What Will MV Switchgear Look Like in the Future?

byJean-Marc Biasse

Executive summary

The development of Smart Grids means that medium-voltage (MV) equipment must become more intelligent. This paper reviews different types of MV switchgear and examines opportunities for future MV switchgear to meet the challenge of Smart Grids. Specifically, replacing manual switches with circuit breakers, leveraging digital technology for greater remote control and monitoring, deploying low power transformers, and using modular architecture are discussed.

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Introduction

The electricity industry is by nature conservative and slow to adopt change in its technology. There are various reasons why the industry has preserved its traditional approach to medium voltage (MV) and high voltage (HV) switchgear. First, although fundamental technological innovations appear about every 20 years, the life cycle of switchgear is about 40 years. “Older” switchgear remain valid architecture for a traditional, centralized power transmission and distribution (T&D) network. Second, T&D operators need stability. As stability is often interpreted as lack of change, the industry has been hesitant to universally deploy new switchgear technologies. Third, maintenance and repair of such long-life devices is easier for service crews if there is no change in technology.

But to take advantage of today’s Smart Grid capabilities and demands, the electricity industry must establish new criteria for switchgear. Smart Grid-era switchgear need to be more “digitally intelligent,” flexible, compact, and able to withstand harsh environments.

The technology exists today that meets these new criteria. **Table 1** summarizes five changes that will become standard within the industry as it transitions from traditional switchgear to Smart Grid–era switchgear.

Table 1
Five characteristics where Smart Grid–enabled switchgear differ from traditional switchgear

Technological change	Smart Grid benefit
Circuit breakers instead of switches	Distribution feeders in MV ring networks: fewer customers affected by outage MV/LV transformers: ability to detect faults earlier, while still low magnitude
Remote control and monitoring	Feeder automation, self-healing networks, optimised loads
More sensors	Real-time management of protection chain
More meters	Real-time insight into power availability
Modular architecture	Flexibility to integrate renewable & distributed energy sources

Switchgear need digital intelligence so utilities can view and measure what’s going on along the network more completely and more frequently, which enables a greater degree of control. Often such control may be automated for greater efficiency—for example, remote devices along the network may identify a fault, isolate it, and restore service without customers experiencing a prolonged outage. Digital intelligence is the key to remote control, which can optimize maintenance and avoid costly manned field service visits. Further, as more renewable and distributed energy sources become integrated into Smart Grids, monitoring and measurement become crucial to the ability to balance supply and demand.

Non-centralized energy sources also mean a wide variety of installations, some of which are in harsh environments. A modular switchgear architecture provides greater flexibility, so switchgear can handle many different applications. Switchgear that remain reliable in less-than-ideal conditions benefit customers through increased power availability and companies through reduced maintenance costs.

Compact switchgear are of great interest in urban areas to limit the cost of infrastructure and to bring medium voltage as close as possible to the place where electrical energy is used.

Given the new criteria for switchgear in the Smart Grid era, a complete Shielded and Solid Insulation Switchgear (2SIS) solution offers greater flexibility, in a compact size, with the environmental toughness to best realize what MV switchgear will look like in the future.

Evolution of MV switchgear technology

MV switchgear incorporate all three categories of power protection chain components: sensors, protection relays, and circuit breakers (CBs). Traditionally, the design of these components has evolved independently, with some interface constraints to ensure interoperability. Electrical switchgear need an insulation medium for two different functions:

- breaking current along the circuit in normal load conditions or in fault conditions. The insulation medium may be air, oil, SF_6, or vacuum.
- isolating between conductors or between conductors and the earth. The insulation medium may be air, oil, SF_6, vacuum, or solid (epoxy or some other resin).

Table 2
Electrical switchgear utilize various insulation media to break and isolate current

Voltage level	Switching medium		Insulation medium
	Circuit-breaking	Load-breaking	
High voltage	SF6, vacuum	NA	SF6, air
Medium voltage	SF6, vacuum Air, oil,	SF6, vacuum Air, oil,	Air, SF6, solids, oil

Circuit breaker technology

Air-insulated CBs are big and noisy. They require a lot of maintenance and, therefore, are withdrawable. **Oil** CBs are smaller but also need frequent maintenance and pose safety risks because of the potential for fire. **SF_6** and **vacuum** breaking are much safer and have become more reliable, to the point where state-of-the-art CBs now require very low maintenance. Often these CBs remain withdrawable because they are installed in traditional metal-enclosed panels.

