A 'rebirth technology' becomes important again
Credit: ABB

An old tool rediscovered to address new grid challenges

Synchronous condenser technology is enjoying a rebirth because, as more renewables are integrated to grids, it is one of the most effective means to maintain grid quality and fault support, writes Csaba Szabo

Many countries now face a trilemma of rising electricity prices versus compliance with international greenhouse gas commitments versus lack of grid resilience, reliability, and availability.

A potential answer could be synchronous condensers (SCs) or compensators, a rebirth technology that is becoming important again as one of the most effective means to maintain grid quality, fault ride-through and fault support, which is essential in order to maintain electricity supply.

The reason for this rebirth is that the increasing penetration of renewables (solar and wind) in the energy mix is unfortunately reducing the resilience and stability of electricity networks. This is because these new energy resources are inherently intermittent and variable. Furthermore, they lack the capability to support or tolerate the faults that can occur on electricity networks. SCs can play a significant role in compensating these shortcomings and, in the future it is expected they will help to mitigate network issues and enhance the reliability of power supplies.

Australia has particular experience of these challenges. The country has a very long transmission system linking its five eastern states, and the relatively small levels of both generation and consumption are scattered across lightly populated areas. In some locations renewables represent about 40 per cent of the energy mix with plans for this to increase. The combination of the effects from low population density and a high level of renewable penetration creates an interesting situation, which offers useful experience for other regions of the world.

The state of networks today

New sources of electrical power – primarily wind and solar – are very different to traditional large rotating generators. They present new challenges for power networks in terms of their complexity and behaviour.

Today's networks can experience many different types of faults or unwanted attributes, like voltage sags, interruptions, swells, transients and distortions, notches, voltage fluctuations and frequency deviations. These can be very damaging for sensitive equipment causing malfunctions and even the shutdown of essential services.

In the case of intermittent renewable generation, network quality and reliability are significantly affected. In most cases the AC power fed into the network is synthesized from a DC source. For example, in the case of a solar farm, the inverter that converts the DC power to true 50 Hz AC will be simply switched off by its protection, if the network parameters differ from those expected or programmed in the unit. There is no ride-through capability.

As the penetration of new 'synthetic' power generation is increasing in the power mix, and the number of traditional high inertia rotating generators is decreasing, network resilience is compromised. If, in the above-mentioned example, the inverter is faced with an external network fault, it will not be able to help the network to recover, will not supply the needed reactive power and cannot ride through.

What is a synchronous condenser?

An SC is a synchronous machine, not a motor (as nothing is driven) and not a generator (as there is no prime mover). However, it is very similar to a generator in its design and behaviour. And, it does produce reactive power. As a rotating electric machine, it is a very traditional device. In the past, SCs used to be applied as compensators to produce reactive power, balancing out highly inductive loads, like induction motors.

The typical users of synchronous condensers are electrical utilities and heavy industries that operate transmission, distribution or industrial power grids. After many years when there has been no interest, ABB has recently received multiple requests for synchronous condensers from grid operators and utilities. Important drivers for this development include the large-scale integration of wind and solar power as well as the introduction of smart grid technologies in networks. In a way, utilities are currently rediscovering the benefits of conventional synchronous condenser technology and are finding new ways to make use of them in their networks.

The decision to use a synchronous condenser in a reactive power installation is usually based on extensive pre-studies, and its selection cannot be narrowed down to one single reason. The reasons for selecting synchronous condensers can therefore vary significantly from case to case. Some typical scenarios where synchronous condensers could be useful are described below.

- **Networks with large amounts of intermittent power generation**
  The intermittent and highly variable nature of wind and solar power introduces stresses on power systems and dynamic reactive power compensation is needed to ensure secure operation. Many renewable resources are remotely located and feed power into a single radial line. Synchronous condensers can be installed close to the connection point to strengthen the grid with additional short-circuit power. This improves both the fault ride-through capability of the power installation itself and provides additional voltage stability.

- **Phasing out fossil-fuelled plants**
  Old coal-fired power plants and, in some countries, nuclear power plants are being phased out. In many cases, they are not being replaced. As the synchronous generators at these locations have been supplying the grid with significant amounts of short-circuit power, simply removing them would put the stability of the adjacent network at risk. Synchronous condensers are therefore needed to maintain the short-circuit capacity of the grid after the removal of the high inertia rotating generators.

