



Medium voltage products

Technical Application Papers No. 18

Smart grids

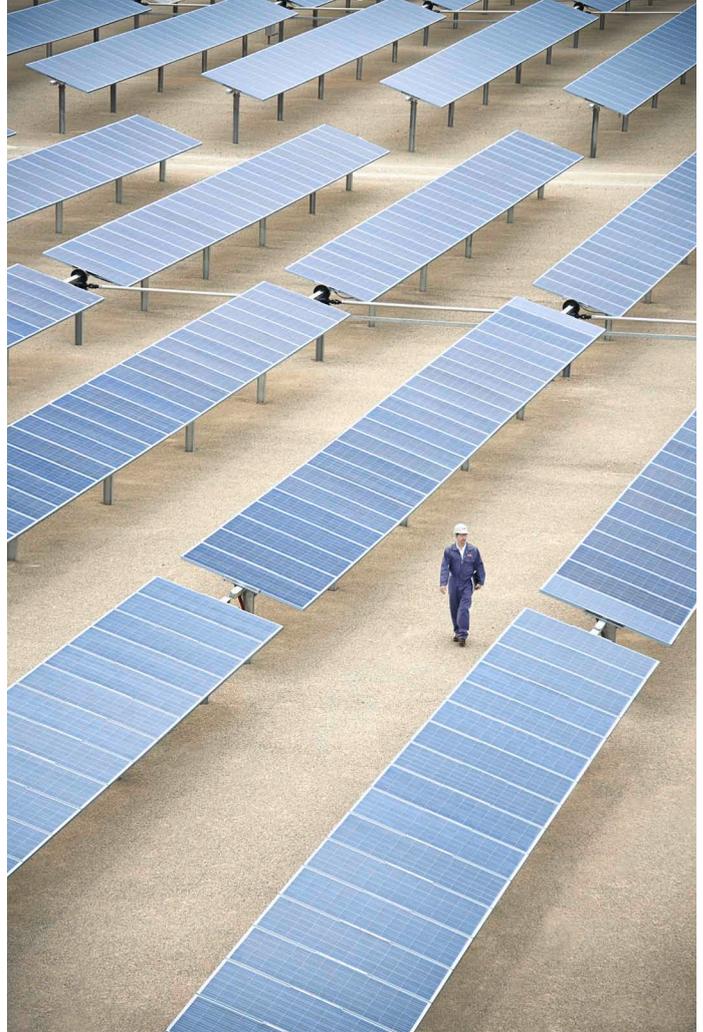
2. The “smart” secondary substation

Index

2	1.	Introduction to distribution automation
3	2.	Electricity distribution
4	3.	Secondary distribution substations
4	3.1	State-of-the-art
5	3.2	Secondary substation evolution: motives
8	3.3	Secondary substation evolution: new requirements
10	3.4.	The apparatus in secondary substations
12	4.	The ABB proposal for a “smart” secondary substation
12	4.1	Monitoring
12	4.2	Control
13	4.3	Measuring
13	4.4	Protection
14	5.	“Smart” substation components
14	5.1	Communication infrastructures
18	5.2	Communication devices: ABB gateway
20	5.3	Control devices
21	5.4	Control and protection device: REC615
22	5.5	Remote input/output and FPI unit: RIO600
24	5.6	Combined current and voltage sensors
25	5.7	Medium voltage switchgear: UniSec and Safering
26	5.8	MV/LV distribution transformer: Smart-R-Trafo
27	5.9	Low voltage components: Emax and Tmax
29	5.9	Low voltage measuring instruments
32	6	Conclusions

1. Introduction to distribution automation

Automating electricity distribution systems is becoming increasingly important as distributed energy sources are being more and more widely used. New requirements are coming to the fore as to the automation, monitoring, control and protection of secondary distribution substations. This technical guide is intended to illustrate the state-of-the-art, but also to help address the subject of distribution automation in a proactive and practical way.



2. Electricity distribution

When it comes to automation, the main goal is monitoring the state of the grid and transmission of measured quantities. This to upgrade the level of knowledge about the grid and its governability via the main electro-mechanical devices installed in the grid itself. To do this, it is necessary to know and use all the innovative technologies that are essential for smart grid development. After all, optimal management of distributed renewable power sources and emerging load demands, such as e-mobility, are the extremely challenging objectives.

Nowadays, the medium voltage (MV) and low voltage (LV) distribution grids already possess a high degree of automation, ensuring that they function in accordance with the stringent requirements dictated by the domestic and European regulations (limits to the number of interruptions and their duration and voltage values within established limits). However, these grids are not built to receive consistent injections of power generated by distributed sources. Obviously, development of the distribution grid is not the whole solution to the problem. What is also needed is a profound change in the relations between producers, public utility companies and users, thus “smart” management of the energy demand and offer, as well as localized dispatching systems at the level of micro-grids or rather small areas. Nevertheless, the most forceful initial intervention as to development concerns the MV and LV distribution network, especially secondary distribution substations, which are the strategic and structural nerve-centers of distribution itself.

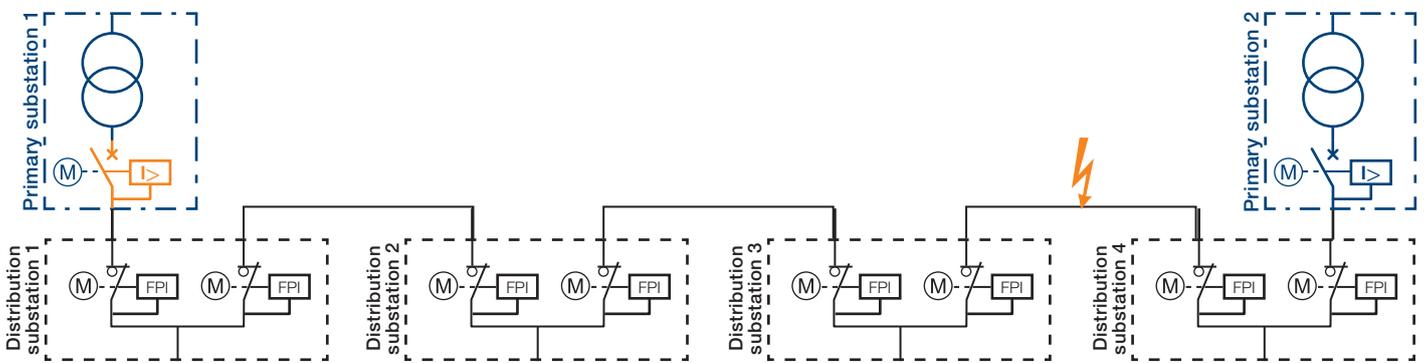


3. Secondary substations

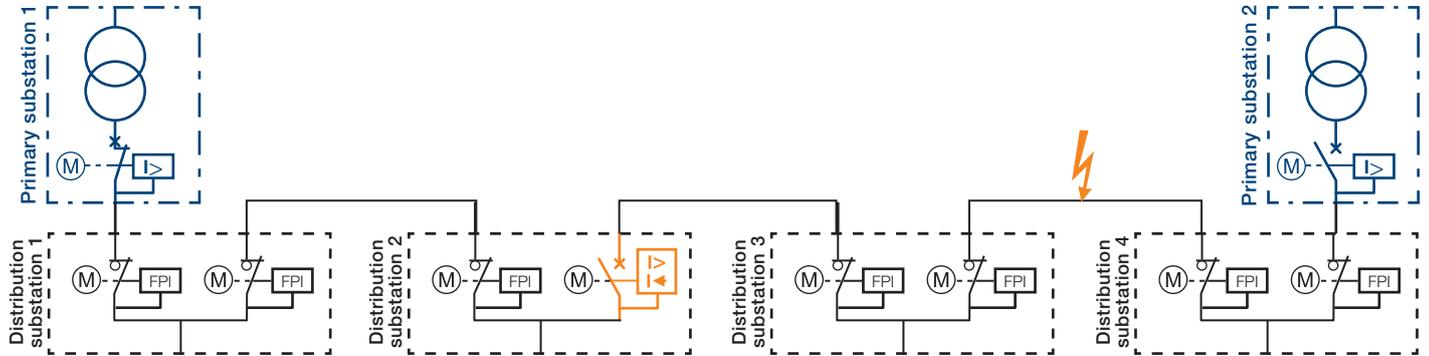
3.1 State-of-the-art

The system currently operating in the majority of grids includes a circuit-breaker in a Primary Substation coupled to a relay that detects overcurrents and provides protection. The MV line from that circuit-breaker connects to Secondary Substations for further MV and LV power distribution, and to delivery substations towards users connected directly to the MV line. The relays of the circuit-breakers in the primary substation are coordinated with fault detecting systems known as FPI (Fault Passage Indicator) installed along the line in the secondary substations. ENEL, the Italian Public Utility Company, began to use these systems in the '90's to meet the demand from industries for better quality power supply. As illustrated in the diagram below, to select the faulty line segment the medium voltage circuit-breaker in the primary substation interacts with the Remote Terminal Unit (RTU) in the secondary substations along the line, which use FPI signals and algorithms to find the position of the fault.

Protection is the task of the circuit-breakers and relative protection relays in the primary substation. These make the relative circuit-breaker open as soon as a fault occurs (the circuit-breaker in primary substation 1 in the example below). High short-circuit currents with an inductive power factor are normally involved, thus unable to be interrupted by switch-disconnectors (IMS) which must therefore operate with the line open. Thanks to fault current direction signals transmitted by the FPI, the faulty line segment is identified and isolated, while the opening command is sent to the switch-disconnectors in distributor substations 3 and 4. After this, the circuit-breaker in primary substation 2 is closed, thereby counter-supplying distributor substation 4. This operation obviously puts the entire line out of service until the circuit-breaker is closed again, after the fault has been eliminated. The limit of the algorithms used to identify the faulty line segment leads to outage lasting a few minutes. Operation of several substations in the same area is guaranteed by peripheral data terminal equipment in a control center.