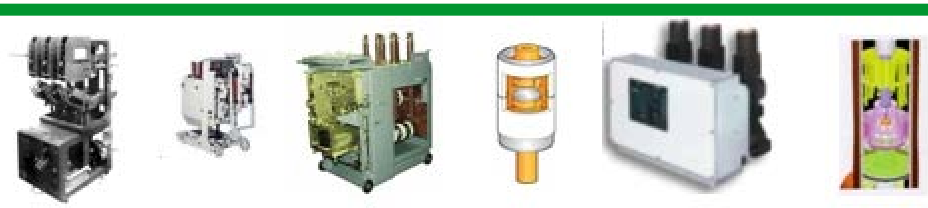


Figure 1
From left: Air-insulated circuit breaker; drawout oil circuit breaker with arc control; withdrawable vacuum CB; withdrawable SF_6 puffer CB

Primary distribution switchboard technology

"There is a progressive shift increase within the industry away from withdrawable components and toward fixed equipment."

Metal-enclosed **air-insulated switchgear (AIS)** cubicles developed in parallel with circuit breaker technology: the first generation integrating withdrawable air and oil CBs, the second generation integrating SF_6 and vacuum CBs. Generally, the CBs are installed in cassette to allow wall mounting and front access cables. But today's CB designs with reduced and optimized maintenance and advancements in protection-relay testing allow fixed CBs in third-generation switchgear.

Recently some fixed-CB metal-enclosed switchgear insulate the busbars and all components, including CBs and connections, with epoxy or some other resin. These panels are generally called **solid insulation switchgear (SIS).**

However, all AIS and SIS panels are still sensitive to environmental conditions if not properly installed in protected rooms. Metal-enclosed **gas insulated switchgear (GIS)** are most resistant to ambient conditions because all components, busbars, and connections are housed in hermetically sealed tanks filled with SF_6. This type of equipment is fitted with fixed CBs and is also very compact.

Both AIS and GIS panels coexist today. The final choice may differ for each application, depending on the importance given to such criteria as compact size, sensitivity to environmental conditions, high-performance availability, criticality of the application, power restoration mode in case of failure, ergonomics of operation, and/or ergonomics of cable testing.

Figure 2
Metal-enclosed AIS panel with CB cassette (left), metal-enclosed AIS panel with fixed CB (center), metal-enclosed GIS switchboard with fixed CBs (right)

Secondary distribution switchboard technology

Secondary distribution switchgear followed a similar evolution, but with some differences. To reduce costs, initially only simple switches with fuse protection were used instead of circuit breakers. A typical secondary distribution switchboard includes three functions, two switches and a switch fuse to protect the MV/LV transformer. To accommodate this three-function repetitive arrangement, a special **ring main unit (RMU)** configuration was developed where the three functions are fitted into a single metallic tank. Modern RMUs use SF_6 because it allows a more compact size and better withstands environmental conditions. Today's RMUs are also equipped with CBs for greater precision and to better protect more powerful MV/LV transformers. Today RMUs can handle up to 5 functions, but the modularity is limited. Consequently, GIS RMUs become inconvenient when further extension of the switchboard is needed or if the switchboard needs to handle more than five functions.

Figure 3
Modern SF_6 RMUs are often outfitted with circuit breakers for MV/LV transformer protection

Compared with GIS RMUs, a complete **Shielded and Solid Insulation Switchgear (2SIS)** solution offers greater flexibility. Busbars and a vacuum interrupter encapsulation and earthing switch enclosure are made of solid insulation that is covered by a conductive layer connected to the earth. The equipment can withstand harsh environments, and its modular architecture makes it well suited for many commercial, industrial, and building applications requiring a large number of units, such as large shopping malls, airports, data centers, and harbors.

