Shunt reactors improve voltage stability and power quality

ABB's leading position in high and ultrahigh-voltage shunt reactors stems from an uncompromising commitment to quality, innovation and technical excellence. ABB shunt reactors provide innovative technology to meet the needs for voltage stability, power quality and integration of renewable energy.

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The networks for transmitting and distributing electrical energy face new demands due to changes in power generation and load structure. Both commercial and environmental drivers contribute to this demand, as does power quality. Dynamic and time varying effects associated with renewable energy also influence networks. The active power flow in the network and the balance of reactive power must both be regulated to maintain voltage stability – a key to power quality in HV transmission. The voltage level in the grid must also be kept within specified limits regardless of the loading, which varies with time (hourly, daily or seasonally).

Shunt reactors are cost-effective and reliable

Shunt reactors (SR) are commonly used to compensate reactive power and to maintain voltage stability, Figure 1. Traditionally, SRs have fixed ratings with no means of voltage regulation. If regulation is needed, fixed reactors are switched in and out along with load variations. However, the resulting large steps in reactance lead to step changes in the system voltage level, especially if the grid

Figure 1. One of ABB's shunt reactor is shown; it is an absorber of reactive power, thereby increasing the energy efficiency of the system.

is weak. This creates power quality issues and places stress on the breakers.

Wherever power quality is essential, variable shunt reactors (VSR) are an attractive alternative to fixed reactors, Figure 2. VSRs have regulation capability and can interact with other regulating devices such as Static Var Compensators (SVC) [1], [2].

VSRs based on transformer tap changers have a regulation speed on the order of minutes between the extreme positions. As load variations occur slowly, i.e. mostly on the order of hours or longer, VSRs based on tap changer technology prove to be the most cost-effective and reliable technology for controllable shunt reactors.

Since the introduction of the gapped-core shunt reactor in the late 1960's, ABB has delivered nearly 3,000 shunt reactors to around 60 different countries

Iron core shunt reactor technology

ABB's high-voltage shunt reactors are built according to the gapped core concept; this is the dominant core-type reactor on the market today.

For the largest reactors (300 MVAr), pulsating forces across air gaps caused by the magnetic field can be as high as 50 tons [3] and appear 100 times per second in 50 Hz systems. Vibrations that result from the electromagnetic forces will generate sound. The degree of vibration depends on the rigidity of the mechanical structure exposed to the electromagnetic forces. Flexible structures will adjust to the forces more than will a rigid structure. The core column must therefore be very stiff to minimize vibrations [3], [4]. For three-phase reactors, the three wound limbs must also be properly aligned during stacking and accurately levelled at the top yoke. These assembly operations require high precision and skilled workshop operators to achieve low vibration and noise levels.

High-voltage shunt reactors can be built either as single- or three-phase units; the three-phase unit is more economical. Apart from a lower direct investment, the three-phase alternative has lower losses and requires less space in a substation. Reactors are selected for reliability in some regions, where the cost of keeping a spare unit is lower than the cost of a three-phase unit. Shunt reactors

Shunt reactors are commonly used to compensate reactive power and to maintain voltage stability

at or above 765 kV are predominantly single-phase, yet can currently be constructed as three-phase units.

High-voltage shunt reactors are designed and optimized according to customers' specifications. Besides the basic design parameters, such as voltage, rated power, linearity etc. limits to losses and sound disturbances also affect design. Generally, the lower the loss, the more material is added to windings and core to keep the current density and flux density low, thereby reducing losses. Similarly, the maximum acceptable sound level of the reactor – often a dimensioning factor in the design process – is important from an environmental and energy saving perspective.

A VSR is based on the same concept as an SR, yet has one or more regulating windings in combination with a tap changer, like a transformer. A VSR is, however, distinctly different from a transformer, because it has a substantially larger regulation range, normally up to between 50 and 60 percent. Larger regulation ranges up to 80 percent at 400 kV can also be achieved, at higher complexity and cost.