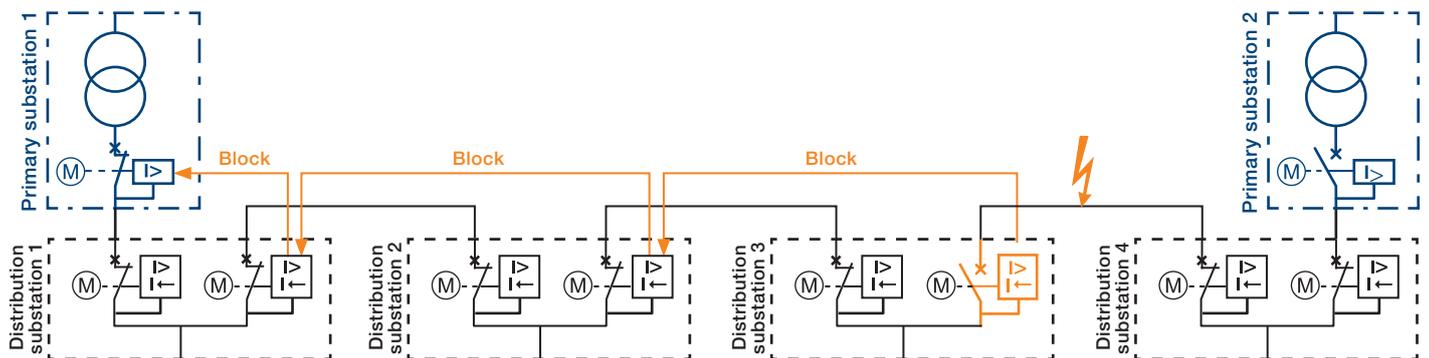
One of the first, fundamental steps towards the evolution of the distribution system was replacement of IMS in secondary substations (typically in a central position on the MV line) with a vacuum circuit-breaker able to interrupt the short-circuit currents and ensure substation independence as to fault extinction. This allowed new automation strategies to be implemented by disconnecting solely the strictly necessary users, i.e. only the ones directly affected by the fault, and by subjecting the others to minimum disservice. Thus the secondary substation with circuit-breaker became equipped with a protection device that provided functions like chronometric selectivity, voltage adjustment at the delivery point and metering.



In the example illustrated in the previous diagram, the line end fault is opened by the circuit-breaker equipped with a protection device known as recloser, installed in distributor substation 2 halfway along the line, in time-selectivity in relation to the circuit breaker of the primary substation 1. At this point, the faulty line segment identification and disconnection logic is the same as the previous example, i.e. obtained by means of the FPI and motor-operated IMS. Faults on the supply side of the master unit are also eliminated in the conventional way by the circuit-breaker in the primary substation. Outage is therefore less extensive, but still occurs.

3.2 Secondary substation evolution: motives

A further step towards power grid development lies in the use of smart devices (IED) able to dialogue with each other via advanced protocols, as defined by IEC 61850 for example. In the figure below, each IED on the supply side of the fault (in distribution substations 1, 2 and 3) transmits a block signal to the IED on the supply side, thereby blocking the tripping action for a certain time, while the IED that has not received the block signal (distribution substation 3) commands the opening action of its circuit-breaker in order to extinguish the fault.



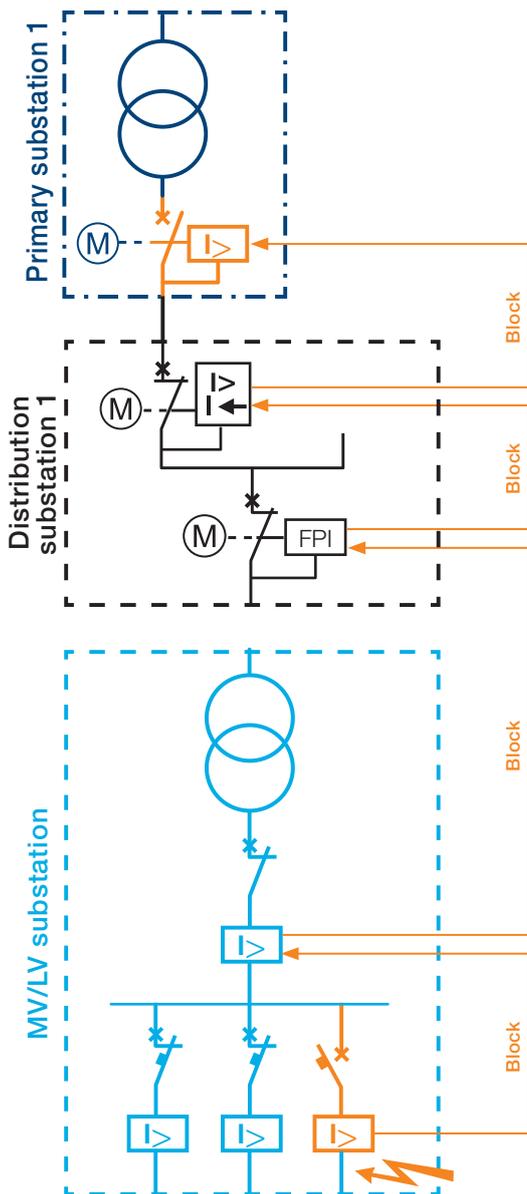
3. Secondary substations

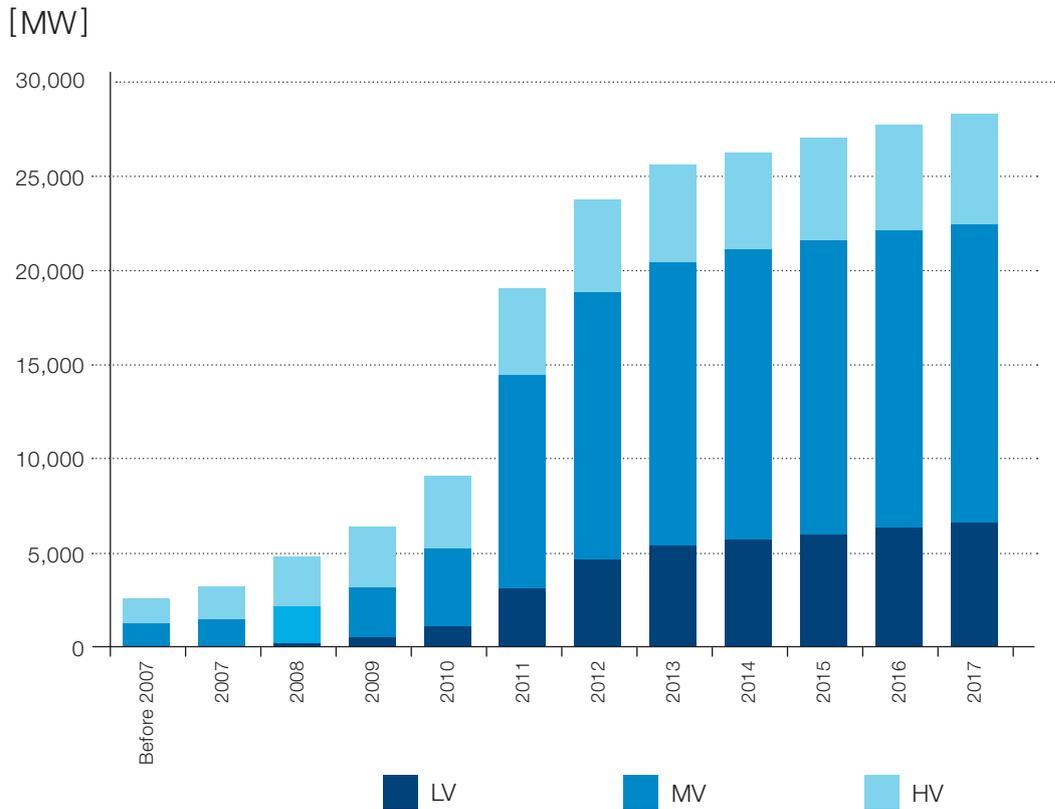
The same strategy can be applied by including the medium voltage or low voltage user installation. Generally speaking, there must always be an IED/circuit-breaker further down on the load side affected by a fault, able to transmit a block signal to the IED/circuit-breakers on the supply side while it interrupts the fault itself.

Obviously the IED must be rapidly reconfigurable so as to update the list of previous and successive devices in the chain. This type of automation effectively reduces inconvenience to the users connected to the MV line, to the minimum.

When it is not possible to interlock the IED in the primary substation, the aim is to isolate the fault within 200 ms in order to prevent time-selectivity operation of the circuit-breaker in the primary substation.

However, this is not sufficient, or it will no longer be sufficient in the near future. Distributed generation, result of important development, and the consequent need to integrate power generation from renewable sources, is undoubtedly the issue that Public Utility Companies will have to face and the one that will affect power grid configuration and technological development to the greatest extent.





Trend of envisaged producer connections to the Enel Distribuzione network: cumulative data. (Data source: Enel Distribuzione)

Nowadays, electric power generation increasingly involves small installations that need to be connected to the power grid near the actual users, either because this is logistically convenient or because they are owned by the users themselves (active consumers). This means that the distribution grid must be managed in a new way, since the power flows are no longer just one-way, from high voltage to low voltage, but in generalized directions from different points and voltage levels of the grid. New active modes for managing the grids in real time are required to control a system that is becoming increasingly complex. E-mobility is another innovation that is becoming widespread and is mainly affecting the LV network. One major car maker recently announced that soon, it will no longer manufacture vehicles

