



VSC-HVDC Transmission Solution



Reliable solution to power transmission to island and renewable energy grid interconnection



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VSC Transmission Overview



VSC-HVDC transmission uses IGBT-based voltage source inverter and advanced control strategies to achieve efficient power transmission and dynamic reactive power support for AC system. It effectively improves low-voltage ride-through capability to enhance the transient performance of grid interconnection and thus is widely applied to renewable energy generation. As one of the most innovative power electronic applications in the world, it becomes the key to smart grid technologies.

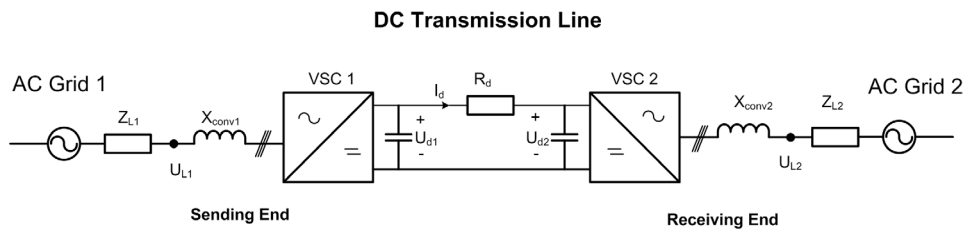


Figure 1 VSC transmission scheme

The point-to-point VSC-HVDC transmission scheme consists of two VSCs interconnected on DC side. Each VSC connects to an AC grids on AC side. A passive or an active AC network can be connected to the AC side of VSC. If connecting to a passive network on the AC side, the direction of power flow can only be from DC input towards the passive load on AC side. However, if connecting to an active AC network, the power flow can be bidirectional by controlling the AC voltage output of VSC.

comparison between LCC-HVDC and VSC-HVDC

LCC-HVDC	VSC HVDC
Thyristor	IGBT
AC system to support commutation	Self commutation
Commutation failure due to system fault of switch operation	No commutation failure
Hard for multi-terminal system and connection to weak system	Easy for multi-terminal system
Large amount of reactive power produced	Reactive power can be self adjusted
Larger site area	Smaller site area
Less losses (0.8%)	More losses(1.2%)

VSC Transmission Overview



Different from traditional thyristor-based HVDC transmission, the direction of power flow for VSC-HVDC on DC line is determined by the direction of DC current. VSC-HVDC has rapid response speed, well controllability and flexible operation mode. It greatly reduces system short-circuit current, and can supply power to passive grid. Thus VSC-HVDC is an effective way to solve large-area power blackout and long-distance power transmission to isolated grid.

There are several system configurations available for DC circuit and converter units in VSC-HVDC transmission application. Each VSC substation can be composed of single converter unit of a phase unit topology resulting in a transmission scheme.

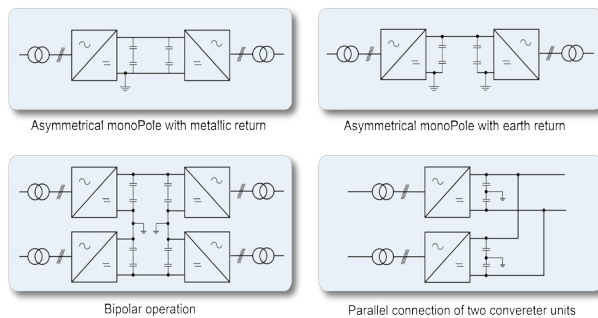


Figure 2 VSC transmission configurations

NR electric provides the total solution for VSC-HVDC transmission. The PCS-9520 VSC HVDC technology features:

- Independent control of active and reactive power
- Suitable for the application to passive power supply

- Suitable for long-distance small power transmission
- Instant supply of reactive power
- Smaller filtering capacity
- Black-start capability
- Multi-terminal network interconnection capability
- Modular design with relatively small cover area

The PCS-9520 VSC-HVDC transmission system has advantages of low switching frequency, small running loss, easily extensible, stable and long life cycle. It is suitable for the applications to:

- Wind, solar and other new energy grid-connection
- Island, offshore platform supply
- City DC transmission and distribution grid
- Remote area power supply
- Asynchronous grid interconnection
- The multi-terminal flexible DC power transmission



VSC-HVDC Primary Equipment



NR undertakes turnkey projects for VSC-HVDC transmission with our own innovative products and qualified third party products. The working scope of turnkey projects includes VSC-based converter valves, converter halls, insertion resistors, optical CTs, electronic CTs/VTs, converter transformer, converter reactors, electric cable or overhead line, control and protection system.

