C-GIS Cable Switching Breaker for Wind Power System Applications

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1. Introduction

With the increased use of renewable energy sources, the wind power industry embarked on full-scale construction of large offshore wind power plants from around 2010, particularly in Europe, and the uptake of wind power is anticipated to increase even further in the future in North America and throughout Asia.

As for construction of such large-scale offshore wind power plants, operation begins from wind turbines for which installation is completed, in order to maximize efficiency without losing power generation opportunities. Minimizing the loss of potential power generation opportunities, like with outages of wind turbine facilities due to inspections or other maintenance is also a key factor.

To operate a wind power system flexibly like this, Mitsubishi Electric has developed Cable switching breaker (CS) based on the conventional Disconnector (DS) with additional switching capability of cable charging current, and applied this technology to 72.5kV type C-GIS "HG-VG-A"[(1)] (below, "HG-VG-A type C-GIS") for offshore wind power system applications.

This paper provides an outline of CS and the technology that has been used.

2. Outline of CS for HG-VG-A type C-GIS

2.1 Roles of large offshore wind power plants and Cubicle-Type Gas Insulated Switchgear (C-GIS)

A diagram of the overall power system for large offshore wind power plants is shown in Fig. 1. Large offshore wind power plants feature around ten wind turbines that are connected in series with undersea cables to create an inter-array cable circuit. Power from multiple inter-array cable circuits is collected and converted to high voltage at the offshore substations and then transmitted to onshore substations in a tree-like configuration power system.

As shown in Fig. 2, power generated by each wind turbine is boosted to 72.5 kV by a transformer immediately beneath the wind turbine. Power then flows through Circuit breaker (CB) that protects the wind turbine by shutting off short circuit (earth fault) currents if there is an accident, and DS that connects or isolates the wind turbine and inter-array cable circuit, before being transmitted to undersea cables. HG-VG-A type C-GIS comprises the components within the dashed lines of Fig. 2, integrating CB and DS required for the operation of wind turbines, installed in the confined space within a wind turbine.

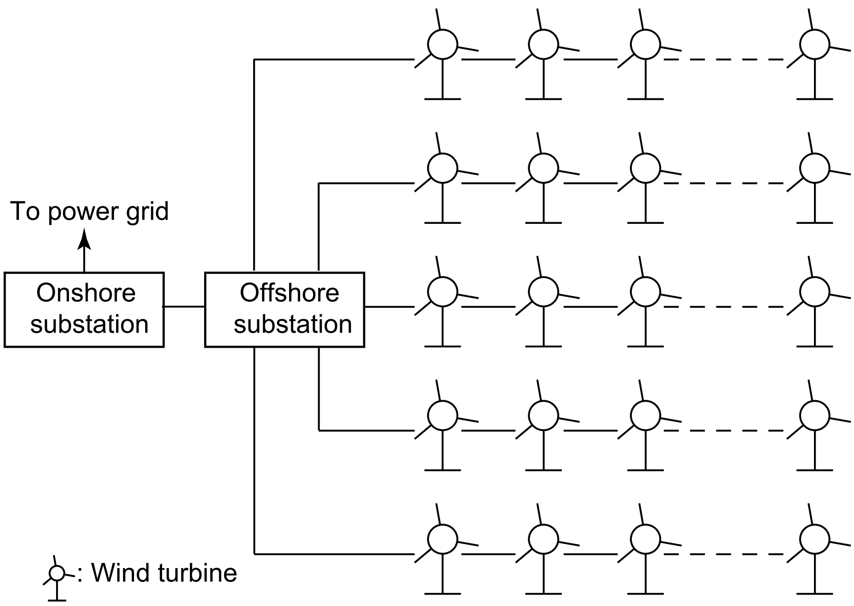

Fig. 1 Diagram of overall power system for large offshore wind power plants

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When a new wind turbine is constructed, DS is closed to ensure the turbine is connected to the inter-array cable circuit, then the CB is closed to begin transmitting power from the turbine. To stop power being transmitted from the turbine for inspections or other maintenance, the CB is opened and DS is isolated to disconnect the turbine from the inter-array cable circuit.