Depending on the tap changer position, the magnetic flux will vary within the reactor; the maximum value is achieved at the maximum rating with a minimum number of connected electrical turns. As flux varies, the sound level and losses of the reactor vary depending on tap changer position.

If the same number of turns per regulating step are installed, each step, albeit small, will not have exactly the same MVAr rating.

Field applications of shunt reactors

Shunt reactors are essential equipment in high-voltage networks operating over long distances and in cable networks to provide voltage stability and increase the transmission efficiency. VSRs are applicable for the compensation of varying load conditions in many circumstances described below.

Power quality

Switching in and out of fixed reactors produces steps in the system voltage. This can be avoided by using VSRs, in particular if the grid is weak.

Integration of renewables and wind parks

Large installations that are connected to the transmission or sub-transmission grid can experience unpredictable fluctuating active-power exchanges and reactive-power fluctuations – serious concern for the operational security of the grid, Figure 3. VSRs provide a way to control reactive power fluctuations and allow the wind park operator to comply with the connection requirements of the grid code, Figure 2 [5].

Emerging grids

VSRs are useful when reactors are installed at HV lines that initially carry a low load that will increase with time – a common scenario in developing economies. One VSR is a more cost-effective solution than two fixed reactors: less expensive, smaller footprint, lower losses and only one breaker.

Zero crossing

This phenomenon occurs more often because of the increasing use of HV AC cables at transmission levels. The absence of current zero-crossing can delay the opening of the circuit breaker, thus leaving the system unprotected and vulnerable to failures [6], [7]. One VSR is therefore the most cost-effective solution.

Tuning of Static Var Compensators (SVC)

The system operator can adapt the reactive power compensation to the actual load, thus running the grid optimally. If SVCs are installed in the grid, the use of VSRs can provide optimum headroom; the SVC can operate in a minimum loss position.

Flexible and universal spare

A VSR can be used in several positions in the grid provided that the voltage levels are similar and can be used as a universal spare if required [1].

Air core reactor technology

Air core reactors are available in oil-free and oil-filled solutions. For moderate voltages and power ratings, the most economical type of current limiting reactor is usually a dry-type transformer without an enclosure or active cooling, Figure 4. Numerous reactors of this type are in operation around the world, mostly in medium to high voltage industrial power systems.

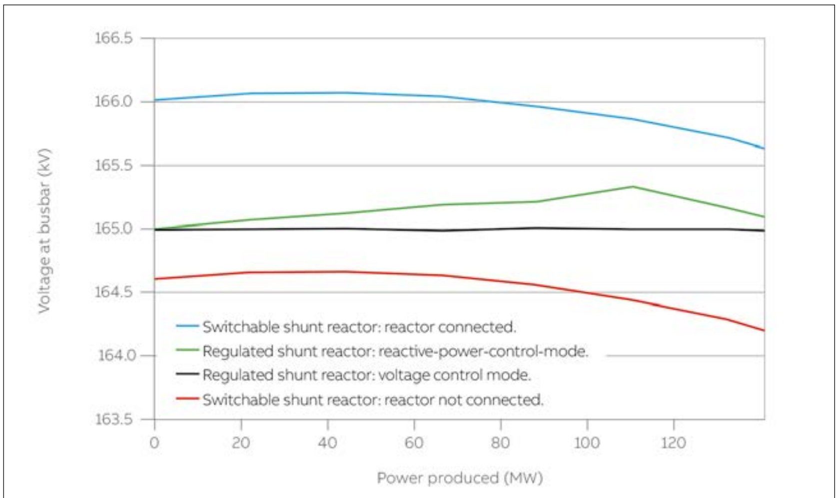

Figure 2. Voltage at a 165 kV substation is shown as a function of the active power produced by a wind park; four different cases are illustrated

Figure 3. Different operators have different requirements for the reactive power exchange at the point of connection on large wind farms

Air core reactors have larger footprints than iron-core options. As a result, the magnetic field that spreads freely in the surroundings may cause excessive heating of iron reinforcements in objects like concrete walls. For this reason these objects should be located at sufficient distances so that magnetic field strength values are below 80 A/m at the floor and ceiling and below 30 A/m at adjacent walls.