Figure 4
Modular 2SIS switchboards offer the greatest flexibility to accommodate the many different Smart Grid applications

Sensor and protection relay technology

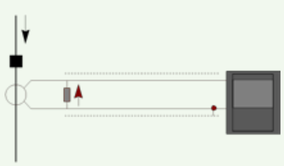
Sensors and protection relays are so closely linked that their technological evolution developed in tandem. Think of sensors as the "eyes" that transmit an image of the current to the protection relay "brain" which analyzes the image to decide whether the signal is normal or represents a fault. In case of a fault, the protection relay sends a tripping message to the circuit-breaker mechanism. Older protection relays were electromechanical, with coils and disks that required a lot of auxiliary power (5A on secondary output) from current transformers (CTs). Technological advancements led to protection relays that needed less auxiliary power from CTs (1A on secondary winding), yet the conservative high voltage industry still saw many specifications for 5A CTs.

Newer digital relays, on the other hand, require very little signal power from the CTs. Today's **low power current transformer (LPCT)** delivers a voltage signal representing the primary signal. This optimized LPCT technology offers several advantages:

- **Simplicity:** Engineering is simplified due to the wide operating range. One LPCT can cover applications from 5A to 1250A, whereas traditional CTs would require five sizes. A single sensor handles both measurement and protection.
- **Easy and safe installation:** LPCT output is plugged directly into the protection relay with no risk of overvoltage when disconnecting.
- **Flexibility:** It's easy to adapt LPCTs to changes in power consumption and/or protection settings, either in the system design phase or during operating life.

The principle behind LPCT sensors

The new breed of LPCT consists of a current transformer having a small core secondary winding connected to an integrated shunt resistor. The shunt resistor converts the secondary current output into a low-voltage signal.



- **Compact size:** Smaller, lighter, and easily integrated, LPCTs reduce the overall dimensions of MV switchgear without sacrificing protection and measurement requirements (**Figure 5**).

In spite of these advantages, the conservative electricity industry has been slow to deploy LPCTs, still specifying 1A or even 5A CTs to feed digital relays. Consequently, adapter transformers are needed in the protection relay to lower the input power.

Figure 5
An LPCT (left) offers the same measurement and protection capabilities as a traditional CT (right) but in a much more compact footprint

Digital relays have become commonplace, and the International Electrotechnical Commission (IEC) has published clear standards to make the interchangeability of LPCTs or protection relays easier, leading to greater deployment of LPCTs.

Evolution of the single line diagrams

Even if sometimes conservative, utilities and other customers still look for ways to reduce the size of equipment, lower costs, improve reliability, and have equipment that can withstand harsh environments. To meet these needs, the industry has progressively moved away from withdrawable and toward fixed equipment

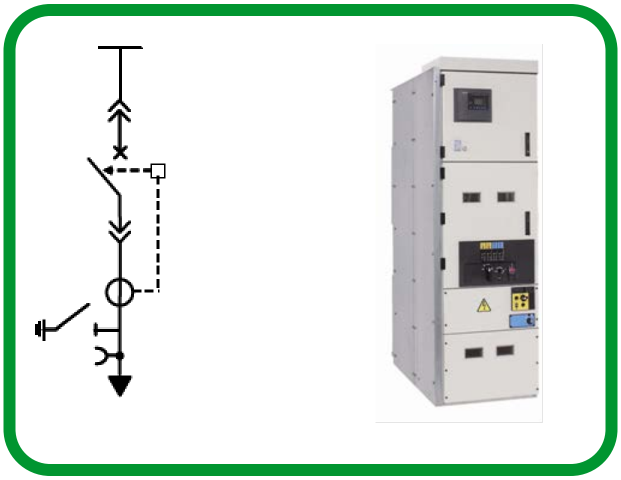
As the technology of medium voltage switchgear evolved, single line diagrams of incomers and feeders were regularly challenged. It is possible to make some comparisons among the most typical single line diagrams, just highlighting some points of importance.

Diagram with withdrawable technology

The diagram with withdrawable CBs is the oldest one. It is still in use for some primary distribution applications. Visible disconnection is made by racking out the CB truck, and usually an earthing switch is directly acting on cable ends.

Maintenance—which was quite often necessary in the past for old CB designs--is very easy. Access to terminals for cable testing is also easy.