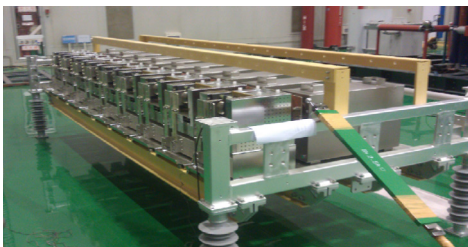


Figure 3 valve physical structure

Converter valves are the core of PCS-9520 VSC-HVDC transmission system. The capacitor and switching devices of converter valve can form a sub-module. Each phase bridge is composed of several sub-modules and a series connected reactor. By varying the number of sub-modules, it is flexible to change the converter output voltage and power levels, and easy to extend the output level with low harmonic distortion and low switching frequency, so as to reduce operation losses and improve system efficiency.

NR Converter advantages:

- MMC topology with low losses
- Easy to achieve various voltage levels and power levels
- Low harmonics output
- No need of AC filters
- Modularized design to ease maintenance
- Good self-protection against fault



Figure 4 converter transformer

In many cases, VSC-HVDC substation design includes interface transformers. In general, interface transformers can fulfill the following tasks:

- Provide reactance between AC system and VSC unit
- Adjust the standard AC system voltage to match the VSC AC output voltage and allow optimal utilization of VSC valve ratings;
- Connect several VSC units together on AC side to obtain different DC voltage potentials;
- Avoid zero sequence currents flowing between AC system and VSC unit.

VSC-HVDC Primary Equipment

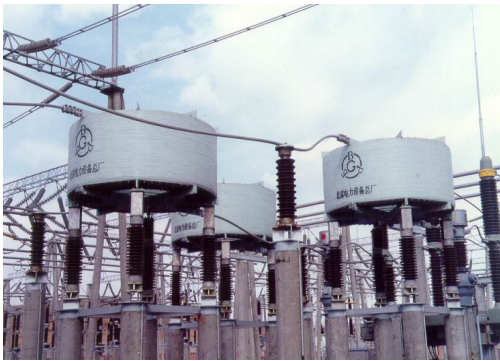


Figure 5 phase reactor



Figure 6 ECT photo

The phase reactors are connected in series to VSC valve. The reactors have different functions:

- Determinate inverter delivery capacity
- Inhibit the inverter output harmonics
- Restrain the rate of rise of fault current
- Limit the short-circuit current peak
- Suppress the circulating current

The type of DC transmission line is determined by environment requirement. For severe sites and submarine applications, DC power cables are preferred. Using DC power cables for VSC-HVDC transmission has following advantages:

- Flexible configuration of voltage level up to 320kV
- High strength and flexibility
- Direct burial technology
- Two cables being close in arrangement
- Preventing fluid leakage and repeated bending
- Capable to work at low temperature
- Lower insulation requirements



Figure 7 EVT photo

In VSC converter station, electromagnetic interference can seriously affect measurement accuracy. NR provides high performance DC electric CT/VT to solve this problem. The DC electronic CT/VT features:

- High reliability
- Large dynamic range: Response time less than 125us
- High accuracy: Measurement precision of 0.2%
- Output signal interface complies with international standards (based on IEC60044 8 or TDM)
- Perfect self-monitoring function and easy fault maintenance

VSC-HVDC Control and Protection



The control and protection system is the brain of PCS-9520 VSC-HVDC transmission system. It provides monitoring, control and protection of all equipment in VSC-HVDC transmission system and converter station.

In VSC-HVDC transmission scheme, the switching of IGBT valves depends on a pulse width modulation (PWM) pattern. The switching control allows the simultaneous adjustment of the amplitude and phase angle of converter AC output voltage while keeping dc voltage constant. With these two independent control variables, the active and reactive power control loops can be used for regulation at the same time.

