Attachment 4

SmartValve™

Overview

The SmartValve™ leverages proven Guardian™ technology and builds upon the success of its predecessors. The SmartValve can increase or decrease the reactance of a line, thereby pushing power away from or pulling more power towards the circuit on which it is installed.

A modular, Static Synchronous Series Compensator (SSSC), the SmartValve injects a leading or lagging voltage in quadrature with the line current, providing the functionality of a series capacitor or series reactor respectively. The SmartValve does not have the negative characteristics of these passive devices, such as the risk of sub-synchronous resonance (SSR) with series capacitors and the constant VAR consumption of series reactors.

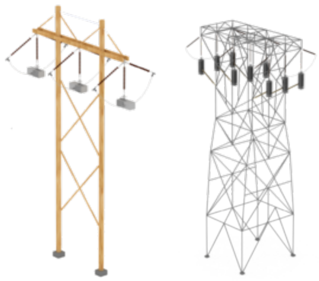
SmartValve solutions are connected in series with a utility facility, operate at line potential and have no connection to ground. This technology is particularly effective in highly meshed electric grids where spare system capacity can be utilized to resolve overload situations. SmartValves can be installed on dedicated transmission towers within the transmission right-of-way or in banks inside or nearby existing substations. Due to their modularity and high kVAr output in compact and lightweight enclosures, they are particularly well-suited for Mobile applications. SmartValve technology is applied to all three phases, with the number of devices per phase determined by the amount of compensation required.

Bypass functionality, which provides protection and control of the SmartValve, is either integrated into the SmartValve or installed as a discrete device, called the SmartBypass, in parallel with one or more SmartValves. The SmartValve 1-900, SmartValve 1-1800 and SmartValve 2-3600 models are deployed with the SmartBypass. SmartValve 5-1800i and 10-3600i models have an integrated bypass.

Regardless of whether the bypass functionality is integrated or discrete, it builds upon the proven success of the bypass systems used in Guardian products. It enables operators to manually bypass a SmartValve or switch them in series with the transmission line.

Note: The SmartValve was formerly known as the Power Router.

Deployment Options



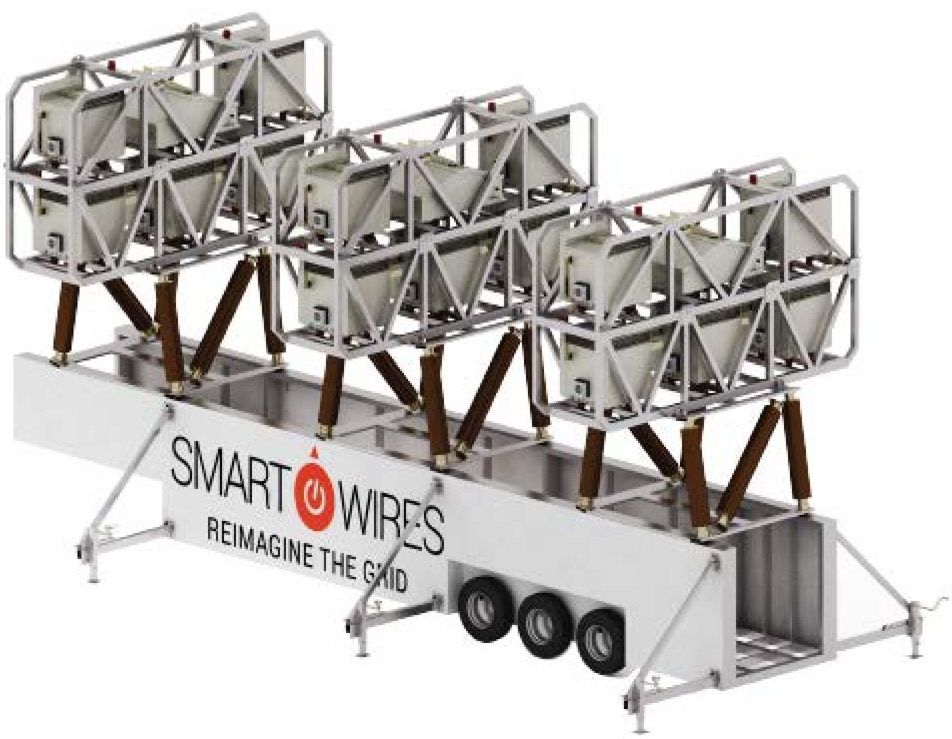
Tower-based Deployment

This tower can replace an existing structure within a circuit or serve as a new dedicated tower in the middle of a span. Existing towers can also be modified to accommodate units. Utilities needing to replace old poles or towers can use this method to upgrade their infrastructure and simultaneously add power flow control capabilities to their system.