- **Intermittent industrial processes; seasonal changes in demand**
  Heavy industries in certain areas can introduce major load fluctuations that cause significant voltage sags in the local network. To strengthen the short-circuit capacity of these types of networks, a synchronous condenser may be used as it will boost voltage and supply reactive power. Areas with significant seasonal variations in power demand could also benefit from the additional short-circuit capacity and voltage stability margins introduced by synchronous condensers.

- **Long distances between production and consumption**
  In some power grids, the physical distance between power plants and major load centres can be substantial. Typically, reactive power should be produced locally to minimize the losses associated with long distance power transmission. Local reactive power generation also ensures the optimal utilization of the power lines. A synchronous condenser can effectively complement the fast-operating static VAr-compensating devices at remote sites where voltage collapse must be avoided at any cost. An important feature of SCs is that their relatively small size allows installation close to the required point in the network where they are needed and their benefits are maximized.

Historically, synchronous condensers have played an important role as controllable sources of reactive power at both the transmission and distribution network levels. Today, however, power-electronics-based static devices such as SVCs (static VAr compensators) or STATCOMs (static synchronous compensators) dominate this market, owing to their superior controllability, flexibility and speed. These or some hybrid devices may be able to push a high amount of reactive power through capacitive operation into the HV (high voltage) grid so that the voltage will not go down to zero and the fault may be cleared. However, in doing so, they will see a swing of over-voltage which then must be cleared through inductive operation. If the HV grid should go down to zero then all types of static devices will not be able to clear the fault and will not ride through.

In contrast to synchronous condensers, static devices do not provide additional system short circuit capacity. Compared with synchronous condensers, they are also somewhat less effective in supplying reactive power during low voltage (voltage sag) conditions, as their output is strongly connected to the network voltage level. And they have no ride-through capability.

To address network issues there are many ways to mitigate the given situation. The table below lists the problems and shows various devices which can be considered. SCs have a very broad coverage of issues.

The illustration on page 8 shows the benefits of increased short-circuit capacity attributed to synchronous condensers. The two figures show results of a simulation of the operation of a utility grid where three synchronous

Typical power quality problems and available mitigation devices

Mitigation devices	Voltage sags	Voltage fluctuations	Over voltage	Under voltage	Inter-ruptions	Swells	Transients	Harmonics	Notches	Fault ride thru	Short circuit contribution
APF (TF)							x	x	x		
BESS	x	x	x	x	x	x	x				
DSTATCOM		x	x	x			x			(x)	
DSC		x		x							
DVR	x	x			x	x	x	x			
PFCC			x	x							
SA							x				
SC	x	x	x	x	x	x	x		(x)	x	x
SMES	x	x	x	x	x	x	x				
SETC	x		x	x		x					
SSTS	x				x	x					
SSCB					x						
SVC	x	x	x	x		x					
TCS				x			x				
UPS	x		x	x	x	x					

APF = Active power filter
BESS = Battery energy storage system

DSTATCOM = Distribution static synchronous compensator
DSC = Distribution series capacitor
DVR = Dynamic voltage restorer

PFCC = Power factor correction capacitor
SA = Surge arrester
SC = Synchronous condenser (rotating)

SMES = Superconducting magnetic energy storage system
SETC = Static electronic tap changer

SSTS = Solid-state transfer switch
SSCB = Solid-state circuit breaker
SVC = Static var compensator

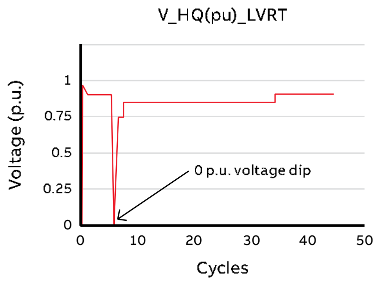
TCS = Thyristor switched capacitor
UPS = Uninterruptible power supply

Source: ABB

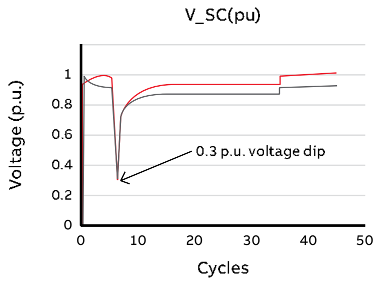
condensers have been installed at a 13.8 kV bus – here designated as the Medium Voltage (MV) bus. They are electrically connected to a transmission level bus (120 kV) via step-up transformers. The 120 kV bus is referred to as the High Voltage (HV) Bus. A three-phase fault is applied close to the HV bus.

