The benefits of using fast-acting grounding switches in wind farms

SIEMENS

Integrating a fast-acting grounding switch into a circuit breaker combines the fault-detection capabilities with circuit grounding, which simplifies the installation and operation of the system and protection coordination.

Index

The motivation 4
Mechanical link 7
Validation 9
Benefits to wind farms 12

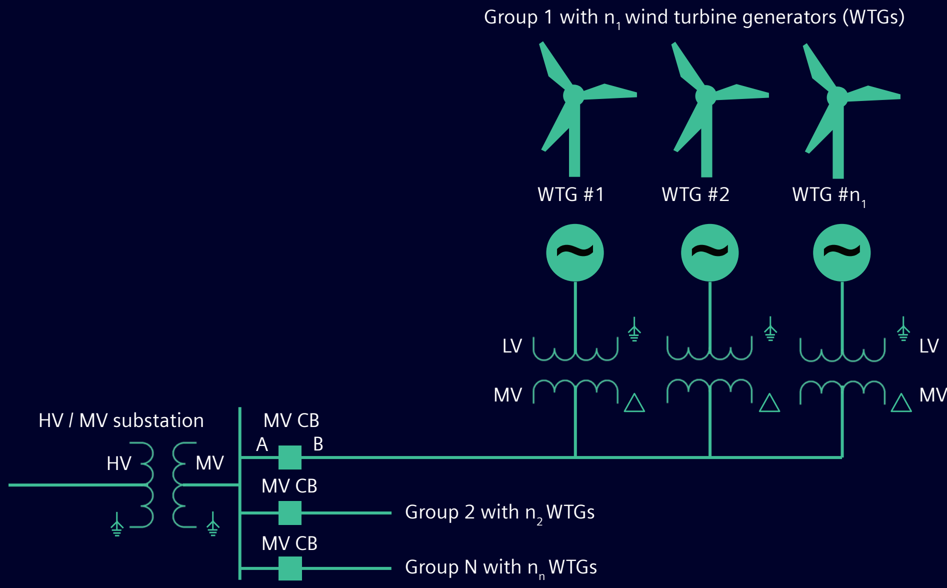


Figure 1: Typical conventional installation

CHAPTER 1

The motivation to improve

In a typical installation, the low-voltage (LV) power source (i.e., wind farm with N groups of wind turbine generators) is connected to the high-voltage (HV) grid as shown in Figure 1. Each wind turbine has a low-voltage / medium-voltage (LV/MV) step-up transformer and each group of wind turbine generators is connected via a MV circuit breaker (MV CB) to the bus of the HV/MV substation.

In most installations, both neutrals of the HV/MV transformer are solidly grounded. Because of this, the insulation coordination with the surge arresters is based on the solidly grounded neutral systems for the MV side and the HV side of the grid. In case of a ground fault between the LV/MV step-up transformer and the MV circuit breaker (side "B" of the MV circuit breaker in Figure 1), opening this circuit breaker will disconnect the circuit from the grid.

This will also remove the ground reference for that circuit while the wind turbine generators continue to operate due to their rotating inertia. Because of the delta-connection of the windings of the LV/MV step-up transformer on the MV side, the phase-to-ground voltage in the unaffected phases will rise to a stationary voltage of 1.73 times the original value. Before the stationary voltage is reached, due to capacitances of the isolated feeder, temporary over voltages with an even higher value can also be expected.

These over voltages may damage exposed components of the installation (i.e., surge arresters, cables, etc.). This must be avoided even though the inherent TOV and RRRV capability of the vacuum interrupters can help reduce or eliminate the need for additional components, like surge capacitors for increased damping, damping capacitors, etc. The preferred solution to avoid this condition is the use of a fast-grounding switch (GS) in combination with the MV circuit breaker. The grounding switch is placed on side "B" of the respective circuit breaker to close the grounding switch directly after the open operation of the circuit breaker (Figure 2) to ground the circuit.

After closing of the grounding switch, fault current will flow driven by the isolated feeder as the wind turbine continues to generate power. However, the value of this fault current will be less than the single-phase fault current available from the grid. Therefore, the grounding switch rating can be lower than the rated short-circuit current of the circuit breaker.