Figure 6
Single line diagram and typical panel for withdrawable technology

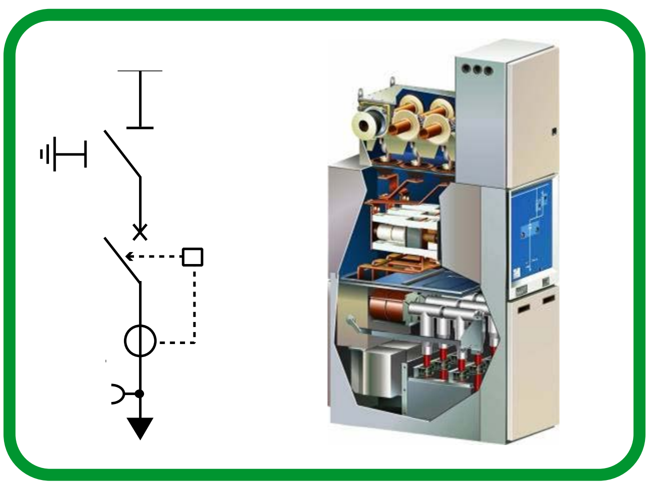


However, some points have to be carefully considered. Remote control of the disconnector is not really practical because the truck has to be racked out. Earthing the busbar needs a dedicated earthing truck, which is heavy to handle. Testing the cables requires opening the cable compartment for direct access to cables. And finally, the equipment must be installed in clean air rooms as AIS technology is sensitive to environmental conditions.

Typical diagram for GIS technology

Gas insulated switchgear (GIS) is drastically less sensitive to environmental conditions. First derived from HV GIS technology, this equipment is fitted with fixed CBs and separate disconnectors.

Figure 7
Single line diagram and typical panel for primary GIS technology



This technology was made possible by the design improvements of CBs that now need very low maintenance. Gas insulation and plug-type cable connectors ensure the highest degree of ability to withstand harsh environments.

Be aware that operation is not especially intuitive because of a five-position scheme. In particular, cables are earthed through CBs that must remain closed to ensure end-user safety when working.

Simplified diagram with upstream two-position selector

An upstream two-position selector simplifies the five-position single line diagram. This arrangement reduces the number of positions thanks to the two-position selector. As the cost is also reduced, it has been possible to use this arrangement in secondary distribution.

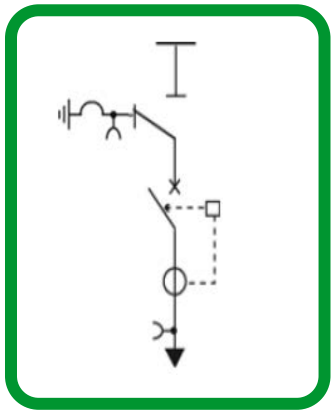


Figure 8
Single line diagram with upstream two-position selector

However, there are still four positions that make the operation less than intuitive, especially for secondary distribution. And earthing the cable remains through CBs that must remain closed to ensure end-user safety when working. The positive earthing indication depends on the status of the combination of two devices.

Reverse diagram for GIS technology

To improve ergonomics, some equipment uses a reverse diagram with GIS technology. Now earthing the cables is done directly via an earthing switch with making capacity. This also makes it possible a dedicated device for cable testing via a removable link.

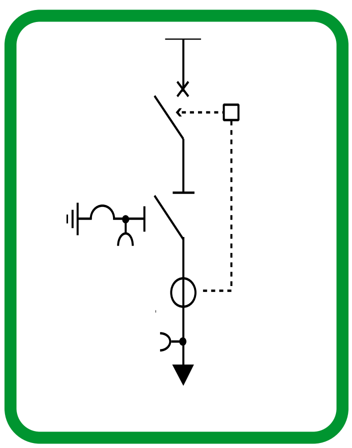


Figure 9
Reverse single line diagram with GIS technology

But there are still four positions, and keys are needed for safety interlocks. It is also more expensive because of the cost for a separate earthing switch having making capacity.

All-in-one arrangement diagram for GIS RMU

Simplicity, ability to withstand harsh environments, and cost effectiveness are often crucial for secondary applications. These criteria were the drivers behind an all-in-one arrangement for GIS RMU.