ABB's outdoor air core reactors utilize a proprietary construction that gives the coils the industry's highest levels of mechanical strength for short circuit and environmental protection. This advanced construction has been validated during decades of robust use by traction rolling stock and in offshore oil and gas production facilities. The construction features a vacuum impregnation process that uses an unique Class H epoxy resin, a dedicated oven-curing cycle to give the reactor additional mechanical strength and a final coating of protective varnish to shield against UV and corrosive elements.

For the largest reactors (300 MVAr), pulsating forces across air gaps caused by the magnetic field can be as high as 50 tons and appear 100 times per second in 50 Hz systems

Field applications of air core reactors

Air core reactors are used for a variety of industrial and utility field applications: harmonic filters, shunt reactors, short-circuit current limiting, thyristor controlled reactors, inrush damping, neutral grounding, smoothing and electrical arc furnaces.

Harmonic filters are typically installed with capacitors and resistors, close to the source of harmonics to provide a low impedance path for harmonic currents; they are tuned to a specific frequency to cancel or mitigate the relevant harmonic.

Shunt reactors are employed when the compensation of the capacity reactive power is required; where lightly loaded long transmission lines or cables are used. They are also installed on the tertiary winding of a power transformer or on the substation busbar system.

Short-circuit current limiters reduce the short-circuit current to values accepted by the installed circuit breakers when faults occur. Consequently, standard equipment can be installed in the network for high short-circuit currents.

Thyristor controlled reactors (TCR) are employed in SVC systems for dynamic load balance in industrial plants where large variable loads are installed. TCR reactors, unlike shunt reactors, use thyristor valves to continuously regulate current.

Inrush damping is commonly installed in series with a shunt capacitor bank, which functions to limit the inrush currents due to switching and the outrush current of the capacitor bank.

Neutral grounding is installed between the network neutral point and earth to limit the line-to-earth fault current. In balanced networks the through current is nil even though the networks are designed with a continuous current in mind; this is due to the unbalance of the network.

VSR is distinctly different from a transformer, because it has a substantially larger regulation range, normally up to between 50 and 60 %, and even up to 80 %

Figure 4. Three-phase, stacked outdoor air core reactors

Smoothing reduces the harmonic voltage and currents in DC lines and the ripple in the DC currents. This is mainly used where large rectifiers are installed, in traction substations or in HVDC substations.

Electrical Arc Furnaces (EAF) are typically installed in series with the primary power transformer in smelter plants. Particular care to the mechanical construction is made to manage the high forces in the winding induced by the switching operations. Furthermore, these reactors are often equipped with taps to increase operational efficiency.

New and future technologies

Since the introduction of the gapped-core shunt reactor in the late 1960's, ABB has delivered more than 2,950 shunt reactors to around 60 different countries. Today, ABB has the capacity to deliver and test both fixed SRs and variable SRs with extremely high ratings, Figure 5.

Customer demands and competition in the energy market have increased over the last decade. Environmental concerns drive growth in renewable energy, extending the use of cable networks and generating an interest in producing lower noise levels. Recognizing these trends, ABB offers shunt reactors tailored to these specific applications, e.g. ultralow noise reactors without the need for external sound damping; three-phase SRs that operate at 765 kV, and the ability to custom design and build VSRs at 765 kV. Relying on experience and know-how, ABB continues to set new limits for reactors and to provide new sophisticated products to meet the often complex needs of customers.

1969	The world's first 400 kV shunt reactor
2004	Introduction of Variable Shunt Reactors
2008	Testing of world's largest 3 phase reactor, 300 MVAr/400 kV at full power
2009	The world's largest Variable Shunt Reactor, 200 MVAr/420 kV
2011	VSRs with 60 % regulation range at 400 kV
2016	VSRs with 80 % regulation range at 400 kV

Figure 5. History of shunt reactor development

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