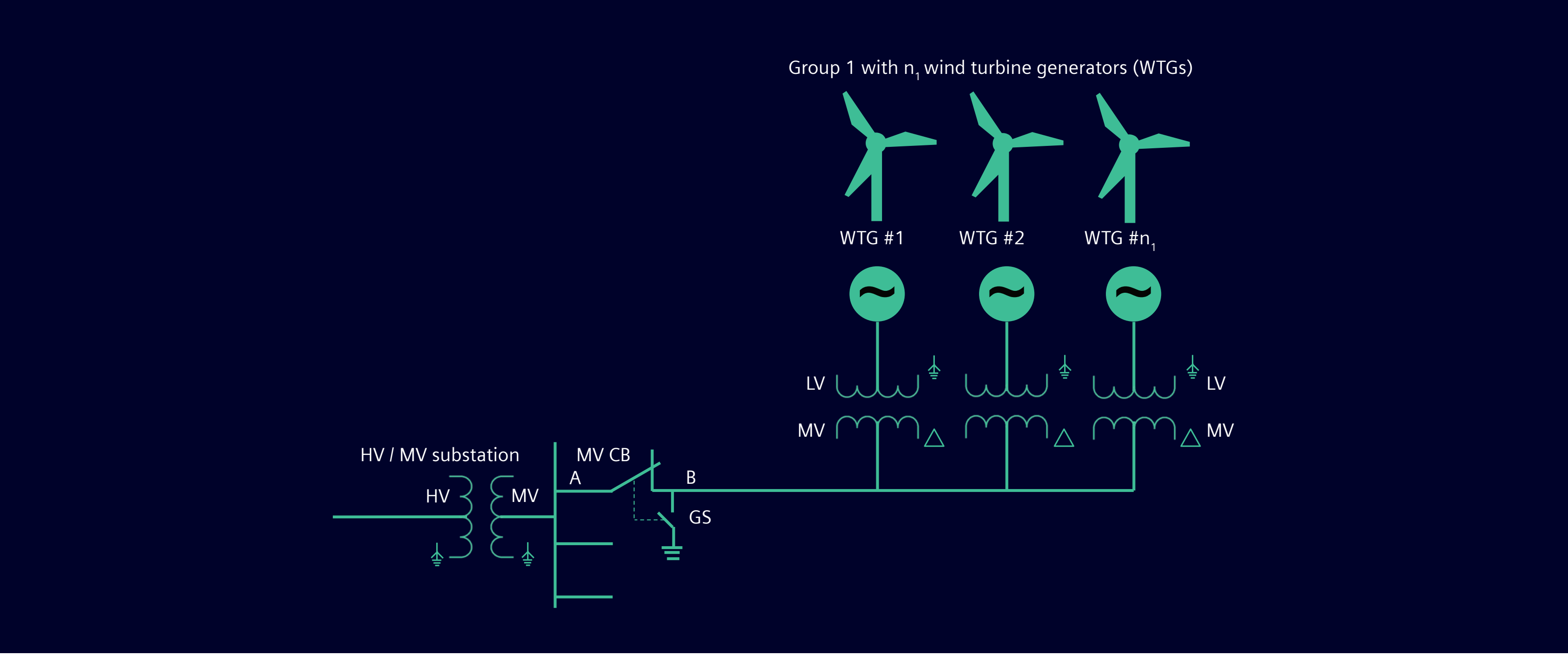


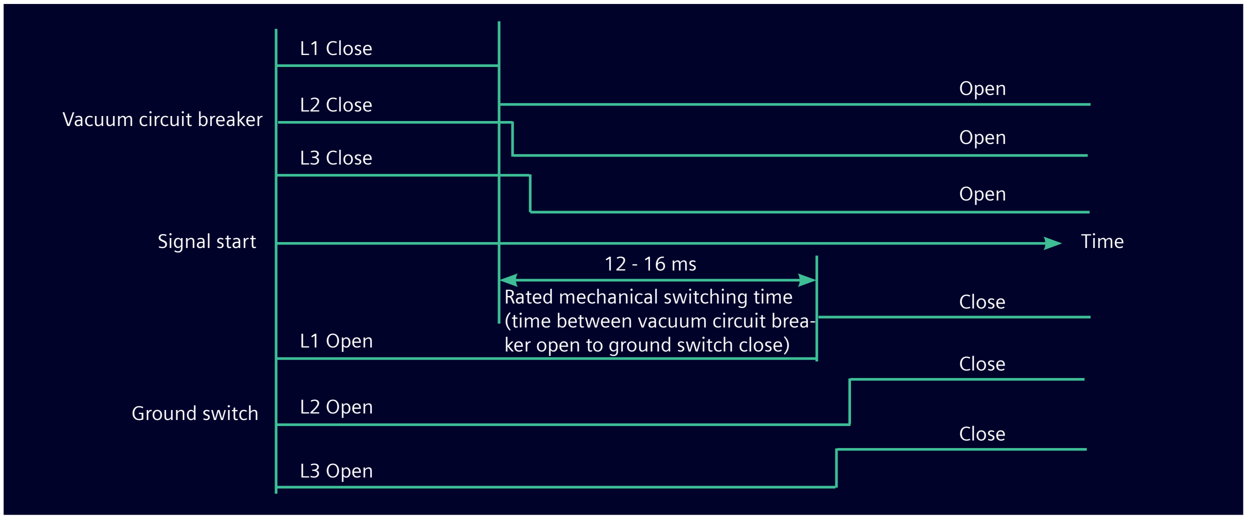
Figure 2: Installation using circuit breaker with integral fast-acting grounding switch