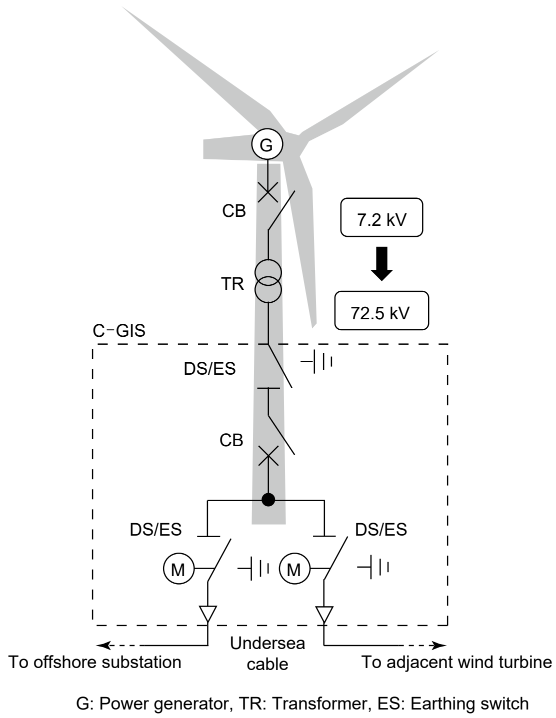


Fig. 2 Single-line diagram inside wind turbine

2.2 CS with switching capability of cable charging current

As DS itself does not have current switching capability while high voltage is applied, connecting or isolating the wind turbine from the inter-array cable circuit outlined above requires the CBs within the C-GIS for all other wind turbines on the same inter-array cable circuit to be opened to isolate the generators from the inter-array cable circuit. CB connected directly to the inter-array cable circuits in the offshore substation also need to be opened to isolate the entire inter-array cable circuit including the intended wind turbine from the power grid. Furthermore, as wind turbines are connected together with undersea cables, DS cannot be switched immediately after power transmission is stopped due to a charging current generated by the residual voltage corresponding to the capacitance of cable—DS can only be switched after waiting for the residual voltage to be discharged. Doing so affects a large area of the system for a long period of time, which implies that switching inter-array cable circuits results in a major loss of potential power generation opportunities (Fig. 3 (a)).

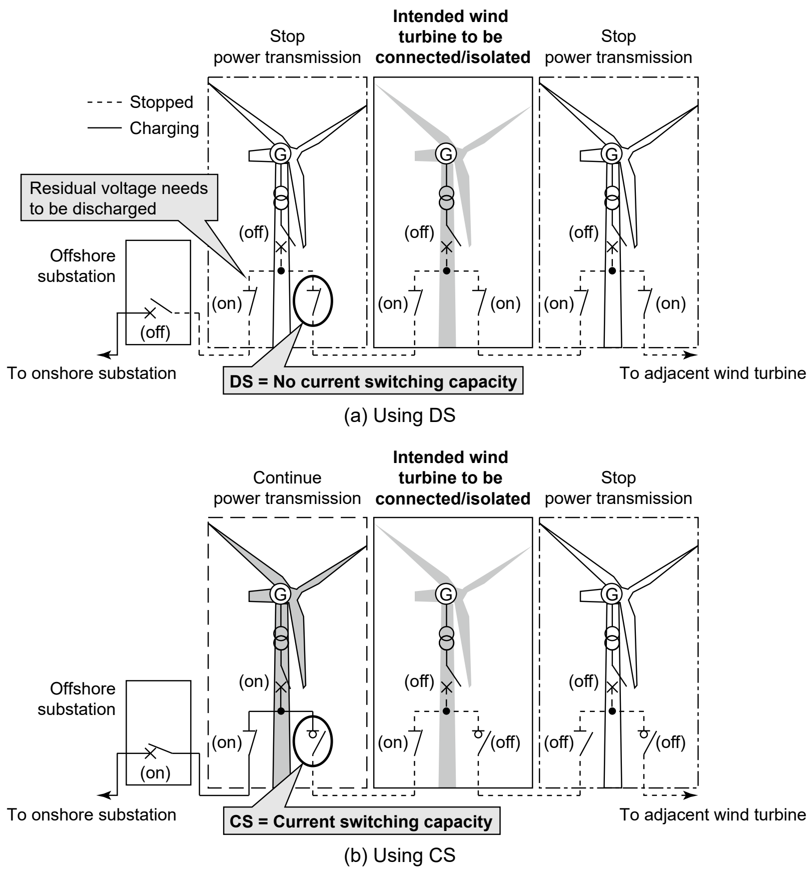


Fig. 3 Connecting and isolating wind turbines with/from inter-array cable circuits

