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HVDC Light for its Enhancement of AC/DC Interconnected Transmission Systems

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ABSTRACT : High-Voltage direct current (HVDC) transmission is an economic way for long distance power delivery and/or interconnection of asynchronous systems with different frequency. With the development of modern power system, HVDC system plays much more important role in power grids due to their huge capacity and capability of long distance transmission. Towards 2015, there will be 7 HVDC transmission systems constructed in the China South Power Grids (the CSGs). Conventional HVDC transmission system is based on line-commutated thyristor rectifier. With the advent of high-voltage and high power gate-turn-off thyristor (GTO), insulated-gate controlled transistor (IGBT) and more recently, insulated-gate controlled thyristor (IGCT), high power solid-state switches have symmetrical turn-on and turn-off capabilities. They have given the birth to a new generation of HVDC stations, HVDC Light, which is also called as voltage-source-converter (VSC) HVDC.

KEYWORDS: High-Voltage direct current (HVDC) transmission is an economic way for long distance power delivery and/or interconnection of asynchronous systems with different frequency

I. INTRODUCTION

I. Mobile Ad Hoc Networks (MANETs) consists of a collection of mobile nodes which are not bounded in any infrastructure. Nodes in MANET can communicate with each other and can move anywhere without restriction. This non-restricted mobility and easy deployment characteristics of MANETs make them very popular and highly suitable for emergencies, natural disaster and military operations.

A. Nodes in MANET have limited battery power and these batteries cannot be replaced or recharged in complex scenarios. To prolong or maximize the network lifetime these batteries should be used efficiently. The energy consumption of each node varies according to its communication state: transmitting, receiving, listening

II. The main purpose of energy efficient algorithm is to maximize the network lifetime. These algorithms are not just related to maximize the total energy consumption of the route but also to maximize the life time of each node in the network to increase the network lifetime. Energy efficient algorithms can be based on the two metrics: i) Minimizing total transmission energy ii) maximizing network lifetime. The first metric focuses on the total transmission energy used to send the packets from source to destination by selecting the large number of hops criteria. Second metric focuses on the residual batter energy level of entire network or individual battery energy of a node [1].

III. HVDC light can control both active and reactive power independently without commutation failures in the inverter side. It doesn't require reactive power compensators resulting much smaller equipment size. HVDC light can be applied to the voltage support in the receiver systems [6], interconnection between asynchronous power systems [7], grid connection of large wind farm [8] or offshore wind farm [9] and subsea power transmission [10]. So far, there are 12 HVDC Light projects for different purposes already in operations world wide. HVDC systems are responding and can be controlled within tens of milli-seconds. HVDC systems can also improve the stability, especially transient stability of power system [11]. The appearance of the HVDC Light, which has more advantages than conventional HVDC systems, can bring a new approach for the AC/DC hybrid transmission systems and multi-infeed HVDC transmission system. If the receiver system is weak, voltage stability and commutation failure may become serious problems in conventi nal HVDC system [12]. By pulse wide modulation (PWM) control, HVDC Light realizes INDEPENDENT CONTROL OF ACTIVE AND REACTIVE POWER CONTROL, AND DOSE NOT NEED REACTIVE COMPENSATION IN BOTH RECTIFIER AND INVERTER SIDE.

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IV. IT can also be used with static synchronous series compensation (SSSC) characteristics to damp the power system oscillations [13]. HVDC Light applies self-commutated solid-state device, so there are no commutation failure issue. For AC/DC interconnected transmission systems, the introduction of HVDC Light can enhance the voltage support and improve the system stability. The following sectors will discuss the effect of HVDC Light for improvement of the AC/DC interconnected systems. Transient dynamic simulations are performed with matlab. Two simulation models have been set up with HVDC Light built in; one is an AC/DC parallel transmission lines system, and the other is a multi-in feed HVDC systems. The performance of HVDC Light in enhancing both power angle stability and

V. voltage stability in these systems is taken into considerations.

II. RELATED WORK

Over long distances bulk power transfer can be carried out by a high voltage direct current (HVDC) connection cheaper than by a long distance AC transmission line. HVDC transmission can also be used where an AC transmission scheme could not (e.g. through very long cables or across borders where the two AC systems are not synchronized or operating at the same frequency). However, in order to achieve these long distance transmission links, power convertor equipment is required, which is a possible point of failure and any interruption in delivered power can be costly. It is therefore of critical importance to design a HVDC scheme for a given availability.

