a HVDC Converter Station with One Bipole Consisting of Two 12-Pulse Converter Unit

Natural Commutated Converters (NCC): CC are most used in the HVDC systems as of today. The component that enables this conversion process is the thyristor, which is a controllable semiconductor that can carry very high currents (4000 A) and is able to block very high voltages (up to 10 kV). By means of connecting the thyristors in series it is possible to build up a thyristor valve, which is able to operate at very high voltages (several hundred of kV).The thyristor valve is operated at net frequency (50 hz or 60 hz) and by means of a control angle it is possible to change the DC voltage level of the bridge..

Capacitor Commutated Converters (CCC): An improvement in the thyristor-based Commutation, the CCC concept is characterized by the use of commutation capacitors inserted in series between the converter transformers and the thyristor valves. The commutation capacitors improve the commutation failure performance of the converters when connected to weak networks.

Forced Commutated Converters (FCC): This type of converters introduces a spectrum of advantages, e.g. feed of passive networks (without generation), independent control of active and reactive power, power quality. The valves of these converters are built up with semiconductors with the ability not only to turn-on but also to turn-off. They are known as VSC (Voltage Source Converters).

A new type of HVDC has become available. It makes use of the more advanced semiconductor technology instead of thyristors for power conversion between AC and DC. The semiconductors used are insulated gate bipolar transistors (IGBTs), and the converters are voltage source converters (VSCs) which operate with high switching frequencies (1-2kHz) utilizing pulse width modulation (PWM).

VSC Based HVDC Technology Fundamentals

The VSC based HVDC installations have demonstrated some excellent advantages and has been applied in several special occasions, such as providing power to a passive ac network, transmission and distribution of power in medium voltage and low voltage and power market etc. Each converter station is composed of a VSC. The amplitude and phase angle of the converter AC output voltage can be controlled simultaneously to achieve a rapid, independent control of active and reactive power in all four quadrants.

The control of both active and reactive power is bi-directional and continuous across the operating range. For active power balance, one of the converters operates on constant dc voltage control and the other converter operates on constant active power control. When dc line power is zero, the two converters can be considered as independent on fact devices.

However, VSC is a double-input and double-output coupled nonlinear control object when it is connected to an active ac network. The double-input are the phase angle δ and modulation index m of PWM, and the double-output are the reactive power output Q and the active power output P or the dc voltage Ud of the VSC. Due to the influence of the couple-relationship between controlling and controlled variables, it is difficult to control active power and reactive power independently and enable the system to performance well.

Therefore, it is necessary to develop a mathematical model for VSC-HVDC to determine the relationship between the two controlling and the two controlled variables and fulfill the requirements of controlling active and reactive power independently. The fully-controlled semiconductor devices available today for high-voltage high power converters can be either thyristors or transistors. These devices can be used for a VSC with pulse-width modulation (PWM), operating at frequencies higher than the line frequency and are self-commuted via a gate pulse.

Typically, it is desirable that a VSC application generates PWM waveforms of higher frequency when compared to the thyristor-based systems. However, the operating frequency of these devices is also determined by the losses and the design of the heat sink, both of which are related to the power through the component. Switching losses, directly linked to high frequency PWM operation, are one of the most serious issues that need to be dealt with in VSC-based applications.

Table 1: List of Acronyms and their Types

Acronym	Type	Full Name
IGBT	Transistor	Insulated Gate Bipolar Transistor
IEGT	Transistor	Injection Enhance Gate Transistor
GTO	Thyristor	Gate Turn off Thyristor
IGCT	Thyristor	Integrated Gate Commuted Thyristor
GCT	Thyristor	Gate Commutated Turn –off Thyristor

HVDC and FACTS systems are important technologies, supporting in their own way the modern power systems, which in many cases are fully partially deregulated in several countries. In the near future, even higher integration of electrical grids and market driven developments are expected as, for instance, countries in the Middle-East, China, India and South America require infrastructure to power their growth.