The main device is an SF_6 disconnecting load break switch or circuit breaker allowing a very simple three-position diagram. Breaking and disconnection are performed in a single operation, leading to the three-position scheme (line, open and disconnected, earthed).

Figure 10
Typical three-position GIS RMU diagram and examples of GIS RMU

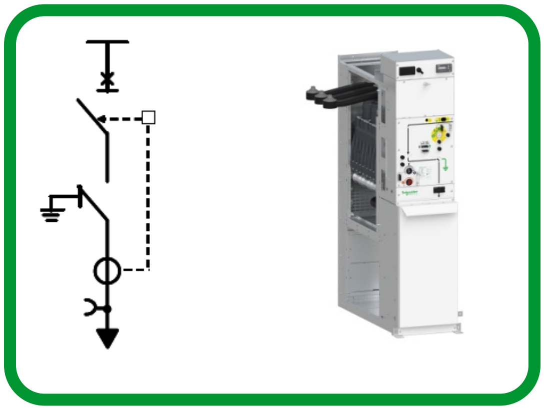
Local or remote operations are very simple. The mimic diagram is easy to interpret. Earthing the cables is done directly. Interlocking safety is inherent between the different positions. It is very easy to implement a cable testing device, allowing one to test cables without opening the cable box or interfering with the cable terminations.

New three-position diagram

The three-position arrangement for GIS RMU has been well appreciated for about 30 years now. The question was whether it was still possible to retain the simplicity of the three-position diagram using another technology. Recent developments brought about the solution of using vacuum breaking. Today using vacuum breakers in secondary applications is commonplace.

The new proposed arrangement includes an upstream vacuum disconnector load-break switch or CB and a downstream earthing switch providing a double-gap isolation between cables and busbars.

Figure 11
New three-position diagram including vacuum breaking and typical unit

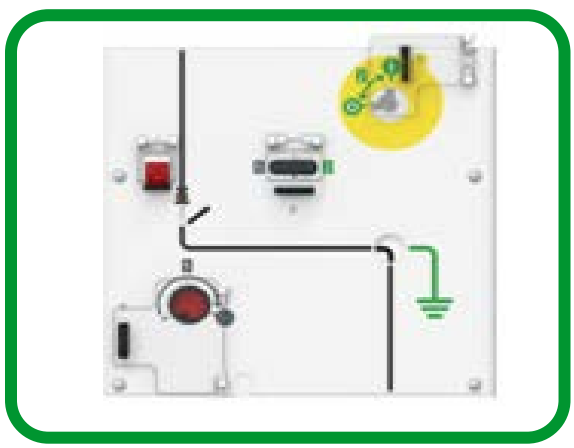


All previous advantages are kept with this real three-position scheme (line, open and disconnected, earthed).

- 1st position: CB or load-break switch closed
- 2nd position: CB or load-break switch opened and disconnected in a single operation
- 3rd position: cable earthing in one single operation

Breaking and disconnection are made in one single operation of a vacuum interrupter. Earthing the cables is done directly, using an earthing switch with making capability. This diagram facilitates the implementation of clear mimic indications, making operations very intuitive and thus safer. Safety interlocks are built-in, short, key-free, and positively driven.

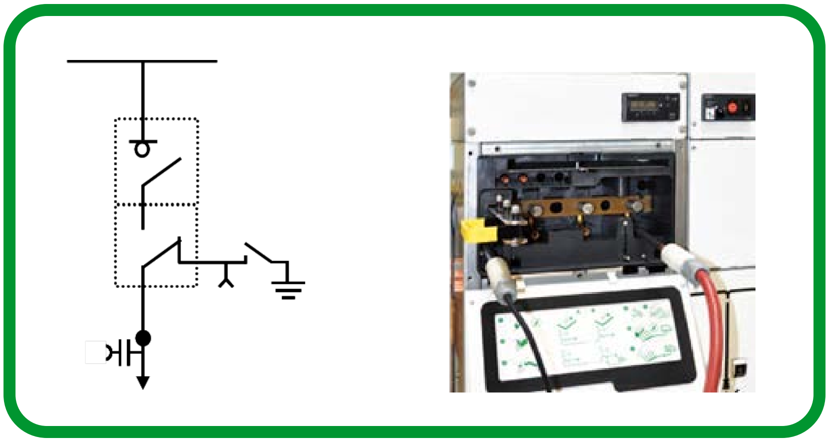
Figure 12
Mimic diagram of 3 position scheme using vacuum interrupter



This diagram also allows the use of a dedicated cable testing device, increasing the safety of people and switchgear. As it is well known that MV cables are generally much older than switchgear, they will need more and more testing and conditional replacement.

