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System for high-voltage direct current transmission

Model-based engineering and PC-based control for high-voltage direct current transmission

Transmitting high power efficiently over long distances

Whether from offshore wind turbines on the high seas to the mainland, from wind turbines in northern Germany to industrial sites in the south of the country, or from hydropower plants in Scandinavia to central Europe – high-voltage direct current transmission is used to transmit large amounts of energy over long distances. For its solution, Siemens Energy relies on MATLAB and Simulink from MathWorks and PC-based control from Beckhoff.

Following the dispute that arose between Nikola Tesla and George Westinghouse over the technology used to supply electricity to the USA in the 1890s, alternating current has become the most widely accepted system. However, the cables used to transmit alternating current over long distances act like a capacitor, which leads to transmission losses and a need for compensation through reactive power. When transmitting direct current, however, this reactive power requirement is negligible, i.e., the current can be transported with significantly lower losses. This is why direct current under high voltage is used to transmit high power.

The basics of direct current transmission

Put simply, this kind of transmission by means of direct current uses two power converters with a common DC link. Each power converter can transmit energy from the grid with alternating current to the DC link with direct current and also feed the energy from the DC link back into the grid as alternating current. This allows electrical energy to be transmitted in any direction between the two grid connections. Direct current with a very high voltage is used for transmission in the DC link, which is how the system got its name: high-voltage direct current (HVDC) transmission. Transistors – known as insulated-gate bipolar transistors (IGBT) – which act like valves are used to convert the current. These can allow the current to pass through or block it and thus generate the desired current curves using pulse patterns.

However, the power converter of an HVDC system is dimensioned differently to conventional converters. This is because modular multi-level converters (MMCs) consisting of hundreds of IGBTs are used and installed over an area of 10 to 15 hectares. The DC link uses a voltage between 100 and 800 kV and transmits power between 500 and 6,400 MW over distances of hundreds of kilometers.

New control concept for large power converters

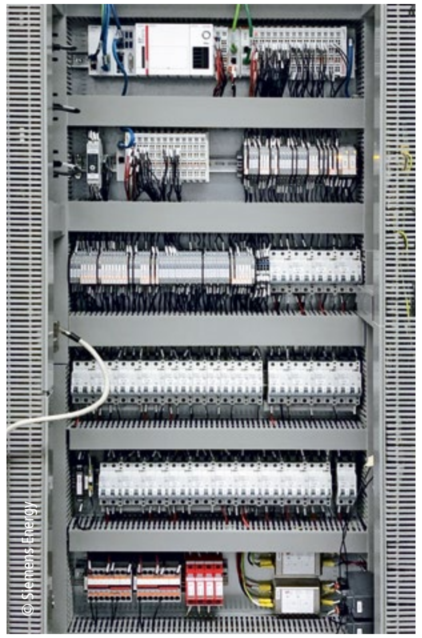
As a manufacturer of systems for energy transmission and stabilization of the power grid, Siemens Energy will in future be putting its trust in PC-based control technology from Beckhoff. Embedded PCs and EtherCAT I/O terminals as well as TwinCAT automation software in conjunction with model-based design are being used for higher-level control and to protect large power converters. Among other things, these power converters form the basis of such HVDC systems, but are also used for systems to compensate for reactive power or to support and stabilize electrical energy grids (flexible AC transmission systems, FACTS).

In order to achieve a high level of reliability for such an important part of the energy grid, redundant systems are often used. The control and protection systems in hardware and software are permanently in a hot standby mode so that they can immediately switch to the redundant system in the event of any malfunction. To achieve this, redundant communication is established via several separate Ethernet networks using the TwinCAT Parallel Redundancy Protocol (PRP) in accordance with IEC 62439-3. This method enables communication to take place between the embedded PCs via the EtherCAT Automation Protocol (EAP) as well as with external systems such as circuit breakers via MMS and GOOSE in accordance with IEC 61850.

Fast response times and safe operation

The requirements for fast response times for higher-level current and voltage control are met using EtherCAT and high-performance embedded PCs. Based on the AMD Ryzen™ CPU in the CX2043 Embedded PCs, control tasks can be executed in TwinCAT with cycle times of 250 µs and minimal jitter. A total of up to twelve such embedded PCs are used per power converter, which exchange fast signals in redundant segments via the EL6695 EtherCAT bridge terminal.

The TwinCAT/BSD operating system was chosen to ensure safe operation of the systems as part of the critical infrastructure. It offers a stable Unix platform for the TwinCAT 3 runtime, which also meets the growing security requirements. TwinCAT modules are then executed in the real-time environment of TwinCAT 3. TwinCAT modules developed directly in C/C++ are used for basic functions or special communication stacks. They make it possible to abstract the control software from the details of the hardware or communication via various protocols such as EtherCAT or IEC 61850. Specific functions and controls for the system are then configured using model-based development in MATLAB and Simulink and transferred to the embedded PCs using code generation.



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Test cabinet containing the CX2043 Embedded PC and directly connected EtherCAT Terminals

Integrated and open software

Since these kinds of HVDC systems are not available for development and verification as a physical system, early testing via simulation is of central importance. In the past, these tests were carried out in various simulation environments, which required the control and protection software to be manually translated into each environment. This manual process was too error-prone and time-consuming to achieve comparable control behavior in all environments.

To enable a single source to be used for the software, Siemens Energy has been successfully using model-based design and engineering for the processes with the help of MATLAB and Simulink® for several years. The development of the control and protection software in Simulink and subsequent code generation with TwinCAT 3 Target for Simulink eliminates precisely all manual steps mentioned above, allowing the developers to concentrate on their core task instead. Running the same software in different simulation environments as well as on the final control hardware enables the behavior to be compared more effectively.

Another advantage is the time saved in the event of an error or when expanding the models. In the past, it was necessary to correct the errors in the respective target system or expand the functions there, but today this is done in the source model in Simulink. In conjunction with TwinCAT, the already tested software modules can then be ported to the powerful, highly real-time-capable embedded PCs with little effort and only need to be connected to the physical interfaces. As a result, both HIL (hardware in the loop) tests and tests involving the control cabinets to be installed in the real system later on can be carried out with the control system in order to deliver a control system that is optimally adapted to all scenarios in the power grid.

More information:
www.mathworks.com
www.siemens-energy.com
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