The figure on the left shows the voltage profile on the HV bus during and after the fault. The figure on the right shows the voltage profile on the LV bus (two different load scenarios, blue and black, are illustrated).

As seen in the figures, the voltage drops to 0 per cent of the nominal value on the HV bus and to 30 per cent of the nominal value on the LV bus. The lower voltage drop on the LV bus is due to the grid strengthening action of the synchronous condenser. The mitigated voltage profile on the MV bus increases the likelihood that the connected electrical equipment is not tripped or damaged by the fault. In general, synchronous condensers have a better chance to stay online and provide voltage support during severe faults like this compared to other var-compensating technologies.



Voltage profile on HV bus



Voltage profile on MV bus with SC is connected

Benefits of increased short-circuit capacity attributed to SCs — Source: ABB

• Is it possible to convert unused large generators into SCs?

Yes, it is possible and there are applications in which converted generators are now operating as SCs. However, compared with new dedicated and optimized SCs they have some disadvantages. They are usually old with outdated technologies, aging components and require lots of auxillaries to run. Their starting is problematic. Lots of laborious maintenance is required. They are usually located less favourably, maybe at remote locations compared with SCs which are smaller, simpler and can be installed in any required place. This results in reduced performance and effectiveness.

On the other hand, new SCs offer many benefits. They can be installed in the preferred location and constructed with optimized features and capablities. Their optimization is based on the results of a network study, usually performed by network owners or third party consultants. They use the latest manufacturing technology and materials and most modern control equipment and communication. Maintenance requirements are very low, as they are simpler and smaller than traditional power generators. Usually they are applied as two or more smaller units, thereby giving required redundancy.

• How is the SC started?

Large synchronous machines can be started by a frequency converter, direct online or – the most ideal way – by a pony motor. This allows the SC to be designed without the constraints of startup considerations. A small pony motor of about 200–300 kW is coupled to the SC and is supplied by a frequency converter which is set up for a few minutes start up ramp which will bring the speed of the SC into synchronous operation, usually at 1500 rpm. The excitation system is then started and at the right moment the main breaker will switch the machine online.

• What capacity can SCs be supplied at?

Large synchronous generators, motors or condensers can be supplied in powers ranging from 1 to 80 MVA at 3–15 kV system voltage. The preferred voltage is a matter of optimization, since the network voltage is usually much higher, so a step up transformer is used. Higher outputs are reached by using several units in a standardized module concept. This configuration offers better redundancy and availability compared to one large unit.

The construction of the SC is not substantially different from synchronous generators as it features a salient pole rotor, brushless excitation and epoxy resin-insulated stator windings. It is usually water cooled, as this is the most effective way to dissipate the heat losses and it is designed to be used outdoor in different ambient conditions.

The major benefits of SCs in the age of rapid development and widespread application of renewables are:

- Network frequency stabilization supported by its spinning inertia reserve;
- Contribution to system short-circuit capacity, making the network more robust against faults;
- Providing voltage support during prolonged voltage sags and interruptions through good fault ride-through capability;
- Reactive power support not affected by network voltage;
- High over load capability for sustained periods.

The most important feature of the SC, apart from its ability to control its terminal voltage, is that it is able to utilize the large kinetic energy stored in its spinning inertia reserve (due to the rotating mass of rotor). This ability is represented in the inertia constant H [s], which is the ratio of its kinetic energy stored and apparent (reactive) power being produced.

This is important for the network study and modelling, as well as other SC-related parameters. The study can identify network issues and determine the desirable features of the SC. In a step-by-step process these requirements then will determine the SC's final optimization. The designer can adjust various parameters of the machine, optimizing it for the specific requirements of the network at the given location.

It is expected that thanks to the need to address network quality issues and reliability, and the new challenges which have come with renewables, then SCs – potentially with a combination of static devices – will enjoy a substantial rebirth in providing a broad, solid, economic and long-lasting solution to increase grid quality and resilience.

Csaba Szabo is Product Manager/Specialist in MV and HV motors and generators at ABB Australia

Visit **www.PowerEngineeringInt.com** for more information