Prior to the cable test, opening the switch or CB disconnector and closing the earthing switch provides a double gap between cable and busbar. Then a safe and fully interlocked earth link switch may be opened to give direct access to the cable conductor. During testing, the cable box remains closed, the cable connections remain intact, and the main contacts of the earthing switch remain in the same position. This recommended test procedure ensures the highest safety for people doing the tests and also avoids any damage to the main circuit or cable connections.

Figure 13
Dedicated cable testing device



The new arrangement is able to withstand hash environments. This is ensured by a complete Shielded and Solid Insulated Switchgear (2SIS) solution. Busbars and a vacuum interrupter encapsulation, and earthing switch enclosure are made of solid insulation that is covered by a conductive layer connected to the earth. The equipment can withstand any kind of harsh environment as well as GIS RMUs can.

Compared with GIS RMUs, the 2SIS technology associated with this new three-position diagram arrangement offers much better modularity, as the general architecture is based on single units. Thus, it is easy to build switchboards for many kinds of applications requiring a large number of units.

While it is obvious that this modular 2SIS technology using vacuum breaking architecture has many advantages, it is necessary to analyse whether it is completely adapted to the Smart Grid deployment of today.

MV switchgear and Smart Grids

Smart Grids have two main objectives. One is to optimize the balance between the demand and supply of energy. The second is to integrate more distributed and renewable energies. Meeting these two objectives means deploying digital technology that allows for two-way communication, between the utility and its customers and between devices along the transmission and distribution network and the network operations center. However, much of today's electrical infrastructure — including switchgear — enables only the simple one-way flow of communication valid for centralized energy production. So, electric utilities face a big challenge at every link in the chain — including switchgear —to make the transition to Smart Grid-capable devices and configurations. From examining existing Smart Grid networks, it is possible to gain insight into how switchgear can meet this challenge and where the greatest opportunities for progress lie.

Smart Grids will include more CBs in the network

Adding circuit breakers (CBs) in distribution network loops is an efficient way to decrease the number of customers affected by an outage and to reduce the time it takes to restore power. The distribution network is generally operated in an open loop, allowing a backup solution in case of fault. Each MV/LV substation along the loop is historically equipped with manual switches. Both parts of the open loop rely only on one protection CB, located in the HV/MV substation. Increasingly substations have become remote-controlled, which has shortened the duration of power outages. Still, in case of a fault, all customers supplied by the faulty feeder are disconnected.

But in fact, the customers upstream of the fault could have been unaffected. Using several CBs in the loop instead of switches would disconnect only the customers along the faulty part, significantly reducing the number of affected customers.

From an ideal point of view, solutions including low cost CBs, low-cost sensors, no need to implement communications, no specific network architecture, and easy possible upgrades could reduce the outage at a cost-effective level. Today, adequate and economically viable answers to the needs of MV/LV substations do exist in both following areas:

- Deploy optimized integrated CBs for network applications, including LPCTs,
- Adapt existing protection systems by reducing the time discrimination interval or using logic discrimination in substations between incoming and outgoing feeders. With this reduction of the time interval, one or two protection stages could be introduced between the primary substation and the customer substations.

In a similar way, it is more efficient and precise to use CBs to protect MV/LV transformers, especially above 800 kVA. Traditionally, MV/LV transformers have been protected by switch-fuses because withdrawable CBs and relays were significantly more expensive. But today's reliable fixed vacuum CBs are now a financially viable option, so switchgear with an integrated fixed CB improve transformer protection at an equivalent lifetime cost, especially for commercial, industrial, and building applications.

An MV/LV transformer generally has a very low failure rate. All faults are starting interturn faults or earth-phase faults and are located inside the primary or secondary windings or on the LV zone. Fuses are not always able to break or have to wait until the fault has degenerated into a two- or three-phase fault of high magnitude to operate properly. Only CBs can quickly and surely detect faults at an early stage when they are of low magnitude.