Ground-based Deployment

This extremely high-density deployment can be constructed on a small footprint within an existing right-of-way, a substation or a dedicated parcel of land adjacent to the ROW or a substation.

Smart Wires works directly with the utility to determine the bank design that is best suited for a particular application.



Mobile Deployment

The mobile deployment method is a containerized solution that can be fully installed and commissioned in 8 hours. Installation requires a very limited line outage. Installation requires a very limited outage ranging from a couple of hours to a couple of days, depending on site conditions. This method is ideal for short-term and near-term needs such as construction & maintenance support, short-term congestion, transmission emergencies and bridge solutions.

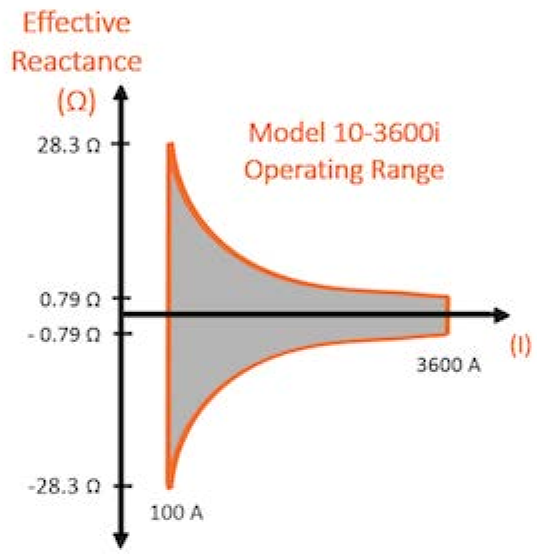
Operating Principles

The SmartValve acts as a solid-state synchronous voltage source, consisting of a series of voltage-source converters. The H-Bridge of each converter employs the use of Insulated Gate Bipolar Transistors (IGBTs). The H-Bridge is controlled to inject a voltage directly into the network facility to maintain a desired reactance. It does this by sensing the line current through a current transformer to determine the correct injection voltage magnitude to maintain the desired reactance.

The bypass provides protection and control of the power electronic converters, enabling the rapid bypass of the power electronic converters during fault conditions. Under normal operation, the bypass enables operators to switch the converters in series with the utility's network facility.

The principal components of the bypass are the normally-closed mechanical contactor (VSL), the Silicon Controlled Rectifiers (SCRs), the Metal Oxide Varistor (MOV) and the differential-mode chokes (DMCs). The bypass is either integrated into the SmartValve or installed as a discrete device, called the SmartBypassTM.

Unlike conventional series capacitors or reactors, the SmartValve can inject the voltage independently of the line current, thus increasing the effective reactance injection when operated below the rated value, as shown in the graph in the figure.



The figure shows the effective reactance injection as a function of line current. The orange boundary of the operating range reflects the maximum reactance available of an individual SmartValve 10-3600i with a maximum output voltage of +/- 2830 V RMS of the fundamental. The grey area inside reflects the range available if the output voltage is varied lower than +/- 2830 V RMS of the fundamental. The collective fleet of SmartValve units can be controlled to maintain a fixed reactance since the injected voltage can be controlled as a function of line current. Other SmartValve models follow a similar operating range curve; the maximum current and maximum reactance values will differ.

Operating Modes

The SmartValve has two distinct modes of operation. The modes during normal operation are determined by the state of the bypass as follows:

1. **Injection Mode** – In this mode, the VSL of the bypass is open and the SCRs of the bypass are not conducting; enabling the power electronic converters to inject a voltage into the network facility. The maximum magnitude of the voltage is determined by the respective converter ratings.
2. **Monitoring Mode** – No voltage is injected as the VSL is closed or the SCRs are conducting and the converters are bypassed.