Summary of fully-controlled high-power semiconductors In the recent years, VSC-HVDC system using power-synchronization control is investigated for interconnection of two very weak ac systems. By using power-synchronization control, the VSC-HVDC link is possible to be applied in more challenging conditions. In addition, the VSC-HVDC link contributes short-circuit capacity to the ac system at the PCC without increasing the short-circuit current thanks to its current limiting capability during ac-system faults. The major consideration for VSC-HVDC links connected to weak ac systems is that the RHP transmission zero of the ac Jacobian transfer matrix, which moves closer to the origin with larger load angles. The RHP zero imposes a fundamental limitation on the achievable bandwidth of the VSC, which implies the following for VSC-HVDC links interconnecting two very weak ac systems.

- At either of the converter stations, the VSC-HVDC converter shall not operate with too large load angles in the steady state to maintain a reasonable stability margin.
- A higher dc capacitance is necessary to keep the variation of the direct voltage within the allowed range.
- The active-power controller at the power-controlling station should use the direct-voltage controller as the inner loop and limit its output in order not to affect the direct voltage level too much from its nominal value.

Typically, many series connected IGBTs are used for each semiconductor in order to deliver a higher blocking voltage capability for the converter and therefore increase the DC bus voltage level of the HVDC system. It should be noted that an antiparallel diode is also needed in order to ensure the four-quadrant operation of the converter. The DC bus capacitor provides the required storage of the energy so that the power flow can be controlled and offers filtering for the DC harmonics. The converter is typically controlled through sinusoidal PWM (SPWM) and the harmonics are directly associated with the switching frequency of each converter leg. Fig. 8 presents the basic waveforms associated with SPWM and the line-to-neutral voltage waveform of the two-level converter. Each phase-leg of the converter is connected through a reactor to the AC system. Filters are also included on the AC side to further reduce the harmonic content flowing into the AC system.

A generalised two AC voltage sources connected via a reactor the relative location of the vectors of the two AC quantities and their relationship through the voltage drop across the line reactor. One vector is generated by the VSC and the other one is the vector of the AC system. At the fundamental frequency the active and reactive powers are defined by the following relationships, assuming the reactor between the converter and the AC system is ideal (i.e. lossless):

$$P = \frac{V_s \sin\delta}{X_L} \cdot V_r$$

$$Q = \frac{V_s \cos\delta - V_r}{X_r} \cdot V_r$$

where δ is the phase angle between the voltage vectors (sending) and (receiving) at the fundamental frequency. *sVr*

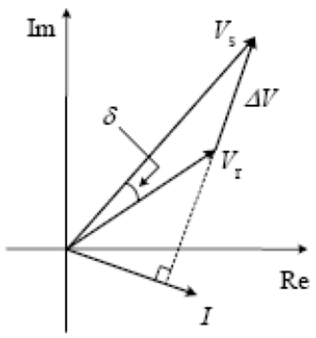

Figure 3: Vector Diagram of Power Transmission Based on Two AC Voltage Sources Interconnected through a Lossless Reactor

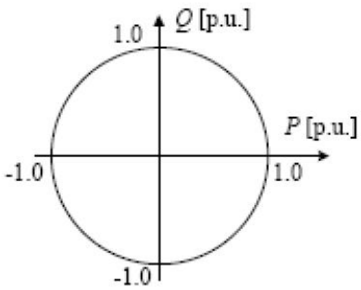

Figure 4: Active-Reactive (*PQ)* Locus Diagram of VSC-Based Power Transmission System

Fig 4.Shows the entire active-reactive power area where the VSC can be operated with the 1.0 p.u. value being the MVA rating of each converter.