The HVDC technology is a high power electronics technology used in electric power systems. It is an efficient and flexible method to transmit large amounts of electric power over long distances by overhead transmission lines or underground/submarine cables. It can also be used to interconnect asynchronous power systems

The fundamental process that occurs in an HVDC system is the conversion of electrical current from AC to DC (rectifier) at the transmitting end and from DC to AC (inverter) at the receiving end.

There are three ways of achieving conversion

1. Natural commutated converters
2. Capacitor Commutated Converters
3. Forced Commutated Converters
4. Natural commutated converters: (NCC)

NCC 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.

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

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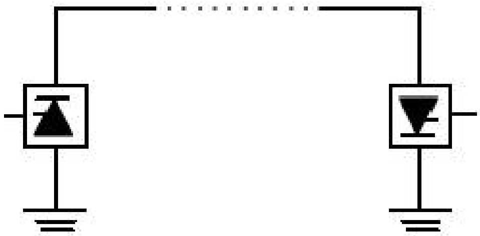
converters are voltage source converters (VSCs) which operate with high switching frequencies (1-2kHz) utilizing pulse width modulation (PWM).

Configurations of HVDC

There are different types of HVDC systems which are

Mono-polar HVDC system:

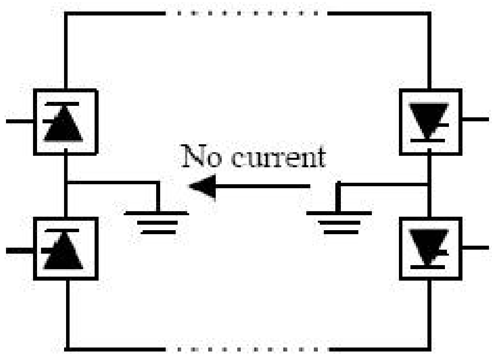
In the mono-polar configuration, two converters are connected by a single pole line and a positive or a negative DC voltage is used. In Fig. There is only one Insulated transmission conductor installed and the ground or sea provides the path for the return current.



Bipolar HVDC system:

This is the most commonly used configuration of HVDC transmission systems. The bipolar configuration, shown in Fig. Uses two insulated conductors as Positive and negative poles. The two poles can be operated independently if both Neutrals are grounded. The bipolar configuration increases the power transfer capacity.

Under normal operation, the currents flowing in both poles are identical and there is no ground current. In case of failure of one pole power transmission can continue in the other pole which increases the reliability. Most overhead line HVDC transmission systems use the bipolar configuration.



Homo-polar HVDC system:

In the homo polar configuration, shown in Fig. Two or more conductors have the negative polarity and can be operated with ground or a metallic return. With two Poles operated in parallel, the homopolar configuration reduces the insulation costs. However, the large earth return current is the major disadvantage.

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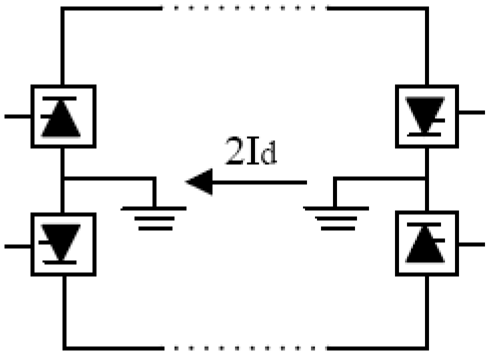
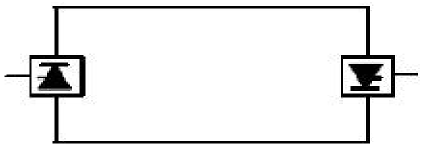
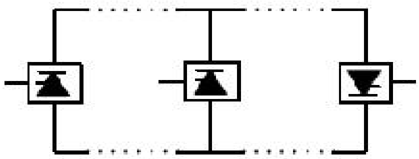