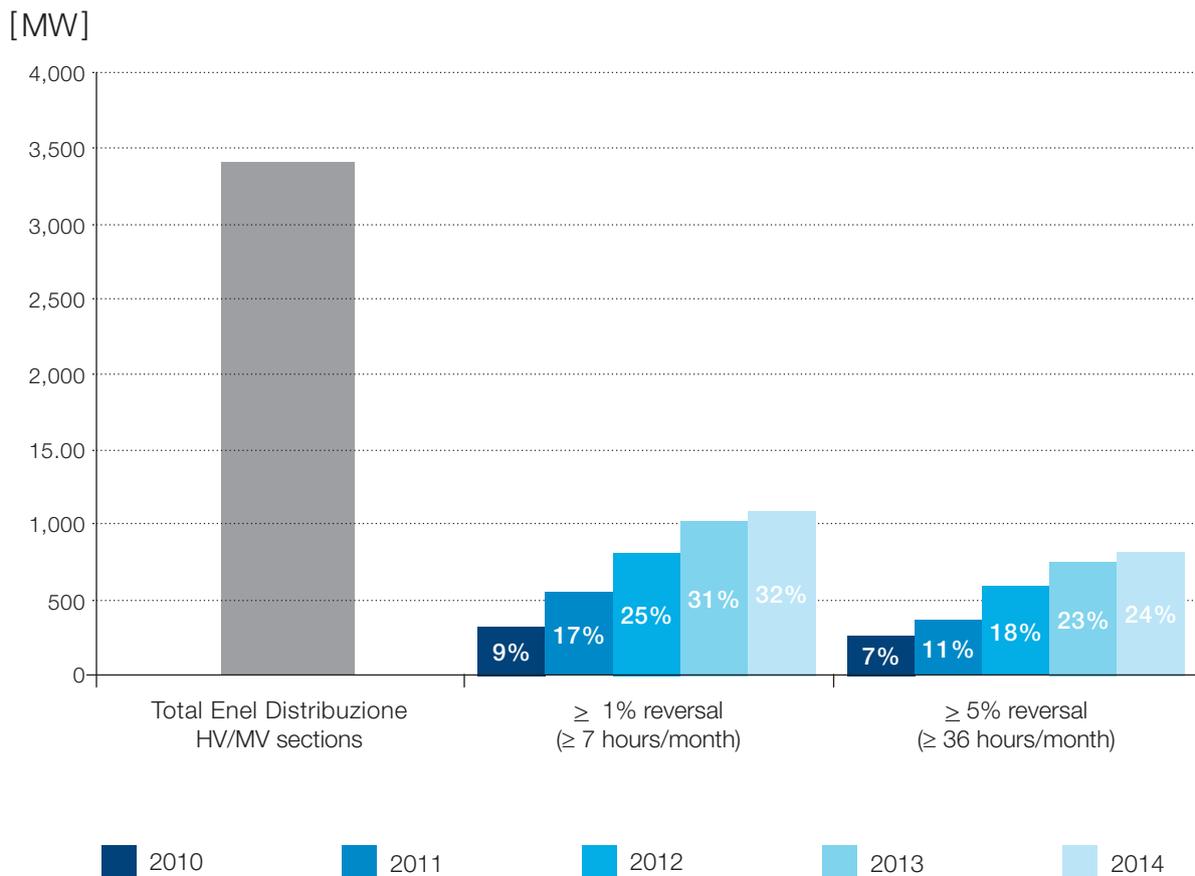
with just combustion engines as the future production will be solely dedicated to hybrid or all-electric cars. Sooner or later, all countries will have to provide public or private charging sources where users can obtain the necessary charging power. The distribution grids are clearly not sized for these sort of charges at the present time. Neither is the communication system ready for their integration into the general power management system. Lastly, one should not forget that smart grid strategies also include other, more interactive aspects involving the end consumers, such as the advanced remote reading system and demand/offering management. Thus the distribution grid and its secondary substations are of crucial importance with respect to smart grid goal achievement.

3. Secondary substations

3.3 Secondary substation evolution: new requirements

As mentioned previously, a large and increasing number of distributed electric power generating sources could lead to active power flows contrary to those that to date, have been

considered normal, i.e. from the MV grid to the HV grid. The data illustrated in the following figure were recorded in HV/MV transformers in primary substations, but evidently also apply to single MV lines from a secondary substation towards the primary substation.



Enel Distribution HV/MV sections where reverse power flow from the MV side towards the National Grid has been recorded.
(Data source: Enel Distribuzione)

In the case of Enel Distribuzione, the percentage of HV/MV sections operating in reverse flow conditions has increased from 7% in 2010 to 24% in 2014, when reverse flow time amounted to at least 36 hours per month.

This means that there is now an increased risk of “uncontrolled island” effects in the distribution grid, with consequent reclosing in “counter-phase” for which specific technical interventions must be provided. Protection devices able to operate with distribution grids that function in both the MV and LV modes must therefore be installed.

The first problem is that the circuit-breaker in the primary substation could reclose when the distribution grid is active: this could lead to out-of-phase closing that would be dangerous for the generators. In addition, the fault would still be supplied by the active generators regardless of the circuit-breaker in the primary substation having opened.

The circuit-breaker in the primary substation would therefore have to be “informed” that islands could be present so as to block reclosing while preventing undesired islands from forming by transmitting disconnect signals to the distributed generators in order to partially or completely reduce the local production. The same considerations apply to the LV grid.

The ability to limit active power from distributed generation systems via an external command from the Public Utility Company's remote control system is already envisaged by CEI 0-16. Among other things, the Standard also claims that since the current remote control system of distribution grids is based on GSM/GPRS technology, a communication system based on that technology must be implemented in all production installations with 100 kW power ratings or more for the purpose of ensuring that active consumers are integrated.. This communication system would be able to receive information (transmitted via GSM network) about the need to disconnect the generating installation.

The same Standard claims that when, in future, the Public Utility Company uses “always on” communication

networks (based on public or dedicated infrastructures), the communication systems in the active Consumers' installations will have to be upgraded and integrated as a consequence. The Standard also establishes that the disconnection modes can be planned (slow mode) or immediate (rapid mode). The first mode is intended for dealing with situations like overvoltage, insufficient regulating capacity of the Public Utility Company or congestion in the primary grid that could otherwise be impossible to resolve, while the second mode resolves rapidly evolving grid events (frequency checks and preventive actions to avoid the risk of grid instability). The first mode can be implemented via an automatic or manual procedure while the second mode can only be automatic. In short, the new requirements for secondary substations are, for example:

- real time exchanges of information with the MV and LV distribution grid (measurements, consumption, grid configuration);
- internal diagnostics for the substation, recording of events and their transmission to the control center;
- advanced automation that considers variable, and no longer fixed, settings. This requirement involves the use of circuit-breakers in all secondary substations, including the low voltage ones (by installing motor-operated circuit-breakers remote controlled by the MV substations);
- control, by the dispatching center, of the power produced by distributed generation;
- acquisition of information from the grid and LV users for the purpose of implementing a demand and offer management policy;
- integration of charging infrastructures for electric vehicles;
- exchanges of information with the the power storage systems;
- exchanges of information for the purpose of managing smart city services.

3. Secondary substations

3.4. The apparatus in secondary substations

The previous descriptions have shown that in order to implement the basic automation functions in the medium voltage line leading to the circuit-breaker in the primary substation, MV compartments equipped with circuit-breaker, current and voltage sensors, innovative protection systems and RTU (Remote Terminal Units) must be installed in the secondary substations. In addition, to integrate the distributed generation sources, secondary substations must be equipped with remote control technologies so that they can be disconnected from the grid and for monitoring and adjusting the generators, and with systems for managing the LV grid. The schematic diagram below illustrates the components required for disconnecting active consumers by remote control, as suggested by Standard CEI 0-16. The GSM/GPRS modem with SIM CARD inserted would be installed in the user's system and would have to guarantee reliable communication.

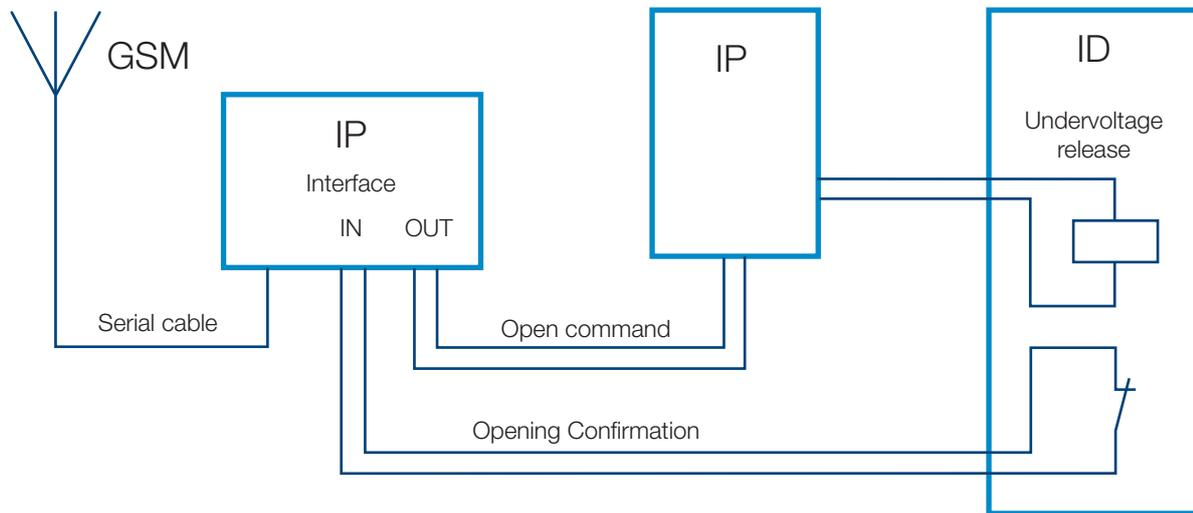
If the parameters of the Public Utility Company's grid are beyond the preset limits, the IP:

- opens the ID and, if necessary, activates the logic that leads to opening of the backup device (BD);
- inhibits input in parallel of the generating units.

The purposes of IP are to:

- allow any faults in the Public Utility Company's local grid to be de-energized;
- prevent the formation of undesired islands in the Public Utility Company's grid;
- prevent reclosing of devices in the Public Utility Company's grid or in the transmission network from damaging people or apparatus.

Able to receive signals from the Public Utility Company, the IP also includes a remote tripping function activated by a command from the Public Utility Company itself. When it comes to the protection system, the present goal is to be able to select trip times and thresholds for the frequency/voltage relays on the basis of local faults and system perturbation with transient frequency variation.



Interface Protection (IP) means the group of protections used for monitoring the frequency and voltage parameters of the Public Utility Company's grid. IP is required in the case of producer installations that operate in parallel with the distribution grid and acts on the Interface Device (ID) via positive logic relays (i.e. energized by grid parameters within preset limits and in the presence of auxiliary voltage).