Two key items must be considered when defining the time difference between opening of the circuit breaker and closing of the grounding switch:

- Due to the rate of rise of the overvoltage after an interruption of the single-phase fault, the time difference should be short.
- The closing of the grounding switch shall occur when the circuit breaker has cleared the single-phase fault current, even for long arcing times (worst-case situation: asymmetric, single-phase fault).

To cover both circumstances adequately, a time difference between contact part of the circuit breaker contacts and contact touch of the grounding switch contacts should be kept in the range of 12 to 16 ms.

Figure 3: Illustration of critical timing between circuit breaker and grounding switch operations



CHAPTER 2

Mechanical link

The vacuum circuit breaker consists of an operator module installed in a weatherproof enclosure with roof bushings for primary circuit connections on top and a terminal pad for a grounding connection on the bottom. The circuit terminals of the operator are connected to the bushings with copper bus risers while the grounding terminals are connected together with a shorting copper bus bar that is also connected to the grounding terminal pad.

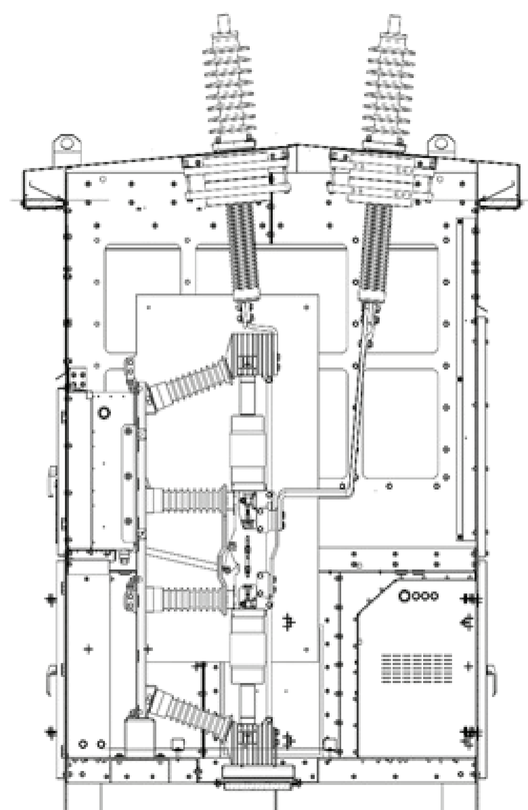


Figure 4

The operator module has three poles, each with its vacuum interrupters and primary insulators mounted to a common operating mechanism housing. Each pole is attached to a pole-mounting channel by four cast-resin insulators. The insulators also connect to the operator and ground switch fixed-end pole heads and to the moving-end connector box that in turn supports the vacuum interrupter. The operating mechanism and all the control and actuating devices are installed in the mechanism housing. The mechanism is of the spring stored-energy type and is both mechanically and electrically trip free. The circuit breaker vacuum interrupter fixed contacts are bolted to the upper fixed-end pole heads while the moving contact ends of the vacuum interrupters are attached to the connector box. The same connector box is attached to the ground switch vacuum interrupter moving contact ends with the fixed-end pole heads connected to the fixed contact ends of the interrupters. This arrangement stabilizes the interrupters against lateral forces via centering rings on the connector box. The external forces due to switching operations and the contact pressure are absorbed by the insulated struts. The primary current-path assembly consists of the circuit breaker fixed-end pole head, the stationary contact, and the moving contact, plus the flexible connector between the moving contact terminal clamp and the moving-end connection pad. For the grounding path, the assembly contains the circuit breaker moving-end connection pad, the flexible connector and the interrupter moving-contact, the stationary contact, and the ground switch fixed-end pole head.