Multi-terminal HVDC system:

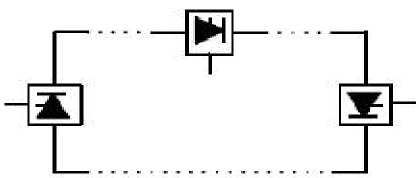
In the multi terminal configuration, three or more HVDC converter stations are geographically separated and interconnected through transmission lines or cables. The
System can be either parallel, where all converter stations are connected to the
same voltage as shown in Fig(b). or series multiterminal system, where one or more converter stations are connected in series in one or both poles as shown in Fig. (c). A hybrid multiterminal system contains a combination of parallel and series connections of converter stations



(a)



(b)



A voltage-source converter is connected on its ac-voltage side to a three-phase electric power network via a transformer and on its dc-voltage side to capacitor equipment. The transformer has on its secondary side a first, a second, and a third phase winding, each one with a first and a second winding terminal. Resistor equipment is arranged at the transformer for limiting the current through the converter when connecting the transformer to the power network. The resistor equipment includes a first resistor, connected to the first winding terminal of the second phase winding, and switching equipment is adapted, in an initial position, to block current through the phase windings, in a transition position to form a current path which includes at least the first and the second phase windings and, in series therewith, the first resistor, which current path, when the converter is connected to the transformer, closes through the converter and the capacitor equipment, and, in an operating position, to interconnect all the first winding terminals for forming the common neutral point.

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 shortcircuit power, as the AC current can be controlled.
Voltage Source Converter based on IGBT technology
The modular low voltage power electronic platform is called PowerPak. 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 PowerPak 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".

The GTO can be turned-on by a gate signal, and can also be turned-off by a gate signal of negative polarity.

Turn on is accomplished by a positive current pulse between the gate and cathode terminals. As the gate-cathode behaves like PN junction, there will be some relatively small voltage between the terminals.The turn on phenomenon in GTO is however, not as relieable as an SCR(thyristor) and small positive gate current must be maintained even after turn on to improve relieabilty.
Turn off is accomplished by a negative voltage pulse between the gate and cathode terminals. Some of the forward current (about one third to one fifth) is "stolen" and used to induce a cathode-gate voltage which in turn induces the forward current to fall and the GTO will switch off (transitioning to the 'blocking' state.)
GTO thyristors suffer from long switch off times, whereby after the forward current falls, there is a long tail time where residual current continues to flow until all remaining charge from the device is taken away. This restricts the maximum switching frequency to approx 1kHz.
It may however be noted that the turn off time of a comparable SCR is ten times that of a GTO.Thus switching frequency of GTO is much better than SCR.

Gate turn-off (GTO) thyristors are able to not only turn on the main current but also turn it off, provided with a gate drive circuit. Unlike conventional thyristors, they have no commutation circuit, downsizing application systems while improving efficiency. They are the most suitable for high-current, high speed switching applications, such as inverters and chopper circuits.

Bipolar devices made with SiC offer 20-50X lower switching losses as compared to conventional semiconductors. A rough estimate of the switching power losses as a function of switching frequency is shown in

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Figure 4. Another very significant property of SiC bipolar devices is their lower differential on-state voltage drop than similarly rated Si bipolar device, even with order of magnitude smaller carrier lifetimes in the drift region.

This property allows high voltage (>20 kV) to be far more reliable and thermally stable as compared to those made with Silicon. The switching losses and the temperature stability of bipolar power devices depends on the physics of operation of the device.

The two major categories of bipolar power devices are: (a) single injecting junction devices (for example BJT and IGBT); and (b) double
injecting junction devices (like Thyristor-based GTO/MTO/JCT/FCT and PIN diodes). In a power BJT, most of the minority carrier charge resides in the low doped collector layer, and hence its operation has been approximated as an IGBT. The limited gain of a BJT will make the following analysis less relevant for lower voltage devices.