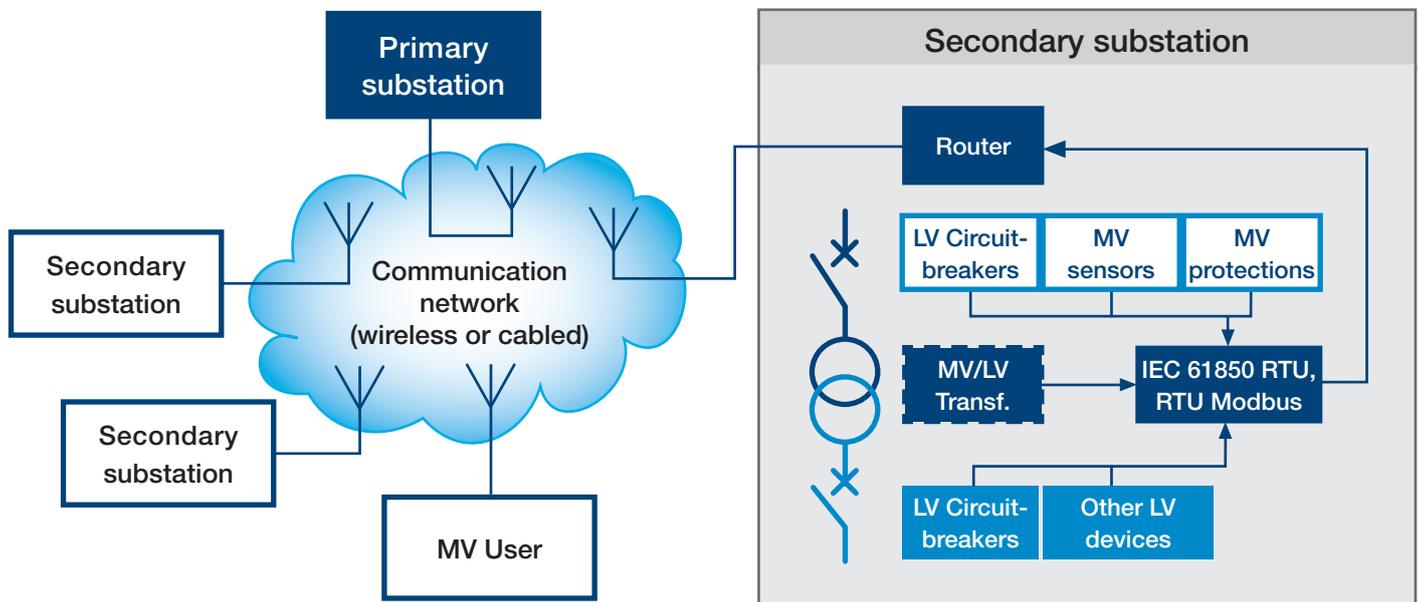
When there is a communication system, the problem is definitively resolved by sending a remote tripping signal. In future, secondary substations must monitor, manage and communicate with all components of the MV and LV distribution grid and with the local or central dispatching system.

To achieve this, the following innovative components must be installed in secondary substations:

- Remote Terminal Unit (RTU) in the IP network in order to supervise and control all the substation components, thereby achieving advanced automation by coordinating and monitoring the protection apparatuses. In addition, it will perform diagnostic functions, chronological acquisition of states and alarms, and will monitor the parameters of the underlying grid components;
- MV compartments equipped with circuit-breakers: to ensure the line opens if faults occur and create logic selectivity along the line. They can be equipped with two groups of three non-conventional sensors, one on the line side and the other on the busbar side, for the purpose of detecting MV fault conditions and undertaking actions in the LV grid.
- innovative Protection systems: these will perform the logic selectivity function along the line as well as allowing several grid settings to be managed by exchanging signals

according to the IEC 61850 protocol and via logic selectivity with the user installation;

- motor-operated LV circuit-breakers: these will be used for automatic reclosing operations and will be equipped with a line-side sensor so as to prevent reclosing in the presence of voltage on the load side;
- user interface: in substations with MV users. It will provide measurements in the interchange point;
- new generation LV meter data concentrators: so as to acquire data from the meters installed in the underlying LV distribution grid and exchange information in real time for the purpose of implementing “demand response” strategies;
- Communication routers, modem/radio/antennas: act as an interface for the purpose of managing all the texts and information to and from the secondary substation and to and from the primary substation routers.

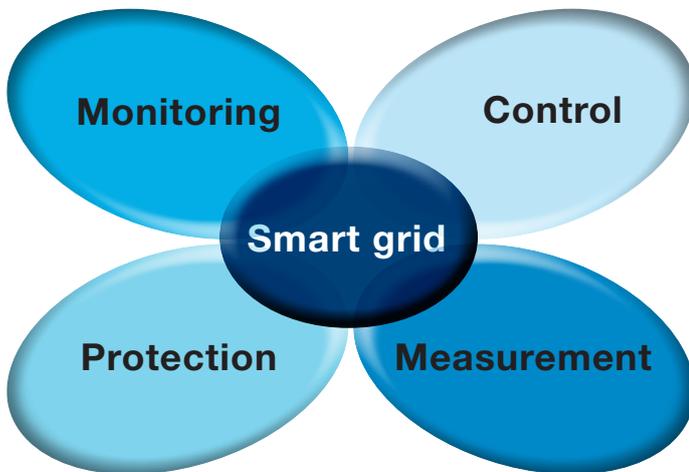


4. The ABB proposal for a “smart” secondary substation

ABB proposes different technical solutions, depending on the complexity of the grid and the different requirements involved.

From a functional aspect, besides basic functions such as breaking,  switching/disconnection of the electrical circuit  and communication,  there are four different functional levels, namely:

1. Monitoring 
2. Control 
3. Measurement 
4. Protection 



Increasingly complete solutions can be created starting with monitoring and control, with the addition of measurement and lastly, by including protection and selectivity. This allows the solutions to comply with increasing levels of automation until reaching the level of advanced power distribution package.

4.1 Monitoring



When it comes to monitoring  for the purpose of acquiring the states of LV and MV apparatuses, this function aims to increase the availability of substation components so as to reduce fault times, monitor grid topology and use manpower more efficiently by:

- reading the state of the MV switchgear and controlgear;
- reading the MV fault indications;
- reading the state and measurements of the LV network;
- monitoring the conditions of the substation.

4.2 Control



Controllo  with automation functions for fault isolation purposes. The purpose of this function is to minimize the time the grid remains out of service and increase grid efficiency by:

- remote localization and disconnection of the faulty segment;
- remote control of circuit-breakers and switch-disconnectors.

4.3. Measurement

Measurement  for the purpose of managing power flows. This function aims to deal with power flow reversal, monitor voltage measurement so as to guarantee stability and minimize losses even in the presence of intermittent distributed generation. This can be achieved by:

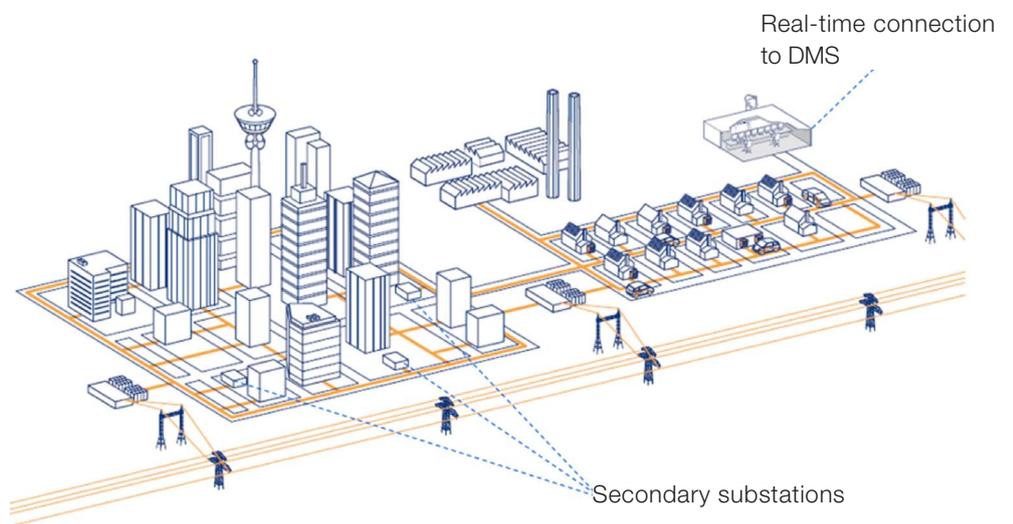
- high precision reading of MV measurements;
- monitoring and controlling the MV and LV switchgear and controlgear.



4.4. Protection

Grid protection  and selectivity. The purpose of this function is to guarantee the highest level of MV grid availability (and also of the LV grid in the event of faults). To do this, it is necessary to:

- adopt advanced protections with the IEC 61850 protocol as long-term solution in accordance with the global standards;
- use logic selectivity by means of GOOSE (Generic Object Oriented System Event).



5. “Smart” substation components

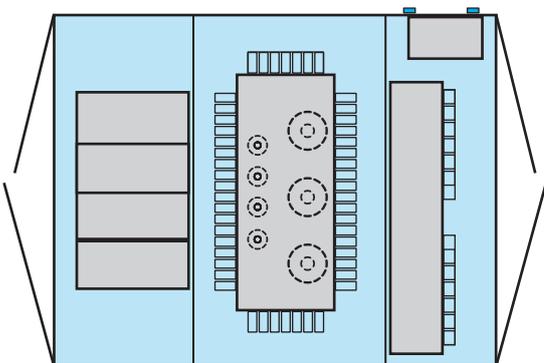
The secondary substation is one of the fundamental parts of a smart grid.



The secondary substation normally contains the following apparatus:

- medium voltage switchgear;
- transformer;
- low voltage switchgear;
- communication and control apparatus.

A “smart” secondary substation differs from a normal one since the apparatus it contains is also “smart”. When functionality is at its maximum, this apparatus will include:



- medium voltage switchgear featuring circuit-breakers with IED able to provide protection and automation logic, and receive commands from a control center;
- MV/LV transformer with automatic on-load switch;
- low voltage switchgear featuring circuit-breakers with electronic relays for state and measurement acquisition;
- system for communicating with the control center.

5.1 Communication infrastructures

A wide range of communication technologies able to support smart grid applications is now available. This range includes products based on cable networks and wireless networks, or on both solutions. A single solution for data transmission in a smart grid is unfortunately impossible. This means that interoperability among different technologies is a key requirement. In actual fact, the devices use different means of communication and must communicate with each other even though they are produced by different manufacturers. This is why the relevant Technical standards, e.g. IEC 61850, play a key role.

Communication performance, security and interoperability are the main requirements to consider.

The bandwidth provided by the communications operator must be scalable and able to support thousands (or millions) of data points in a Public Utility Company's system. The problem of security, or cyber security, in strategic infrastructures is also an important and priority issue.

Lastly, as already mentioned, interoperability and standardization are essential criteria when it comes to cost cutting and protecting investments in any Public Utility Company.

Only communication systems able to satisfy the above criteria can be considered as viable alternatives for major applications such as distribution automation.

The following proposals are among the main communication technologies currently available on the market.

Cable communication networks belonging to Public Utility Companies

When laying power cables, a Public Utility Company can also add a duct for its communication cables. These cables can be made of copper and be able to carry modem signals of the low speed telephone type or broadband signals of the digital type (DSL). A further alternative is to lay fiber-optic cables able to support Ethernet and develop a metropolitan broadband network (MAN) with a high speed data transfer rate of several Gb/s.

Radio systems controlled by Public Utility Companies

These systems are installed and controlled directly by Public Utility Companies at modest transmission rates (kb/s) but with a wide range of action, generally around 30 km.