Other advantages of the CB solution are:

- better discrimination with other MV and LV protection devices
- improved transformer protection performance for inrush current, overloads, low-magnitude phase-faults, and earth faults
- greater ability to withstand harsh environments
- reduced maintenance

The modular architecture of 2SIS, based on highly reliable vacuum interrupters, is very flexible and allows for an infinite number of combinations.

Remote control becomes essential

As mentioned above, Smart Grids depend on two-way communication all along the network. Switchgear with remote control and monitoring features are essential to such two-way communication. Feeder automation and self-healing networks are possible only if switchgear can be controlled remotely. Optimizing loads along the distribution network will also be possible using remote control to operate the switchgear and change the protection settings. To be prepared for Smart Grids, it is recommended to upgrade MV/LV substations by implementing remote-controllable MV switchgear whenever possible. When this upgrade is not possible, progressively replace old manual MV switchgear with modern switchgear.

Low-consumption sensors and digital meters enhance control and monitoring

Control and monitoring are increasingly important to properly manage the real-time connections to the grid. Consequently, more and more sensors are needed. The advent of digital technology for measurement and protection devices (e.g., digital meters, digital protection relays) has reduced the current transformer burden. Compact low-power current transformers (LPCTs) and low-power voltage transformers (LPVTs) can replace heavy traditional CTs and VTs. Today's low-power transformers offer innovative current sensors that allow greater degree of control and monitoring along the protection chain. Upgrading to modern solutions, including low-power sensors associated with digital devices, will be different for each situation. Implementing additional LPCTs around cables is generally easy, but replacing old ones may require further study of the structure of the switchgear. Implementing LPVTs is even trickier and may involve envisaging an extension of the switchboard with a metering panel. The remaining lifetime of the switchgear also has to be considered. The life expectancy of the medium voltage part and the electromechanical part are now 30 years or more, while the electronic devices' life expectancy is around 15 years. If possible, consider a move to modern control and protection schemes when the time has come to refurbish the equipment.

Having a real-time view of the available power is crucial in Smart Grid applications and will require installing more power meters associated with the sensors. A great advantage of 2SIS architecture is that it is now possible to have 2SIS LPCTs and LPVTs, making metering equipment insensitive to harsh environments.

Modularity is key

The variety of different switchboard sizes and configurations will only increase as renewable energies become more integrated and greater energy efficiencies are sought. MV switchgear will also become more distributed throughout the Smart Grid network. Modular switchgear meet the need for flexibility. Depending on the number of incomers and feeders and on the responsibility of different actors (utility or private consumer) in charge of operating some portions of the switchboard, there may be many different ways the order and arrangement of cubicles are specified or preferred. Cable access may be required from the front or side or rear.

The 2SIS system offers the greatest flexibility. As each part of the busbar and cable connection is 2SIS technology, there is no external influence of environmental conditions, no matter what the arrangement of the switchboard. As a result, many different cable entries are possible, and extension of a switchboard is very easy.

Conclusion

As Smart Grids develop, MV switchgear need to include more intelligence. New criteria should be applied when evaluating equipment: flexibility, ability to withstand harsh environments, compact size, optimization of remote control, ease of local operation, ease and simplicity of maintenance, life expectancy, ability to upgrade, and company service availability. While the physics of switchgear remain basically the same, the technology is changing as well as the way to optimize it.

There is a great confidence that the 2SIS modular architecture with vacuum interrupters is well suited for Smart Grids. This architecture can accommodate a large number of applications in secondary distribution but, thanks to its modularity, can also handle some low-end applications where, traditionally, primary equipment has been used. In this respect, this architecture is able to bridge the gap between secondary and primary specialized equipment.

About the author

Jean-Marc Biasse is a Senior Edison Expert at Schneider Electric's Medium Voltage Switchgear Strategy Department. He holds an Engineering degree from Ecole Centrale de Lille and a PhD from Institut National Polytechnique de Grenoble and has spent more than 25 years in R&D activities. He has published multiple articles at international conferences focused on Medium Voltage Switchgear.