Silicon carbide has been projected to have tremendous potential for high voltage solid-state power devices with very high voltage and current ratings because of its electrical and physical properties. The rapid development of the technology for producing high quality single crystal SiC wafers and thin films presents the opportunity to fabricate solid- state devices with power-temperature capability far greater than devices currently available. This capability is ideally suited to the applications of power conditioning in new more- electric or all-electric military and commercial vehicles.
These applications require switches and amplifiers capable of large currents with relatively low voltage drops. One of the most pervasive power devices in silicon is the Insulated Gate Bipolar Transistor (IGBT). However, these devices are limited in their operating temperature and their achievable power ratings compared to that possible with SiC. Because of the nearly ideal combination of characteristics of these devices, we propose to demonstrate the first 4H-SiC Insulated Gate Bipolar Transistor in this Phase I effort. Both n-channel and p-channel SiC IGBT devices will be investigated. The targeted current and voltage rating for the Phase I IGBT will be a >200 Volt, 200 mA device, that can operate at 350 C.
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, 23th, 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,

VI. PROPOSED ALGORITHM

Step 1: Comparison of Different HVAC-HVDC

In order to examine the behavior of the losses in combined transmission and not in order to provide the best economical solutions for real case projects. Thus, most of the configurations are overrated, increasing the initial investment cost and consequently the energy transmission cost. The small number of different configurations analyzed provides a limited set of results, from which specific conclusions can be drawn regarding the energy transmission cost. Nevertheless, the same approach, as for the individual HVACHVDC systems, is followed in order to evaluate the energy availability and the energy transmission cost.
Presentation of Selected Configurations and Calculation of the Energy Transmission Cost

For the combined HVAC-HVDC transmission systems only 500 MW and 1000 MW windfarm were considered.
The choices for the transmission distance was limited to 50, 100 and 200 km. The three following, general combinations were compared:

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1. HVAC + HVDC VSC
2. HVAC + HVDC LCC
3. HVDC LCC + HVDC VSC

The specific configurations for each solution, based on the transmission distance and the size of the wind farm, are presented in Tables .

POWER SYSTEM STABILITY

In this section, we provide a formal definition of power system stability. The intent is to provide a physically based definition, which, while conforming to definitions from system theory, is easily understood and readily applied by power system engineering practitioners.

"Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact."

Stability considerations have been recognized as an essential part of power system planning for a long time. With interconnected systems continually growing in size and extending over vast geographical regions, it is becoming increasingly more difficult to maintain synchronism between various parts of a power system.

CLASSIFICATION OF POWER SYSTEM STABILITY

A typical modern power system is a high-order multivariable process whose dynamic response is influenced by a wide array of devices with different characteristics and response rates. Stability is a condition of equilibrium between opposing forces. Depending on the network topology, system operating condition and the form of disturbance, different sets of opposing forces may experience sustained imbalance leading to different forms of instability. In this section, we provide a systematic basis for classification of power system stability.

III. PSEUDO CODE

Step 1: Generate all the possible routes.
Step 2: Calculate the TE_{node} for each node of each route using eq. (1).
Step 3: Check the below condition for each route till no route is available to transmit the packet.

```
    if (RBE < = TE_node)
        Make the node into sleep mode.
    else
        Select all the routes which have active nodes
    end
```

Step 4: Calculate the total transmission energy for all the selected routes using eq. (2).
Step 5: Select the energy efficient route on the basis of minimum total transmission energy of the route.
Step 6: Calculate the RBE for each node of the selected route using eq. (3).
Step 7: go to step 3.
Step 8: End.