Control Methods

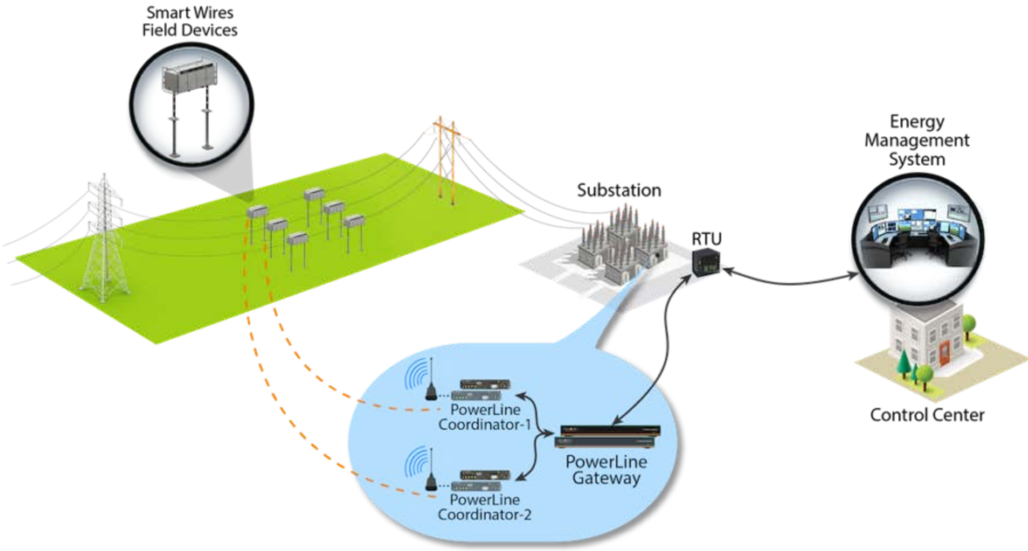
There are various control methods for the SmartValve, defined by levels of required automation and communication.

- **Without a Communication System** – This is the simplest control method for first and early-stage deployments. The fleet of deployed SmartValves continuously delivers a pre-programmed default level of reactance or voltage and does not require backhaul communications.

- **With a Communication System** – This control method is the most common and most flexible. The E2E Communication and Control System communicates wirelessly with the entire fleet. Details on the communication system are provided in Section 5. The operator does not need to control individual devices, but can program a desired value for the fleet to achieve as follows:
    1. **Injection at a fixed voltage** – The SmartValve fleet is set to output a fixed voltage injection that is either capacitive or inductive. In this control method, the injected reactance will vary as the line current changes.
    2. **Injection at a fixed reactance** – In this control method the SmartValve fleet is set to output a fixed reactance that is either capacitive or inductive. In this control method, the injected voltage will vary as the line current changes to keep the reactance at a set value.
    3. **Current control** – In this control method the SmartValve fleet actively regulates the magnitude of the current through the facility to stay below a given level or equal a given level.
    4. **Set point** – In this control method the SmartValve fleet is set to output a preset reactance level. The operator may choose among various presets.

More advanced control methods are possible, depending upon utility needs and how the equipment is integrated into the system. For example, it is possible to change the injected reactance of a fleet of SmartValves connected to Facility A based on a parameter measured from Facility B.

Communication & Control



The End to End (E2E) Communication and Control System (referred to as the E2E system) seamlessly interfaces with utility Energy Management Systems (EMS) and manages the operation of Smart Wires Field Devices (SWFDs).

Utilities operators control of the amount of reactance provided by the fleet of SWFDs at the EMS level. EMS commands are transmitted to the PowerLine Gateway over a secure communication channel. The PowerLine Gateway is an IT/SCADA device, located at the substation, which provides configuration, observation, control and asset management services for the SWFDs. The PowerLine Gateway supports multiple communication protocols – including DNP3, IEC 61850, 60870-5-104 and others – and transmits the utility's EMS commands to the PowerLine Coordinator. The PowerLine Coordinator, an IT/SCADA device located either in the substation or in the field, manages the secure wireless network that is used for communication with the SWFDs.

Once the SWFDs are programmed initially, each unit largely controls its individual reactance injection on the transmission circuit. The SWFDs detect faults and automatically bypass when the current is at fault condition levels.

The Smart Wires Difference

Smart Wires solutions offer key advantages compared to traditional approaches to infrastructure investments. All of Smart Wires products are **modular** in-nature, meaning that deployments can be fine-tuned to meet system needs. Should utilities require a different amount of power flow control at some point in the future, Smart Wires' installations can be easily scaled up or down. Smart Wires solutions are **quick to deploy**, providing utilities with an installed solution capable of addressing emergency needs. Also, all products are designed to be **easy to re-deploy**. This means that if grid conditions change and power flow control is no longer needed on a specific circuit, the Smart Wires solution can be moved to a different location on the grid. This reusable investment is perfectly suited for addressing problems that are known to be short-term or temporary in nature.