The active power control loop can control either the active power or the DC side voltage. In a DC link, one station is selected to control the active power while the other must be used to control the DC side voltage. The reactive power control loop can control either the reactive power or the AC side voltage. Either of these two modes can be selected independently at each end of the DC link.

NR VSC-HVDC control includes the constant AC voltage control for passive network, constant P-Vac control, Vac-Udc control, P-Q control, Q-Udc control and frequency control. The control configuration of VSC substation is shown in figure 8.

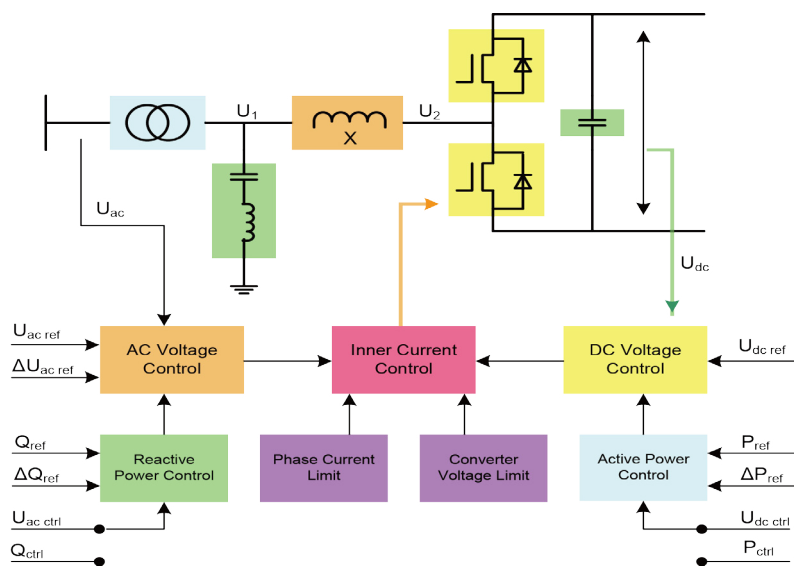


Figure 8 VSC control configuration

VSC HVDC Control and Protection



In practical, VSC systems shall allow system rest in case of AC disturbance, DC disturbance and internal faults within one converter station. The typical protection diagram for a VSC substation is shown in figure 9.

- over-current protection of a.c. circuit breakers(1);
- abnormal a.c. voltage protection(2);
- earth fault protection(3);
- a.c. filter protections(4);
- differential protection(5);
- over-current protection of the converter(6);
- abnormal d.c. voltage protection(7);
- over-current protection of the VSC d.c. capacitors(8);
- d.c. discharge unit(9);
- valve protection, e.g., in the valve gate electronics(10).

Additional protection functions are also integrated, such as loss of cooling protection; d.c. line/cable earth

fault protection/supervision, frequency protection; impedance relay protection, fire protection and mechanical protection.

NR's PCS-9520 VSC-HVDC control and protection system features high sensitivity and reliability. It supports many configuration schemes, including:

- Duplicated configuration, i.e. two complete sets of protection equipment that each protection adopts the logic of "fault detection + protection calculation".
- Two-out-of-three configuration, i.e. three complete sets of protection equipment which works simultaneously and use two-out-of-three vote logic. The tripping command is issued if and only if two of three protection elements are activated.
- Redundant configuration, i.e. two complete sets of protection equipment that one set is activated, while the other is hot standby. During fault, system switchover is required prior to protection element operation.