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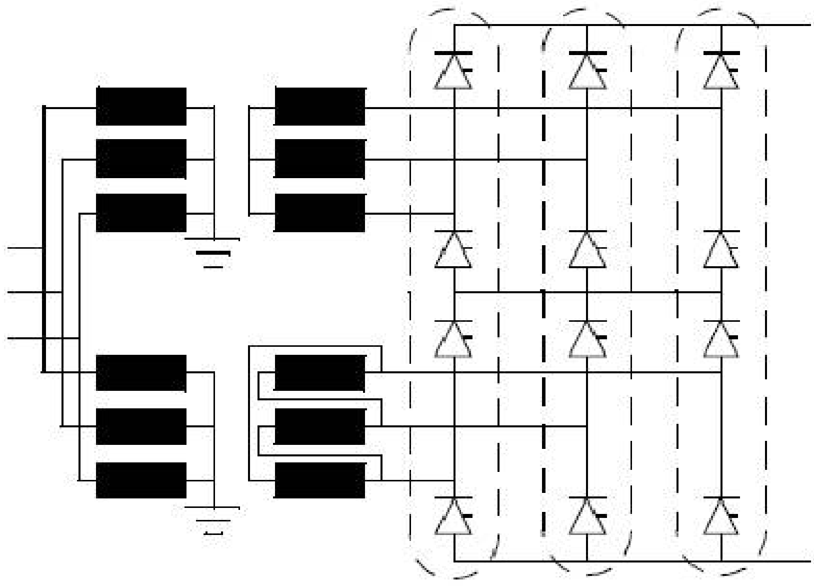
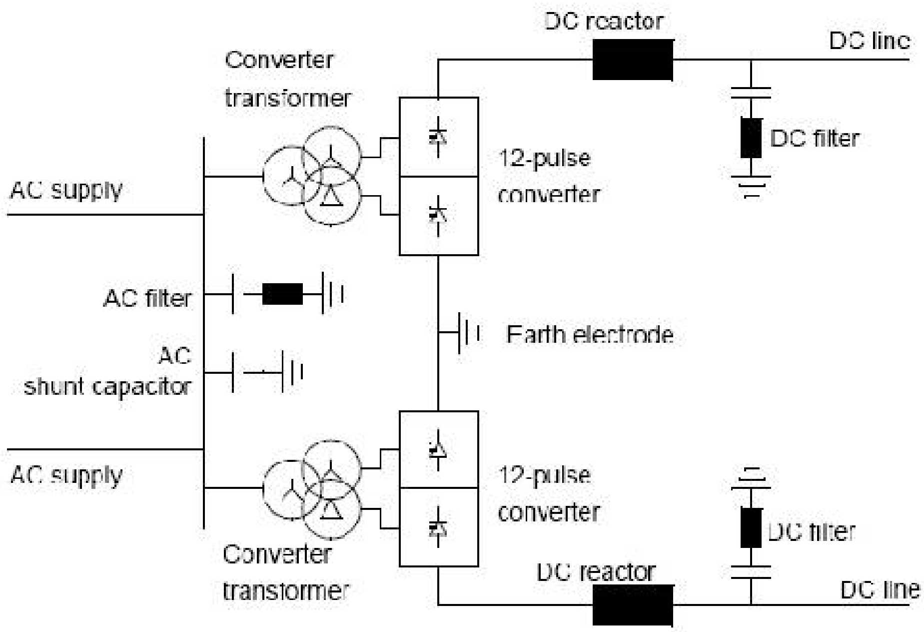
IV. SIMULATION RESULTS





V. CONCLUSION AND FUTURE WORK

HVDC Light is a novel power electronic device, which utilizes the technology of VSC converter. By PWM control model, it can control the output of active power and reactive power independently. It is the major difference from linecommutated HVDC transmission system. In AC/DC interconnected transmission system, the rotor angle stability of power systems can be improved by the control of active power. The AC voltage in inverter side can be supported by the control of reactive power. In multi-infeed HVDC transmission system, system faults can cause commutation failure in

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several HVDC systems. With the capability of voltage support from HVDC Light, the AC voltage can be supported to prevent the commutation failure in some HVDC systems. As a conclusion, HVDC Light is a novel approach to improve the performance and stability of power system. It has bright future to be applied in power systems in many fields.

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