Table 1 CS Ratings

Item		Specification
Standard Compliance		IEC 62271-104: 2020
Rated voltage		72.5 kV
Rated continuous current		1,250 A
Rated frequency		50 Hz
Rated lightning impulse withstand voltage		350 kV
Rated cable-charging current	Breaking current	40 A (class C1 switch)
	Making current	700 Apeak
Insulation medium		SF_6 (sulfur hexafluoride)
Rated gas pressure		0.05 MPa-G (at 20°C)

Equipment that provides more flexible operation is required in order to maximize power generation efficiency and achieve a stable supply of power, so Mitsubishi Electric has developed CS based on DS with additional switching capability of cable charging current (Table 1). To ensure that the external dimensions of C-GIS remains unaffected due to the space limitations for being installed within wind turbines, the CS was developed with added functionality based on the same structural layout as the conventional DS.

Replacing the conventional DS with a CS not only eliminates the need to wait for residual voltage in the cables to be discharged, but also negates the need to open the CB in the offshore substation. Simply stopping wind turbines upstream of the inter-array cable circuit allows the intended wind turbine and inter-array cable circuit to be connected or isolated (Fig. 3 (b)).

3. Technology underpinning CS for HG-VG-A type C-GIS

The highly technically challenging aspect of switching capability for cable charging currents is the opening operation, and this is due to the small capacitive current breaking. While the small capacitive breaking current is much smaller compared to the fault current during a short circuit, the small current means the current can be easily chopped and the recovery voltage rises immediately to peak after around half a cycle (around 10 ms for 50 Hz). As such, current switching generates a restriking of arc between the terminals if sufficient insulating distance cannot be achieved quickly during opening operation. The resulting over-voltage poses a risk of endangering the proper operation of devices. Accordingly, CS requires non restrike current interruption for the cable charging current.

The technology used to ensure CS has the capability of small capacitive current breaking is outlined as follows.

3.1 High-speed mechanism using mechanical latch

Fig. 4 shows the opening operation of the conventional DS installed within HG-VG-A type C-GIS. DS converts the rotational movement from the operating mechanism to linear movement with a trapezoidal screw installed inside the cylindrically shaped movable contact. The contact arm moves left from the terminal on the closing side toward the terminal on the disconnecting side, to disconnect the terminals.

This drive design is advantageous in that it achieves a long moving distance with a compact operating mechanism, but cannot achieve the required insulating distance quickly to withstand recovery voltage due to the relatively low opening speed of the contact arm that is dependent on motor rotation.

CS adds a drive spring and high-speed movable contact different from the main conducting contact arm within the terminal on the closing side at the opposing side of the terminal on the disconnecting side as shown in Fig. 5. This design engages the contact arm and