The vacuum interrupters moving contacts are operated by angled levers attached to the main drive shafts via insulating switching rods and levers. Contact pressure springs are connected directly under the moving contacts. The circuit breaker and ground switch vacuum interrupter movable contacts are connected and move in the same direction. This configuration operates in such a way that as the circuit breaker closes, after a close command is initiated, the ground switch opens at the same time; or vice versa when an open command is initiated.

CHAPTER 3

Validation: qualifying the solution via design testing to industry standards

To validate the solution, not only were qualification tests for the key elements required (i.e., circuit breaker and grounding switch tests) but also additional tests focused on the combination of the two elements were performed.

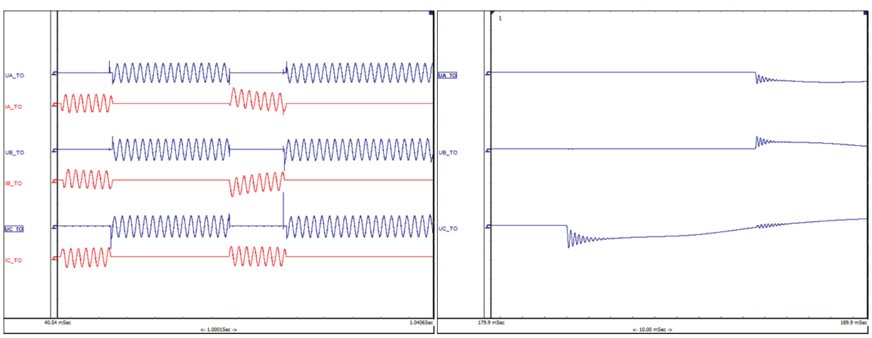


Figure 5: Short-circuit test T100s with two interruptions in sequence, transient-recovery voltages

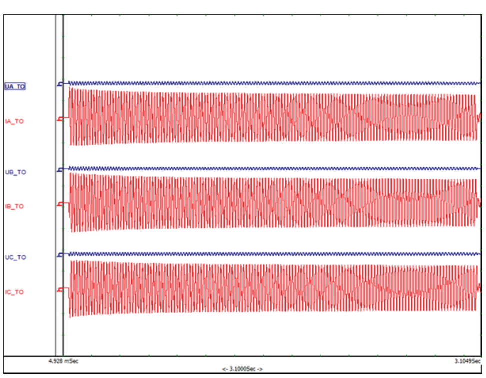


Figure 6: Test of peak and short-time current

The interrupting capability of the circuit breaker portion of the solution was tested in accordance with both IEC 62271-100 and IEEE Std C37.09 at 50 Hz with a 2.6 power factor to evaluate performance during the worst-case conditions due to longer arcing times. There is a marginal difference in the rise angle of the current shortly before current zero and interruption however for interruption using vacuum interrupters, this effect is insignificant. The worst-case parameters for demonstrating other aspects of the circuit breaker performance, like cable charging, continuous current, dielectric, and both electrical and mechanical endurance, were similarly selected from both standards.

The grounding switch portion of the solution was tested in accordance with both IEC 62271-102 and IEEE Std C37.20.4 in similar fashion where the worst-case parameters were used. Since the circuit breaker and grounding switch are directly linked, the mechanical endurance test of the grounding switch was performed with 10,000 cycles to match the circuit breaker M2 rating. For the grounding switch, this duty exceeds the usual requirement by a factor of five. Additionally, the grounding switch was subjected to the same low-temperature test to demonstrate performance down to minus 50 °C (minus 58 °F).