The transmission frequencies usually use license-free bands (e.g. 900 MHz in North America) or licensed bands (e.g. VHF 150 MHz or UHF 400 MHz in Europe). Different solutions have been developed, depending on the performance required by the specific application (e.g. telereading or automation).

Systems for data reading via public cellular network

CDMA and GSM/GPRS are firmly established, widespread examples of these types of network. More modern, fourth generation systems such as WiMax and LTE (Long Term Evolution) for UMTS have recently been introduced.

These systems have been optimized for public use as to coverage and traffic load so they must be checked to make sure that their performance is sufficient to guarantee the requirements involved.

Satellite communication

As in the previous case, this type of communication is managed by third parties. Both low and high speed systems are available, more expensive in this latter cases owing to the satellite dishes used. Both shared and dedicated services are available. Dedicated services are normally used for distribution automation purposes.

Communication via transmission and distribution lines (PLC, DLC)

The actual electric lines are an obvious communications medium for Public Utility Companies. Use of HVPLC technology has been established for some time in HV transmission grids, while in low voltage networks it is now widely used for telereading and to provide further services for the customers.

The ABB proposal

In the case of systems for transmitting data via the public network, the Public Utility Company must clearly bear in mind that the service must be purchased from a third party, and incur the recurrent costs established by the contract with the service provider.

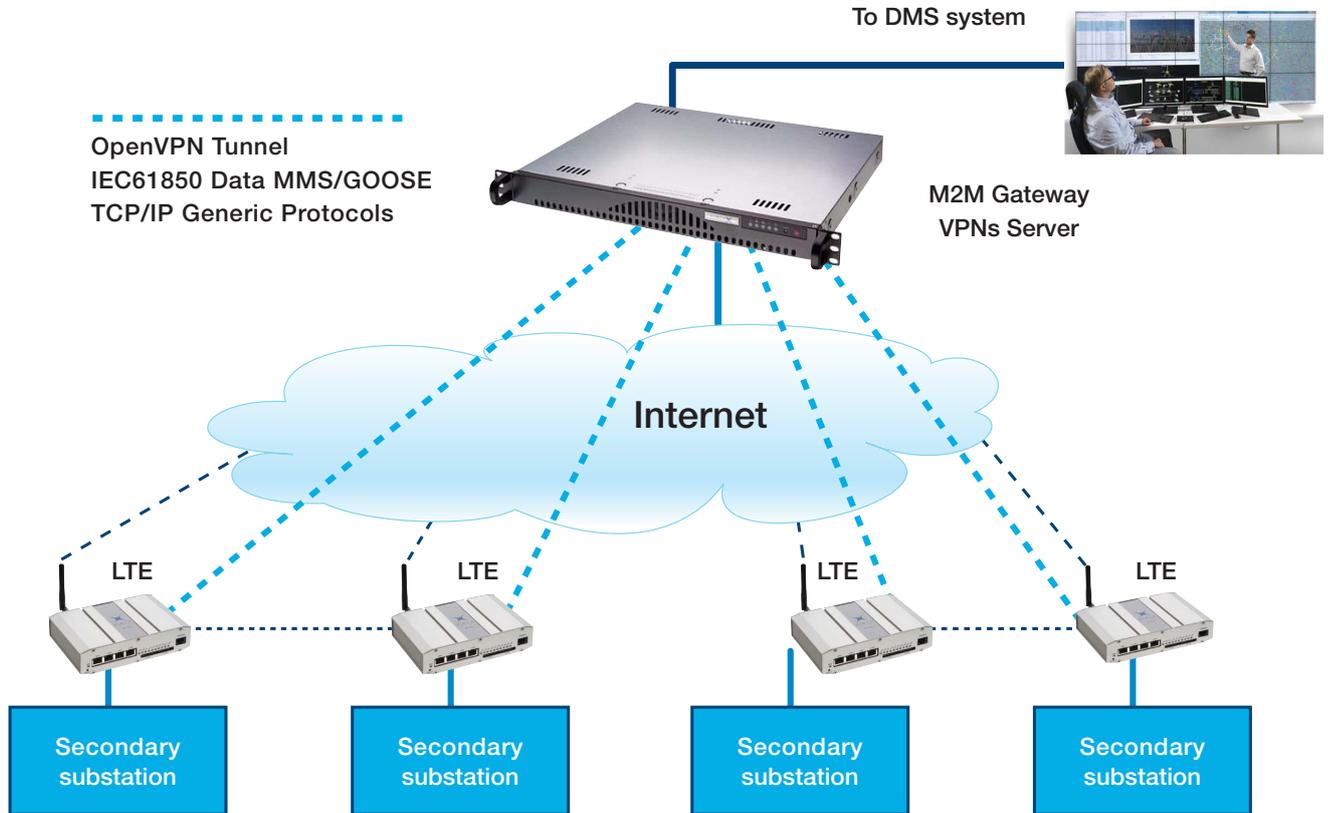
However, the numerous advantages include:

- rapid implementation: no need to install networks or apply for licenses;
- low investments, solely in communication devices;
- low maintenance costs;
- compliance with requirements thanks to multidirectional connection with multinational coverage;
- broadly available network in conjunction with use of communication devices supplied to Public Utility Companies by qualified providers;
- data security thanks to multiple encryption and access levels.

Communication systems for smart grids are therefore complex and use different technologies. ABB can assist Public Utility Companies by offering long-term, scalable solutions that are also able to meet future requirements.

The proposed communication architecture involves connection to a public cellular network with LTE, a technology with very low latency, suitable for application to the protections in the distribution system, between the Arctic communication devices of the secondary substation and the M2M gateway with VPNs Server function. Communication takes place in a secure way via Open VPN channels, which allow GOOSE and Data MMS services to be used, in accordance with IEC 61850 standards. The M2M gateway resides with the Public Utility Company and communicates with the DMS system.

5. “Smart” substation components

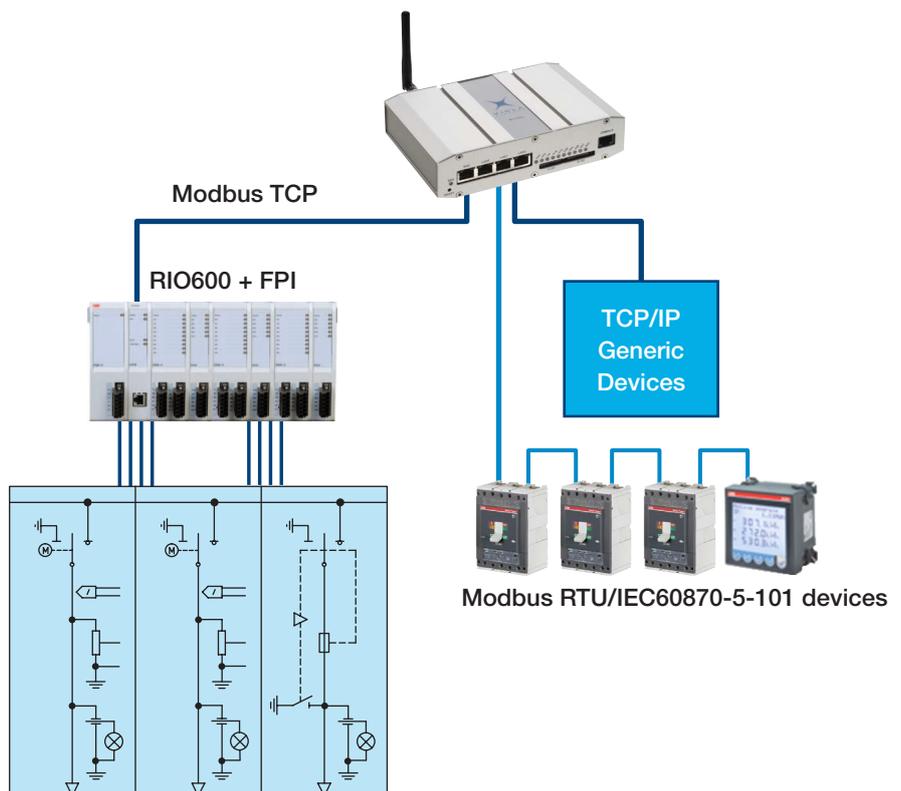


There can be more than one solution inside the secondary substation.

If solely monitoring and control are involved, the most suitable solution is the following:

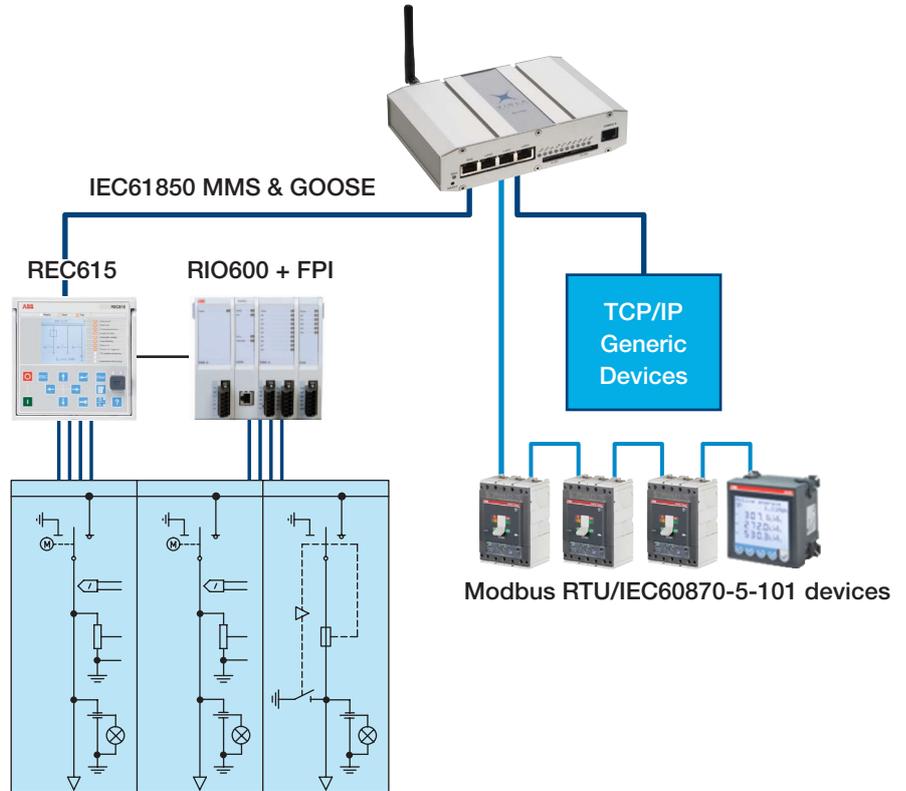
the Arctic P substation communication device allows connection to low voltage and generic TCP/IP devices via conversion protocol Modbus ASCII/RTU and Modbus TCP.