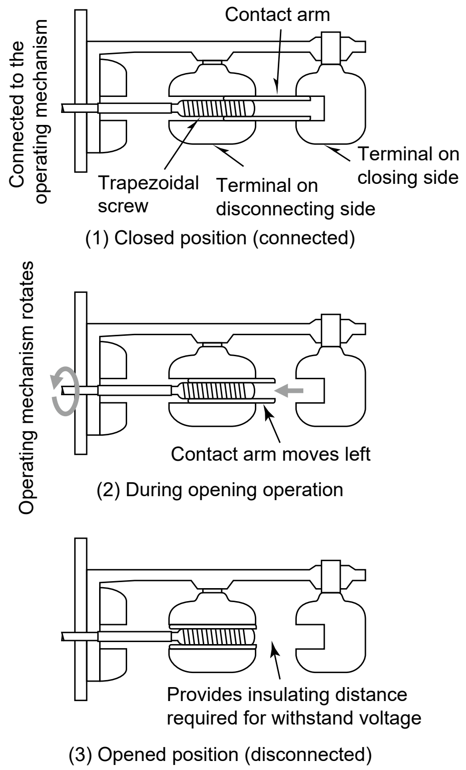


Fig. 4 Opening operation of DS

high-speed movable contact with a latch when the contact arm provides a connection between the terminals like with DS. During opening operation, the contact arm moves left and pulls out the high-speed movable contact while charging the spring. The latch opens when the high-speed movable contact reaches the terminal position on the disconnecting side, and the high-speed movable contact moves quickly to the right with the driving force of the charged spring to completely interrupt the current flow while quickly ensuring the required insulating distance.

3.2 Movable electrical shield

The required insulating distance to interrupt the current flow is affected by the electrical field strength. The electrical field strength of the high-speed movable contact is higher at the tip where the diameter is smaller—ensuring the high-speed movable contact moves quickly into the terminal on the closing side that has a large diameter relaxes the electrical field strength, which shortens the insulating distance required to interrupt the current flow.

Yet just like DS, CS also has withstand voltage requirements as disconnected poles between the terminals; a larger insulating distance is required at the opened position than when interrupting current flow, so the terminal on the closing side could not be designed closer to the terminal on the disconnecting side.

To overcome this issue, the terminal on the closing side of CS features a movable electrical shield that moves with the high-speed movable contact (Fig. 5). The shield is normally separated by a large distance from the terminal on the disconnecting side, but during opening operation it moves left with the contact arm and approaches the terminal on the disconnecting side. When the latch is released and the high-speed movable contact moves to the right into the terminal on the closing side, the shield subsequently moves to the right and returns to its normal position to disconnect the circuit, thus ensuring the insulating distance required for withstand voltage performance in the opened position.

3.3 Stiffness enhancement of terminal support

Compared to the slow opening speed of DS, CS suffers from significant shock in the direction of movement of the high-speed movable contact during opening operation. Whereas the terminal on the closing side of DS is secured with insulating support in one position at the top, CS features an additional insulating support at the bottom of the terminal on the closing side to enhance stiffness (Fig. 6).

3.4 Electrical interlock

When power is being transmitted from the wind turbine, load current corresponding to the generator capacity flows to the inter-array cable circuit via CS. The maximum value is set to the same 1,250 A rated current as that of the HG-VG-A type C-GIS, but adding switching capability of rated current to CS was expected to make it significantly larger. As such, CS was designed for switching the cable charging current under conditions where power transmission from upstream wind turbines has been stopped.