The use of VSC as opposed to a line commutated CSC offers the following advantages:

- Avoidance of commutation failures due to disturbances in the AC network.
- Independent control of the reactive and active power consumed or generated by the converter.
- Possibility to connect the VSC-HVDC system to a "weak" AC network or even to one where no generation source is available and naturally the short-circuit level is very low.
- Faster dynamic response due to higher (PWM) than the fundamental switching frequency (phase-controlled) operation, which further results in reduced need for filtering and hence smaller filter size.
- No need of transformers for the conversion process

  There are various pulse width modulation techniques to vary the voltage source converter gain. The commonly used techniques are:

  - Single-pulse-width modulation

- Multiple-pulse-width modulation
- Sinusoidal pulse-width modulation

Sinusoidal Pulse Width Modulation

Instead of maintaining the width of all pulses the same as in the case of multiple-pulse modulation, the width of each pulse is varied in proportion to the amplitude of a sine wave evaluated at the center of the same pulse. The distortion factor and lower order harmonics are reduces significantly. The control signals are generated by comparing a sinusoidal reference signal with a triangular carrier wave of frequency fc as shown in fig.10. This sinusoidal pulse width modulation is commonly used in industrial applications. The frequency of reference signal fr determines the inverter output frequency fo, and its peak amplitude Ar controls the modulation index m, and then in turn the RMS output voltage Vo. Comparing the bi-directional carrier signal vcr with two sinusoidal reference signals vr and –vr, produces control signals gt1 and g4 respectively as shown in fig.10(b).

The output voltage is vo = Vs(g1-g4). However, g1 and g4 can not be released at the same time. The number of pulses per half-cycle depends on the carrier frequency. Within the constraint that two transistors of the same arm(Q1 andQ4) cannot conduct at the same time, the instantaneous output voltage is shown in fig.10(c). The same control signals can be generated y using unidirectional triangular carrier wave as in fig/ 12(d). It is easier to implement this method and is preferred. The generation of control signals is similar to that for the UPWM, except the reference signal is a sine wave vr= Vr sin wt, instead of a dc signal. The output voltage is vo = Vs(g1-g4).

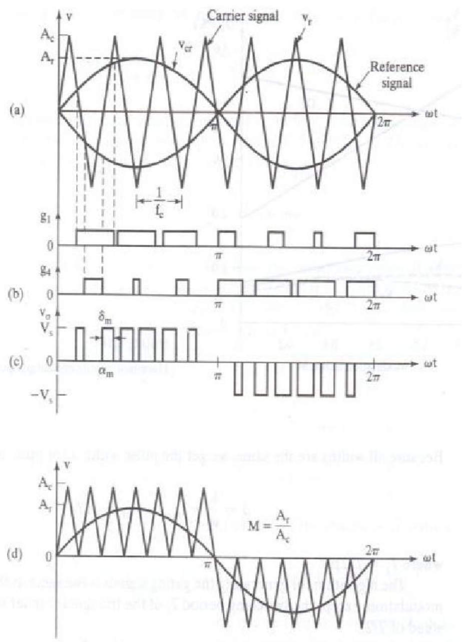

Figure 5: Sinusoidal PWM

The RMS output voltage can be varied by varying the modulation index M. it can be observed that the area of each pulse corresponds approximately to the area under the sine wave between the adjacent midpoints of off periods on the control signals. If

(δ_m) is the width of mth pulse, then the RMS output voltage is’

[illegible]

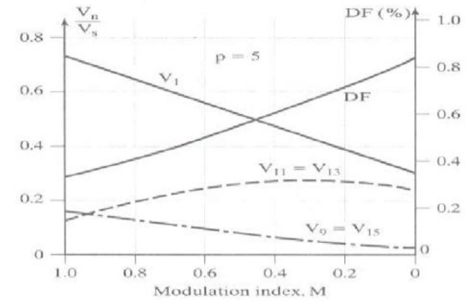

Figure 6: Harmonic Profile of Sinusoidal PWM

The harmonic profile of SPWM is shown in fig.13. The output voltage of an inverter contains harmonics. The PWM pushes the harmonics into a high-fequency range around the switching frequency fc and its multiples, that is , around harmonics mf, 2mf, 3mf and so on.