The RIO600 I/O unit allows the UniSec medium voltage switchgear equipped with switch-disconnectors to be monitored and controlled, and is connected to the communication device via Modbus TCP.

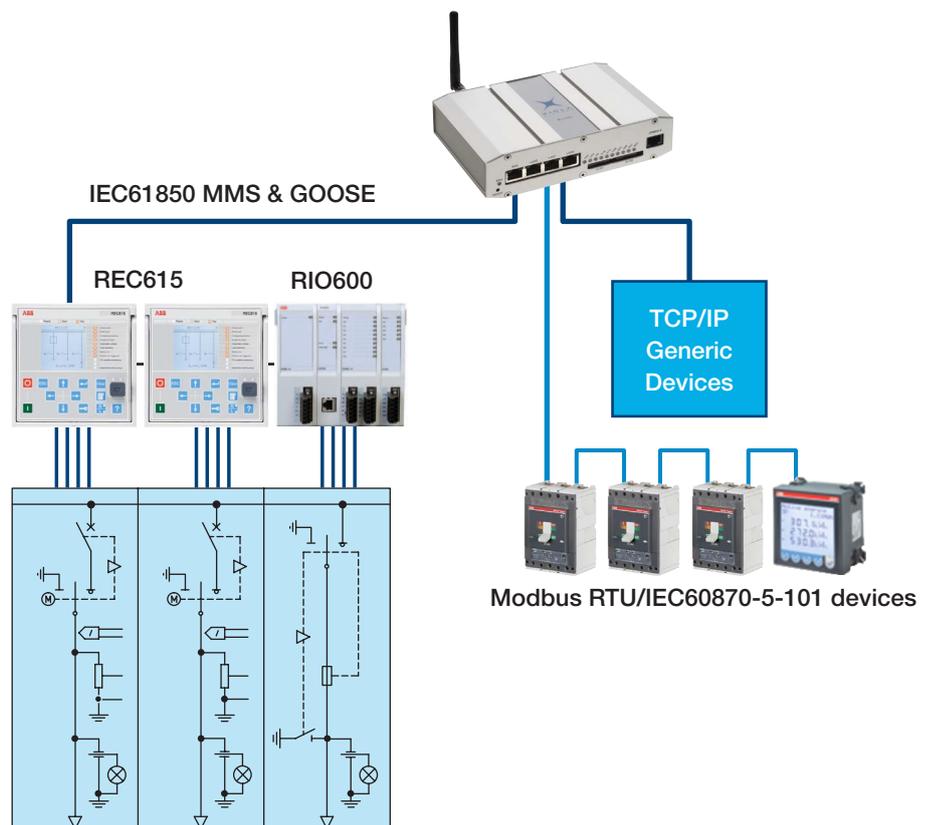


The second solution, which is illustrated in the next figure, supports the measuring function and a first level of automation since it can implement fault elimination logic. The fundamental unit for this purpose is REC615, which can be used in conjunction with the RIO600 I/O unit if the inputs and outputs in REC615 are not sufficient to control the UniSec medium voltage switchgear, again equipped with switch-disconnectors.

The GOOSE services of IEC 61850 are available in REC615 and can be exchanged with other secondary substations and with the control center via the Arctic unit.



The third and most complete solution involves medium voltage use of UniSec switchgear equipped with circuit-breakers. Each circuit-breaker is associated with an REC615 device and, if further signals are acquired, with an RIO600 unit. The full protection function can be implemented in this case. Here again, the GOOSE and MMS services of IEC 61850 are available in the REC615 and can be exchanged via the Arctic unit with other secondary substations by implementing even complex automation logic with the typical trip times and options of circuit-breakers.



5. “Smart” substation components

5.2 Communication devices: Arctic Gateway



The ABB Arctic and M2M gateways are the devices proposed for the communication on public network. The former are available in three versions with increasingly comprehensive functions.

Specifically:



ARG600 Wireless Gateway

ARG600 provides complete communication solutions so as to integrate devices equipped with serial ports or Ethernet with the central control system via GPRS, 3G or LTE connection.



ARP600 Wireless Protocol Gateway

ARP600 provides the functions of the previous version but can also connect and convert various industrial protocols. Thanks to this function, devices with the IEC-101 or Modbus RTU protocol can be connected to centralized control systems via TCP/IP modems with IEC-104 or Modbus TCP.



ARR600 Wireless I/O Gateway

ARR600 provides the functions of the ARP version with the addition of an integrated System of inputs/outputs. This RTU function improves the way field devices are connected while enabling the devices and main value variations to be monitored and controlled.

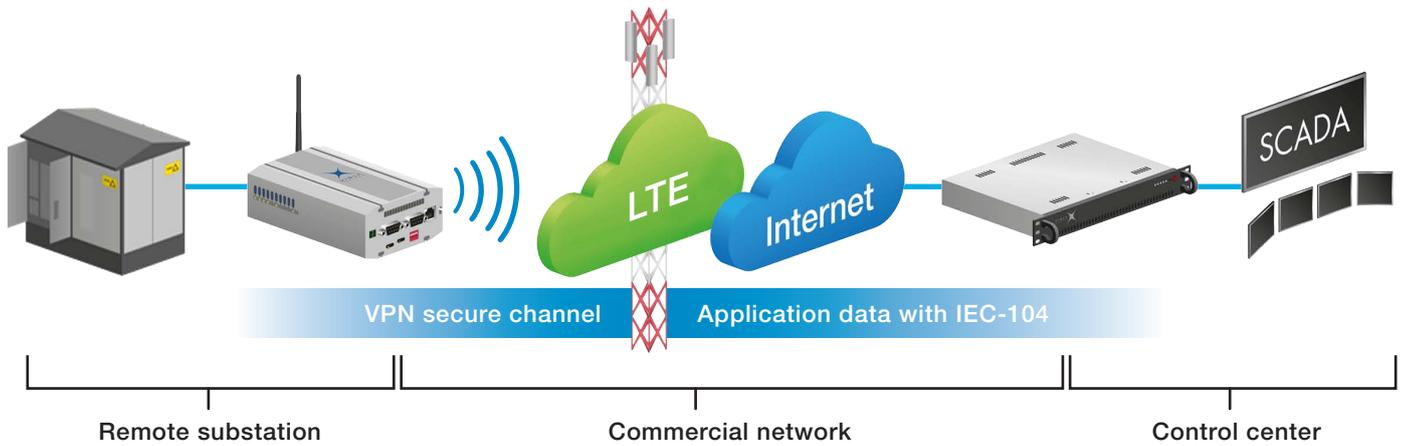
Arctic Gateway – versions ARG600, ARP600, ARR600

Characteristics	ARG	ARP	ARR
Ethernet, GPRS, 3G, LTE	x	x	x
TCP/IP router	x	x	x
Serial Gateway (on TCP/IP)	x	x	x
DNP3 on TCP/IP	x	x	x
IEC-101 protocol conversion to IEC-104	-	x	x
Modbus ASCII/RTU protocol conversion to Modbus TCP	-	x	x
RTU functionality – integrated I/O function support	-	-	x



ARM600 M2M - Gateway

The ARM600 M2M gateway is a high quality industrial server with preinstalled software for secure communication between the control center and remote locations, such as secondary substations outfitted with Arctic devices. This allows Ethernet to be extended to a wireless network (LTE/3G/EDGE/GPRS) and to thus integrate remote installations as though they were part of the local network. Using the commercial network, any distance can be covered in the most secure way since M2M provides a secure two-way communication channel (VPN and static IP addresses).



Here are the key features of M2M:

- it's an industrial-grade gateway for interfacing with Arctic series products;
- it allows an Ethernet network to be expanded over wireless (LTE/3G/EDGE/GPRS) networks;
- it offers mobile operator-independent static IP addressing;
- it's easy to install and configure;
- it provides secure communication via Firewall and VPN with level 2 bridge for GOOSE services;
- it has a pre-installed software application for remote monitoring of devices;
- it has two 10/100 Base-T Ethernet ports.

Lastly, the ARM600 M2M gateway comes with a pre-installed centralized communication network management application called Patrol, which monitors the connection status of remote devices and provides an alarm in real time if the connections are faulty. This application can receive critical information from dozens of remote devices and rapidly update even large grids. It also allows the grid to be efficiently serviced and monitors all the devices connected through a web browser.

5. “Smart” substation components

5.3 Control devices



The device proposed is ARC600 of the Arctic series for wireless remote monitoring of apparatuses in secondary substations.

This solution allows up to 3 devices in a secondary substation (such as disconnectors, switch-disconnectors or ring main units) to be monitored and controlled at convenient costs. The unit also provides communication functions, such as:

- protocol conversion from IEC 60870-5-101 to IEC 60870-5-104;
- a 10/100Mbit/s Ethernet connection for LAN applications;
- two-way communication based on GPRS/3G/LTE.

Other, accessory functions are also available and include battery monitoring and recharging.

Additional functions available and integrated include:

- measurement of the operating time and power required by the disconnectors or switch-disconnectors, as well as their local or remote control;
- all the inputs and outputs required for managing the operations as well as for controlling the LV circuit-breakers and transformer;
- easy configuration in the local or remote modes.

A further option is offered by the control devices in the RTU family, which includes four product lines: RTU511, RTU520, RTU540 and RTU560. The first three are particularly suitable for use in secondary distribution substations.

The products comprise a basic RTU unit plus additional modules with a large number of analog and digital inputs and outputs that allow the final product to be configured as required by the customer's.

Specifically:

- RTU560 is supplied in a rack with modular platform. On request, our redundancy concepts provide high availability where needed. The typical area of application is HV transmission and in primary substations, in view of its ease of extension and potential;
- RTU540 comes in a metal housing that can be mounted in DIN rail and is extremely compact. This makes it ideal for applications where the available space is limited, i.e. in primary substations but also in secondary ones;
- RTU520 is very simple to configure and is perfect for user and process automation or for secondary substations;
- RTU511 is supplied in a modular enclosure that can be mounted on DIN rail. Extremely compact and economical, it is used in certain simple applications in secondary substations, mainly for feeder automation.