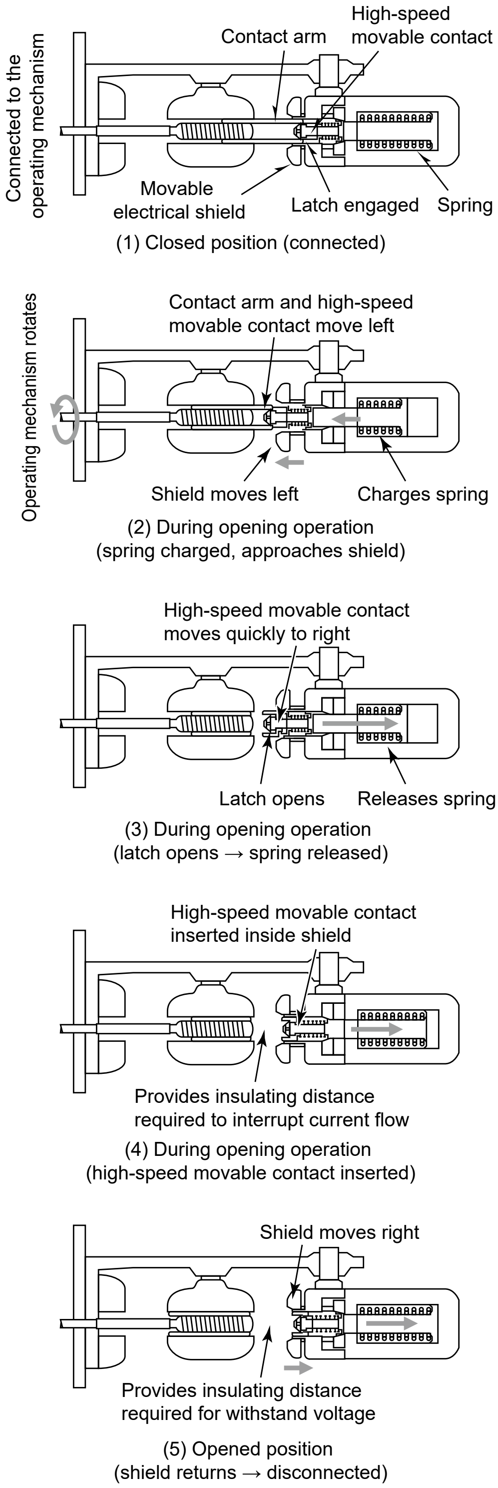
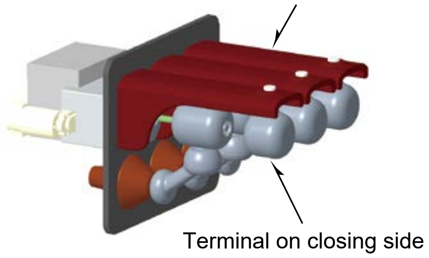
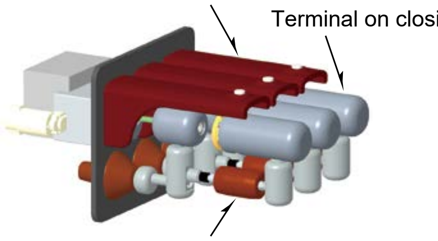


Fig. 5 Opening operation of CS



(a) DS unit



(b) CS unit

Fig. 6 Terminal supporting structure of DS unit and CS unit

In light of this, CS is only capable of interrupting the cable charging current (up to 40 A), and cannot interrupt currents that exceed the breaking current in Table 1, even with fault currents in the event of short circuits or load currents flowing through inter-array cable circuits under normal operations.

To address this, an electrical interlock featuring a combination of compact current transformer (CT) and current sensor has been installed in the cable—if the CT measures current that exceeds the breaking current, it blocks the operating signals so that the CS cannot be opened (Fig. 7).

Note that arc resistance material has been used for the tips of the contact arm and high-speed movable contact to allow switching of cable charging currents.

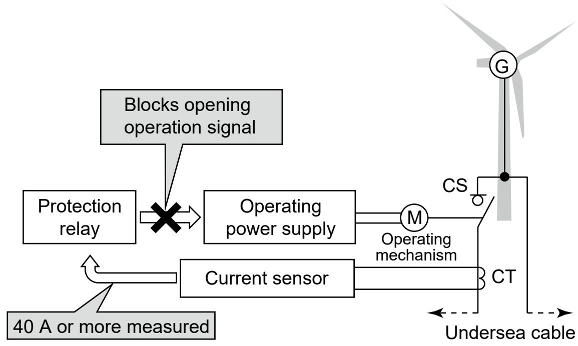


Fig. 7 Electrical interlock

4. Conclusion

This paper outlined the development of CS applied for HG-VG-A type C-GIS for offshore wind power system applications.

CS has been developed and applied that complies with IEC 62271-104 standards for switching capability of cable charging currents. It is based on the conventional DS and features such as a high-speed mechanism using mechanical latch so that it does not affect the external dimensions of HG-VG-A type C-GIS that have severe space restrictions for installing inside wind turbines.

The scope of application of CS will be expanded in the future in order to maximize the power generation efficiency of large offshore wind power plants and achieve flexible power system operation with minimal loss in potential power generation opportunities.

Reference

(1) Kagawa. K., et al.: 72.5kV C-GIS for Overseas Offshore Wind Turbine “HG-VG-A,” Mitsubishi Denki Giho, 94, No. 11, 618-622 (2020)