SIMULINK DIAGRAM OF PROPOSED SYSTEM

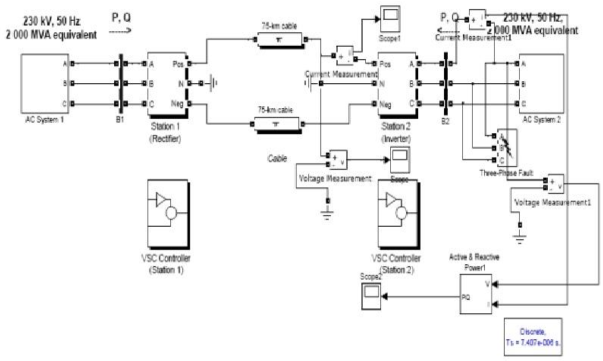

Figure 7: Main Circuit of Proposed System

SIMULINK OUTPUT WAVEFORMS

Current Waveform

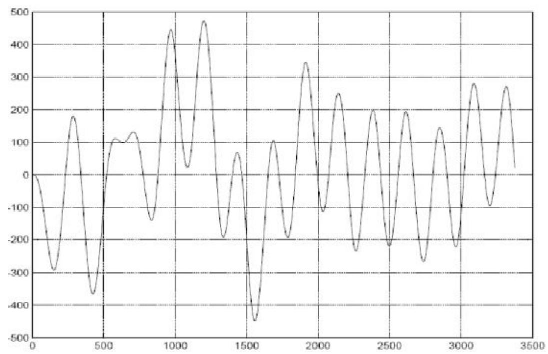

Figure 8: On X-Axis Time in Ms Y Axis Current in Ma

Voltage Waveform

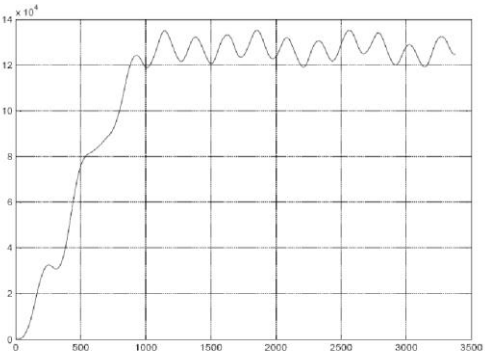

Figure 9: On X-Axis Time in Ms Y Axis Voltage in Pu

Active Power and Reactive Power

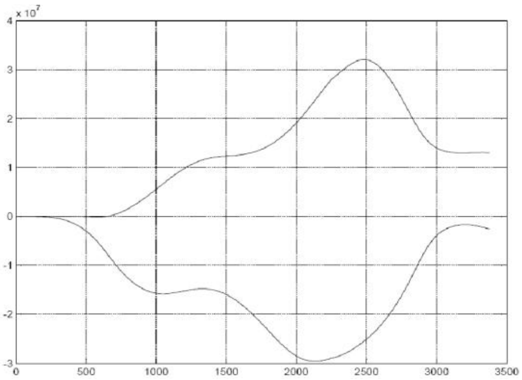

Figure 10: On X-Axis Time in Ms Y Axis Active & Reactive Power in Pu

CONCLUSIONS

The Sinusoidal Pulse Width Modulation (SPWM) switching uses a single-phase triangular carrier wave with a frequency of 27 times fundamental frequency is applied to the voltage source converter. The transformer tap changers and saturation characteristics are not simulated. Converter reactor with the 0.15pu transformer leakage reactance permits the VSC output voltage to shift in phase and amplitude with respect to the AC system Point of Common Coupling (PCC) (bus B1 for station 1 and B2 for station 2) and allows control of converter active and reactive power output. They have an influence on the system dynamics and the voltage ripple on the DC side.

The high-frequency blocking filters are tuned to the 3rd harmonic, i.e. the main harmonic present in the positive and negative pole voltages, the harmonics are eliminated in the circuit. The discrete control system generates the three sinusoidal modulating signals that are the reference value of the bridge phase voltages. The amplitude and phase of the modulating signals can be calculated to control either: the reactive and real AC power flow at the PCC, or the reactive power flow at the PCC and the pole to pole DC voltage. It would also be possible to control the AC voltage amplitude at the PCC

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