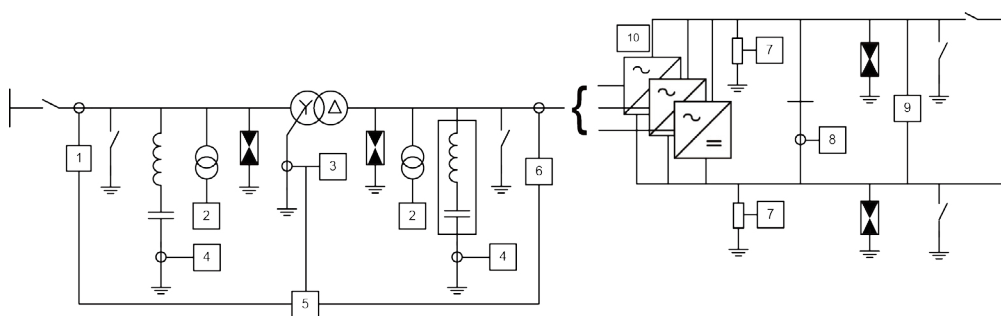


Figure 9 VSC protection configuration

VSC HVDC Control and Protection



VSC-HVDC control and protection system adopts distributed structure. It consists of flexible HVDC control and protection units, distributed I / O units for field device and fiber optical field bus which is connecting the master unit to I / O devices. (Figure 10)

The control and protection system includes state-of-the-art computers, micro-controllers and digital signal processors. Each VSC has two independent control and protection systems for redundancy to ensure high reliability. Multiple transient fault recording (TFR) functions are integrated to record signals in the control and protection system at selected time spans to provide complete information of the dynamic performance of converter.

The above system is the control platform and data processing center of the entire VSC-HVDC control and protection system. It provides station GPS, remote-dispatch center's communication interface and other related functions.

The operating control system covers operating personnel workstation, engineer workstation, owner workstation, system server, file server, SCADA, LAN, station clock system and remote dispatch center/control center interface.

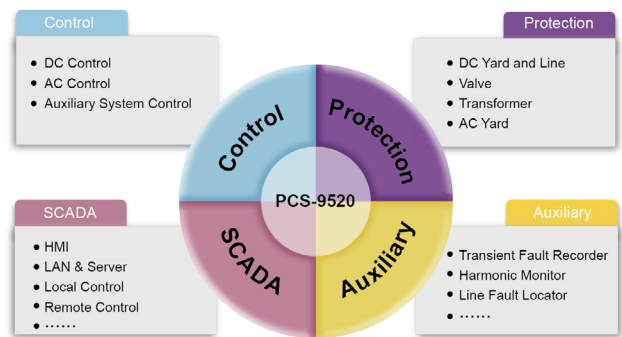


Figure 11 PCS9520 configuration

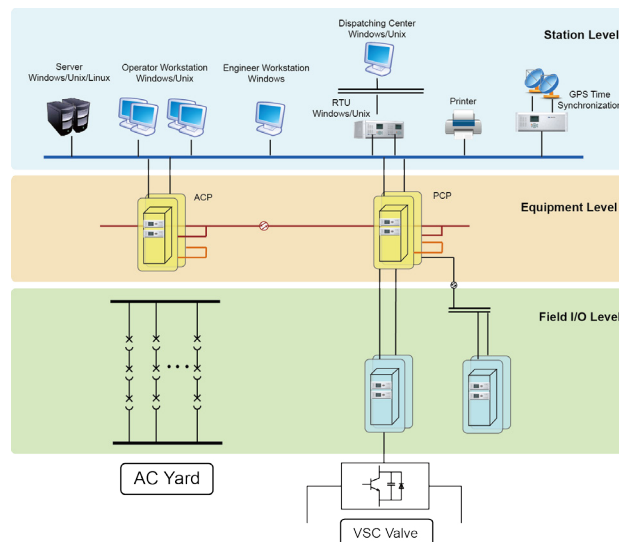


Figure 10 PCS9520 control and protection structure

VSC-HVDC Control and Protection



The Operator Work Stations (OWS) is serial connected to SCADA system via common hardware. It offers the on-line access to operational status and settings of control and protection systems and integrates diagnostic information such as event list, alarm list, fault list, and disturbance recordings of control and protection system.

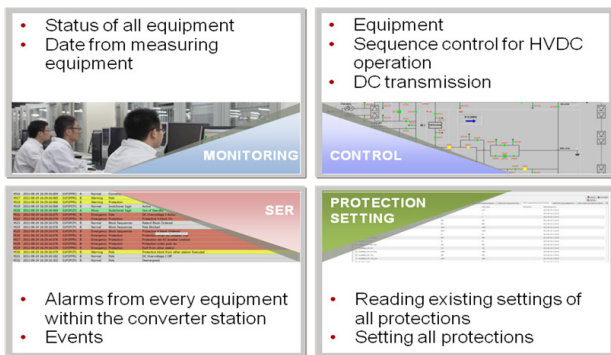


Figure 12 HMI functions

NR PCS-9520 VSC-HVDC control and protection has high reliable system, hardware and software.