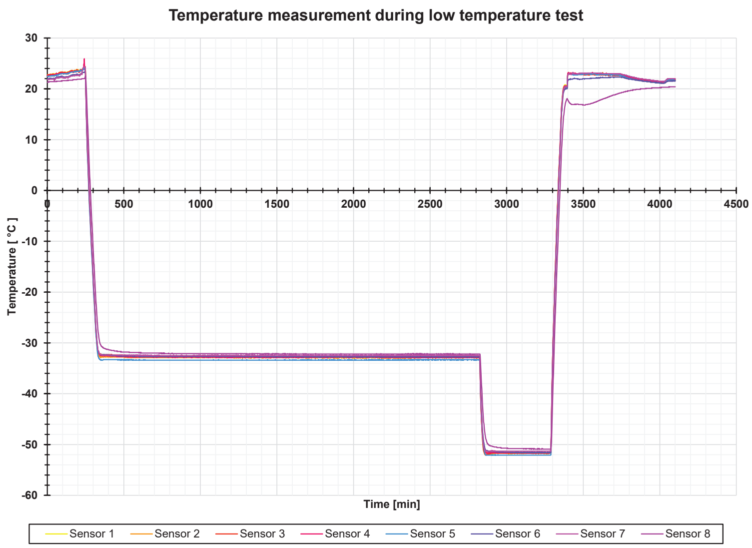


Figure 7: High and low temperature test

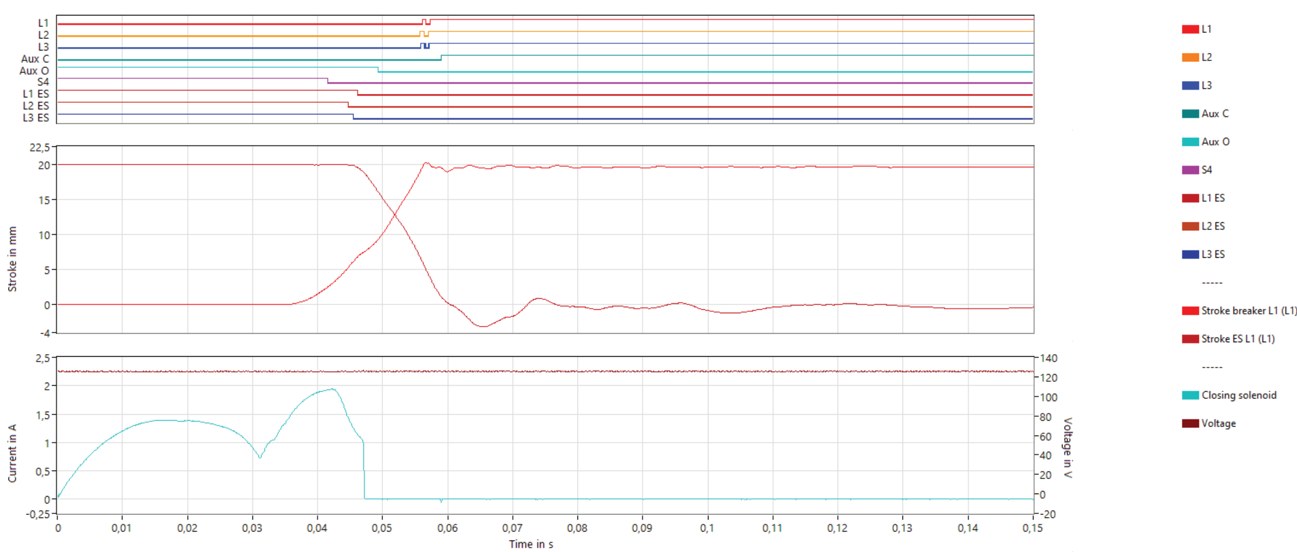


Figure 8: Opening of circuit breaker and closing of grounding switch

After the design tests in accordance with the relevant industry standards were completed, additional tests to demonstrate the performance of the combination were performed. The most critical of which validated the timing between the opening of the circuit breaker and closing of the grounding switch. The time between contact part of the circuit breaker contacts and contact touch of the grounding switch contacts is crucial to the proper functioning of the combination. If the time is designed too small, the fault current may not be interrupted before the grounding switch closes, and although the grounding switch will close as required it may not reopen due to contact welding. Alternatively, if the time is too long, an overvoltage after interruption may occur for longer than the surge arresters can tolerate leading to damage to the arresters. Special care was taken to measure this time parameter over the full range of allowable manufacturing tolerances and under a variety of environmental conditions.