5.4 Control and protection device: REC615

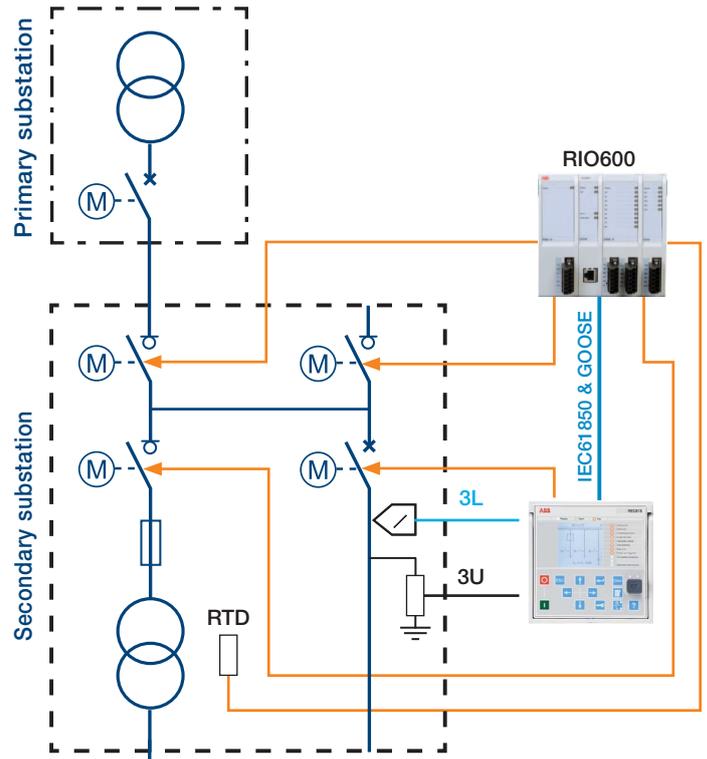
REC615 is an extremely flexible unit expressly designed for protection, monitoring, measuring and supervision in secondary substations.



REC615 supports a variety of protocols for remote communication, such as IEC 60870-5-104, IEC 60870-5-101, Modbus® and DNP3. It also provides standard IEC 61850 natively and supports GOOSE messages. Lastly, it allows a redundant network to be created thanks to a second communication port.

When it comes to protection functions, the device can be configured to suit the customer's requirements. The selection of protection functions depends on the application, on whether the network is the compensated neutral type or not, if the network is managed on a closed-loop basis and on the presence of distributed generation. In its standard version, REC615 includes the non-directional overcurrent function, negative sequence overcurrent protection, thermal overload protection for feeders, cables and distribution transformers, voltage and frequency protection. Optional functions include advanced methods for detecting earth faults in various types of distribution networks. An algorithm can detect intermittent and transient faults so as to localize possible future problem points in the network. One of the standard configurations also includes the Synchrocheck function, which is especially useful if active users are connected.

The unit is able to control up to 5 disconnectors and 1 circuit-breaker, but can be extended with RIO600 units. These devices are controlled via the front panel HMI or a remote system.



The combination of motor-operated switch-disconnectors and measurement of current and voltage by sensors in the circuit-breaker unit illustrated in the figure above, allows selective feeder protection thanks to directional earth fault and overcurrent protection and the auto-reclosing function. In addition, the device offers a graphical local HMI, energy measurement in all four quadrants and a power quality monitoring function.

In the version dedicated to sensors, REC615 can receive three resistive or capacitive voltage sensors, three current sensors and the signal from a toroidal CT for residual current measurement.

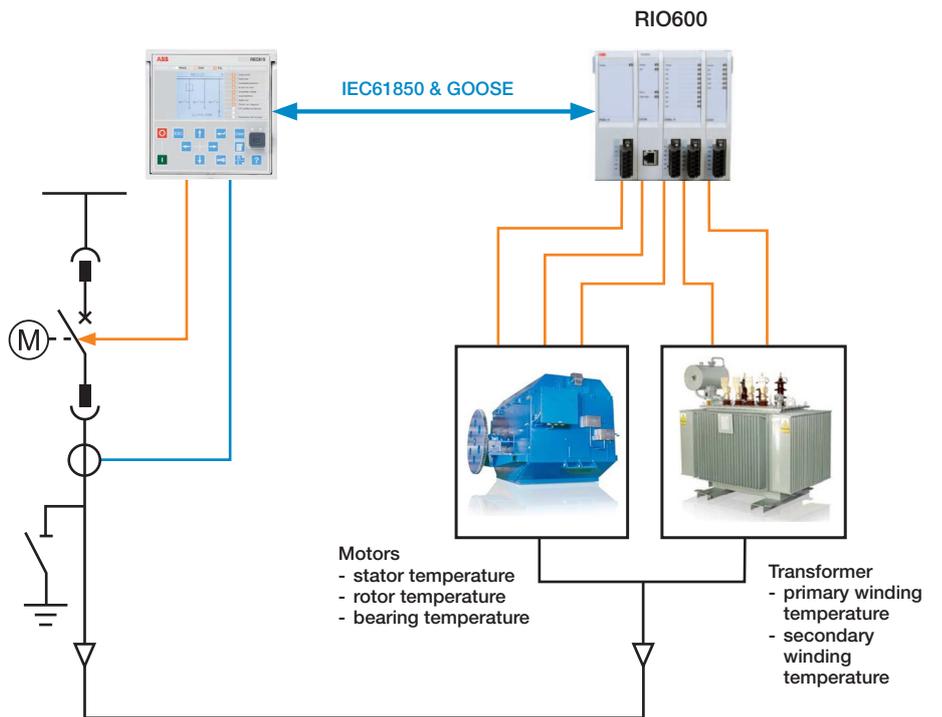
5. “Smart” substation components

5.5 Remote input/output and FPI unit: RIO600

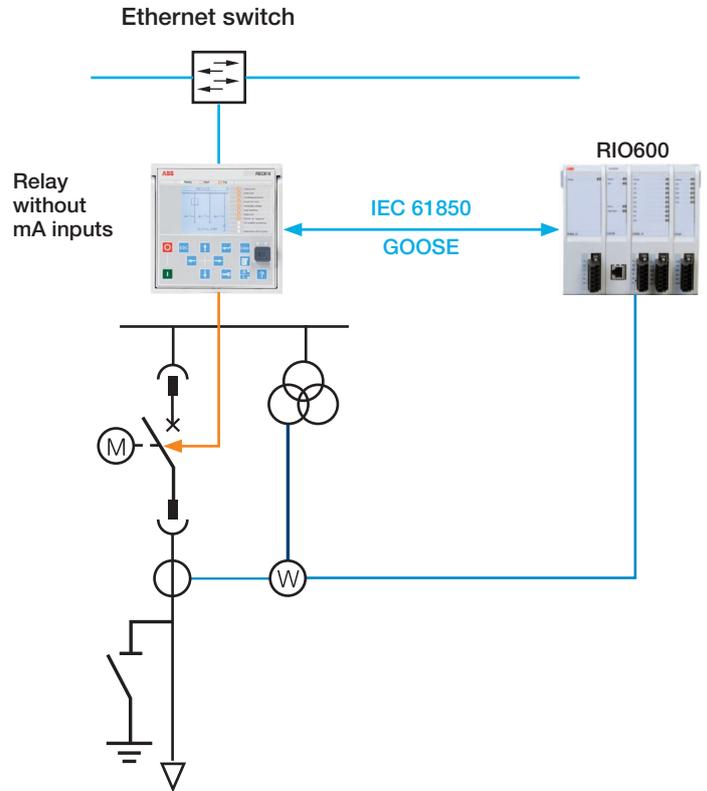


RIO600 units are modular analog and digital input/output units designed to expand the control capacity of REC 615. RIO600 allows combined current/voltage sensors to be connected and analog measurements to be received for the purpose of improving the way all the apparatuses in secondary substations are monitored and controlled.

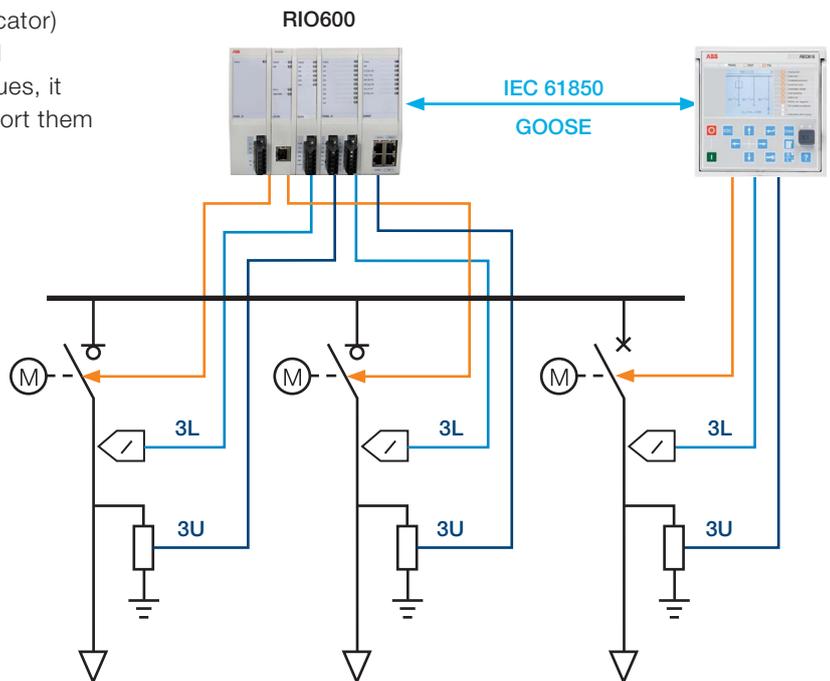
Via an Ethernet connection, RIO600 allows additional modules to be installed in the substation so that information can be acquired and transmitted to, for example, REC 615 using IEC 61850 GOOSE communication.



The modules can be used both for applications concerning medium and low voltage switchgear devices (disconnectors, circuit-breakers, etc.) and, via the analog inputs, for different monitoring applications such as temperature control of certain components and transformer on-load tap changer monitoring. Lastly, via the analog outputs, they can interface with any device equipped with inputs of this type. RIO600 includes a measuring module able to directly interface with ABB measuring signals and to send these values via GOOSE messages to the protection and monitoring devices. The module can also monitor power flows and power quality. The typical accuracy for voltage, current and active power measurements is at least 0.5% and at least 1% for other power measurements.



RIO600 can also perform the FPI (Fault Passage Indicator) function. This module is designed for distribution grid automation applications. Based on the measured values, it can give directional fault passage indications and report them to a superior protection system.