- Embedded Systems
- No operating system in realtime applications
- Overall enclosed design without fan
- Advanced system monitoring and fast switching
- Reliable protective redundant configuration
- Dedicated high-speed data bus
- Overall redundant design
- System electromagnetic shielding with high immunity

NR PCS-9520 is also easy to maintain, operate, monitor and upgrade.

- Modularized application software
- Graphical programming and debugging tool
- Less field bus fiber
- Remote software maintenance from workstation
- IO boards Plug and Play
- Cross-platform operator control system
- Multiple accurate alarm events
- Internal fault recording
- Spare parts guarantee and free chip upgrade

NR PCS-9520 has other features.

- High flexibility
- Compatible to electronic transducer interface
- Complied with IEC-61850 standard
- Supporting centralized control center scheme
- Supporting protective redundancy configuration
- Providing communication interface to stability control system
- Backup control system



Figure 13 On site OWS photo

Multi terminal VSC-HVDC Transmission (MTDC)



Renewable energy grid interconnection can reduce operational costs and CO₂ emissions. As the core of renewable energy interconnection, MTDC network offers new power market opportunities. The multi terminal VSC HVDC has following advantages:

- Power reversal is easily achieved by current reversal without mechanical switch.
- Commutation failure is eliminated in an VSC based inverter.
- Pulse Width Modulation(PWM) eliminates low frequency harmonics
- Simple AC filters.
- No need of reactive power compensation.
- Limited short-circuit currents.
- No additional capacity required for voltage support or stability.

The MTDC link shall have at least one of the terminals configured in constant DC voltage control mode. When there is one DC voltage regulator in the MTDC while others operate in constant power control mode, the system remains stable that power demand and supply are balanced. The disconnection between DC regulating terminal and MTDC can result in system instability and finally lead to blackout. To avoid such situations, the P-UDC characteristics of some terminals (connected to active AC networks) can be modified to cross the line $P=0$. By doing so, DC voltage controllers will have redundancy that the MTDC system can operate at different DC voltage levels within limits.

In another method, DC voltage control implemented by droop characteristics can realize DC voltage regulation of two or more terminals in the MTDC based on their DC voltage droop characteristics.



Work flow and Test Lab



Figure 14 work flow and Quality assurance

NR possesses professional test labs and realtime simulators that can perform up to 50 levels converter test. The RT-lab digital lab can be used to do close-loop system test and system optimal design.



Figure 15 digital simulator lab

NR also provides high voltage and large current test especially for IGBT converter valves.



Figure 16 large current and high voltage test lab

Case Study



Nanhui VSC-HVDC project interconnects power grid to the wind farm which has eleven wind generators with each rated capacity of 1.5MW and additional $\pm 4\text{Mvar}$ reactive power for voltage support at common coupling point.

Converter station	NanHui	ShuYuan
AC system voltage	35kV	35kV
AC system frequency	50Hz	50Hz
DC rated voltage	$\pm 30\text{kV}$	$\pm 30\text{kV}$
DC rated power	18MW	18MW

VSC-HVDC transmission operation modes:

- Interconnection between wind farm and power grid via HVDC line
- Parallel operation between HVDC lines and HVAC lines
- STATCOM operation mode
- Direct power supply to passive network
- Interconnection between wind farm and power grid via AC line during maintenance or VSC-HVDC line outage

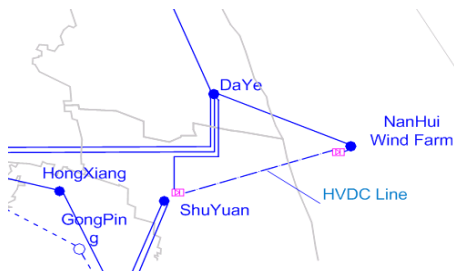


Figure 17 Nanhui VSC transmission connection grid



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