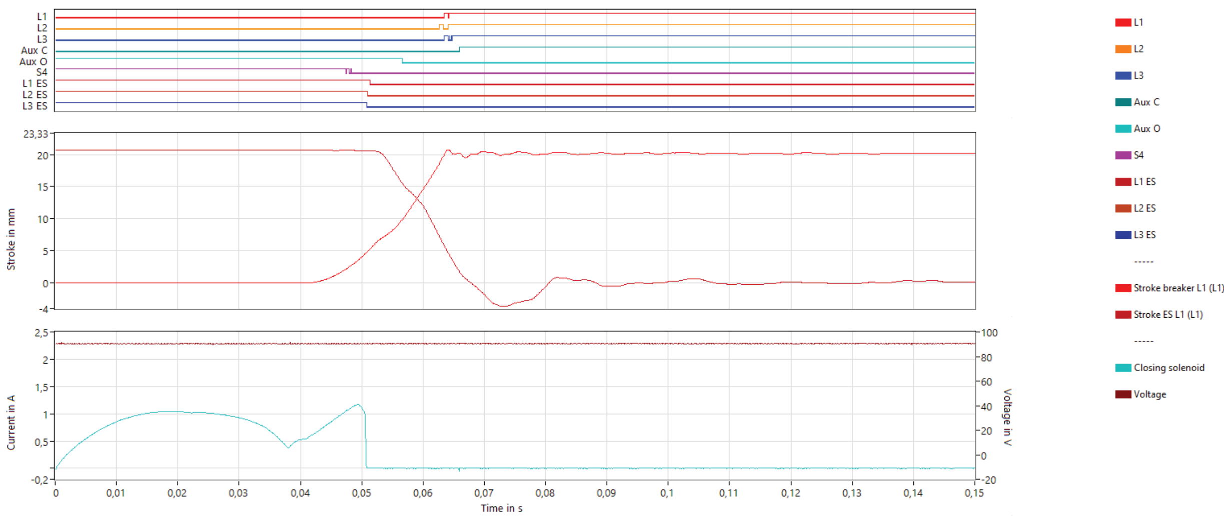


Figure 9: Oscillogram 16 closing operation at 90 Vdc Ua after test

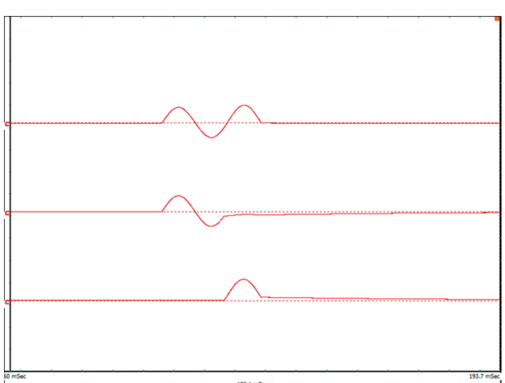


Figure 10: Current measured commuting from grid into ground via grounding switch

Another capability demonstrated was that the grounding switch operating duty was not influenced by the circuit breaker when interrupting the maximum rated fault current. Under certain conditions, the vacuum interrupter may not clear the fault at the first current zero after a major loop but interrupts after the next minor loop. The testing demonstrated the grounding switch performs this duty without contact welding.

CHAPTER 4

Benefits to wind farms

When the medium voltage circuit breaker opens, the system loses the ground connection between the open circuit breaker and the medium-voltage side of the LV/MV transformer. As described earlier, the voltage in the healthy phases increases to as much as 1.73 PU as the wind turbines continue to put power into the system. This high voltage acts like a permanent hi-pot test, which is particularly hard on surge arresters. Long periods at these excessive voltage can shorten the life or even damage the surge arresters. Since the loss of the ground reference leads to these problems, restoring a ground connection can eliminate them.

The conventional alternative to using a grounding switch, as described in this paper, would be to use a grounding transformer instead. This transformer would be connected on the B side of the MV circuit breaker and set up so that during normal operation has a high impedance to ground but during a line-to-ground fault provides a low-impedance path for the fault current.

The disadvantages of using a grounding transformer are the installation and maintenance costs of the equipment and the environmental risks associated with spills. Although the grounding transformer needs to be only roughly 5% of the size of the connected load, this can still require a transformer in the MVA range. Additionally, the cables connected to the grounding transformer add a significant expense. Finally, the maintenance of the transformer, particularly for oil-insulated transformers, costs can be significant over the life of the wind farm.

In comparison, a circuit breaker with an integral grounding switch is a relatively simple device, being very similar to a conventional circuit breaker in design and construction. Integrating a grounding switch into a circuit breaker combines the fault detection capabilities with circuit grounding, which simplifies the installation and operation of the system.

Legal Manufacturer

Siemens Industry, Inc.
7000 Siemens Road
Wendell, North Carolina 27591
United States of America

Telephone: +1 (800) 333-7421
www.usa.siemens.com/mediumvoltage

Order No. SIDS-T40152-00-4AUS