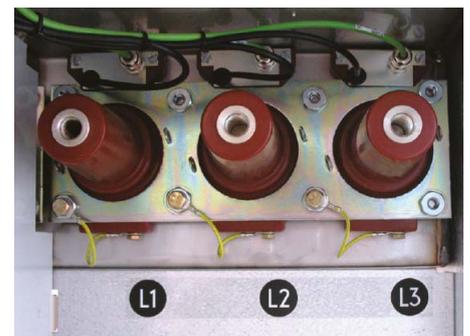
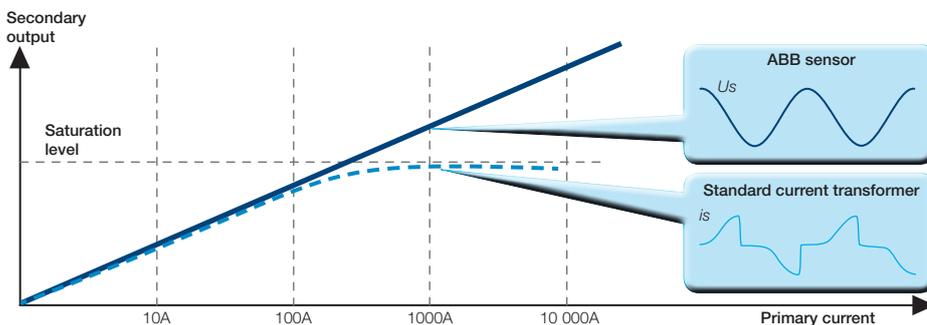
5. “Smart” substation components

5.6 Combined current and voltage sensors



Electronic instrument transformers, also called sensors, offer an alternative way of taking voltage and current measurements with respect to conventional inductive transformers. Due to the absence of a ferromagnetic core, current sensors provide numerous benefits for both the user and application. The main advantage is that the sensor overcomes the problem of a non-linear response due to the hysteresis cycle of the core. This allows it to provide a highly accurate and linear response over the entire operating range. Measuring and protection classes can therefore be combined. Electronic relays (such as REC 615) are now designed for use with these sensors and since they provide both measuring and protection functions, they are perfect with the modern combi sensors.

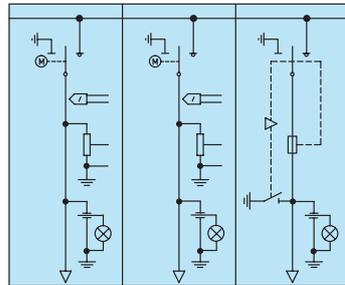
When it comes to accuracy, the previous considerations concerning current sensors also apply to combi sensors. Measuring class 0.5 is reached in the current measurement accuracy range between 5% of the rated primary current up to the rated continuous thermal current. In the case of measurement for protection, the sensor maintains class 5P up to short-time withstand current I_{th} (thus with 5P630 accuracy class).



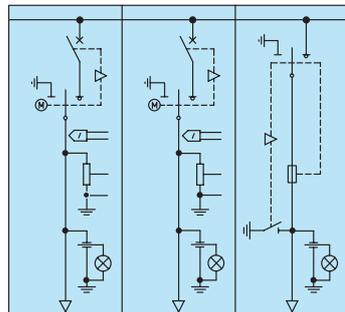
With current sensors, measuring class 0.5 is reached in the accuracy range between 5% of the rated primary current up to the rated continuous thermal current. For example, in the case of measurement for protection, the sensor maintains class 5P up to 8000 A (thus with 5P100 accuracy class). These sensors are small. The external cone conforms to EN 50181 standards, Interface C (400-630 A series, M16 nuts) and can therefore be connected to compatible cable sockets. Combi sensors are particularly compact. Considering that they combine the functions of a conventional VT and a CT, they are extremely small and light with respect to the size and weight of the previous two together. For example, a combi sensor for 24 kV weighs about 15 kg. This means that they can be easily installed and handled in MV switchgear.



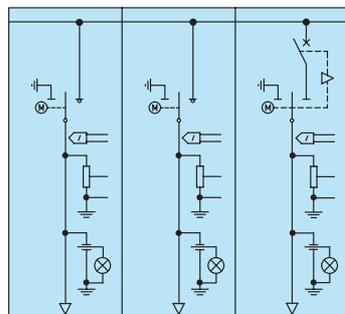
5.7 Medium voltage switchgear: UniSec and Safering



In the smart grid version, the UniSec medium voltage switchgear is equipped with various devices for substation automation, ranging from the Fault Passage Indicator through to integrated protection and monitoring devices. UniSec switchgear features a wide range of typical units that allow the basic solution to be adapted to suit grid requirements. Two typical solutions have been selected for use in secondary distribution substations. The first comprises two units with motor-operated switch-disconnectors (SDC) plus another which also has protection fuses (SFC).



The second solution includes two circuit-breaker units (HBC) plus a unit with switch-disconnector and fuses (SFC). This version allows the grid functions to be rapidly restored since the circuit-breakers are remote controlled, thereby enhancing grid efficiency. Use of the REC615 integrated protection and control unit is also envisaged, with functions that include power flow management and voltage stability measurement monitoring.



Use of SF6-insulated switchgear of the Safering and SafePlus type is also a viable alternative. Available in different configurations, this sort of switchgear can be used for applications up to 24 kV. The units comprise stainless steel enclosures housing switching and protection devices like switch-disconnectors or circuit-breakers and can be equipped with advanced protections and sensors conforming to smart grid technology.

5. “Smart” substation components

5.8 MV/LV distribution transformer: Smart-R-Trafo



250 kVA to 800 kVA power ratings and voltage ratings up to 24 kV are available.

The switching contacts are maintenance-free since 700,000 switching operations are guaranteed. Substation design need not be modified since the apparatus is extremely compact.

The transformer can be connected to the centralized control system via Ethernet or serial line using IEC 60870-5-1 and 61850 protocols.

The MV/LV transformer is one of the main components in a substation since it supplies the low voltage users. Not only is its reliability of great importance but also, in the light of smart grids, its ability to maintain the voltage within the contractually established band, something that is becoming increasingly complicated as the amount of energy produced from renewable sources grows.

The solution proposed is Smart-R-Trafo, with on-load voltage tap changer configurable for 5, 7 and 9 positions (e.g. $\pm 4 \times 2.5\%$, thus $\pm 10\%$ bandwidth). Up to 24% bandwidths can be obtained with the maximum 9 positions and 3% adjustment steps.

5.9 Low voltage components: Emax and Tmax



Present day technology now provides devices, for use in low voltage systems, with individual units that integrate 'smart' protection functions hitherto possessed by independent external devices, like supervision, control, measuring and communication.

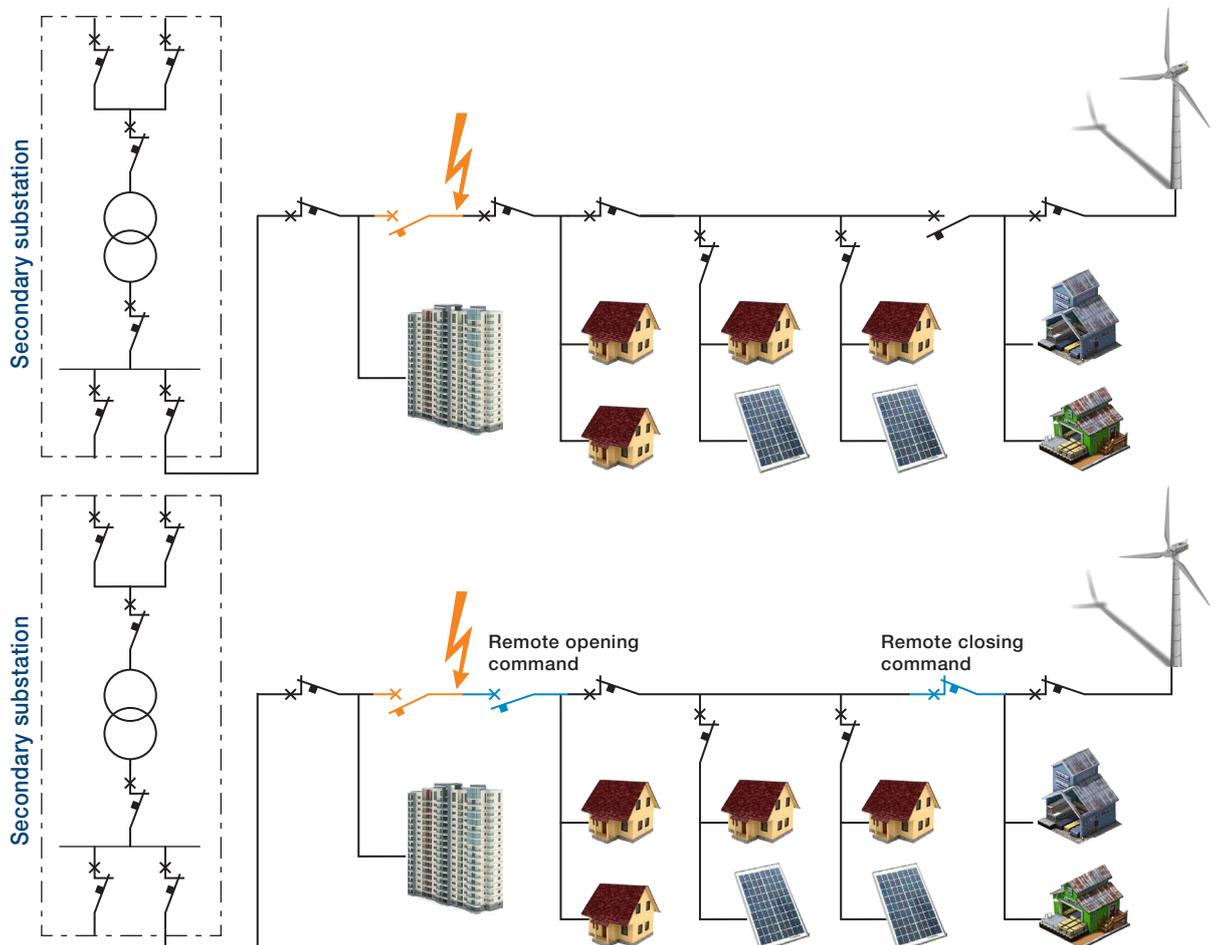
An example of this sort of integration is provided by the Emax 2 air circuit-breakers and Tmax XT circuit-breakers in an insulating enclosure.

Thanks to these devices, certain smart grid concepts can also be applied to low voltage networks with undoubted benefits as to reliability of the electric power supply.

A first example is the availability of voltage and current measurements which, along with the communication interface, allow the circuit-breakers to be used both as protection apparatus and as sensors connected to a supervision system. If the protection trips, the supervision system also receives the relative data: it can identify the reason for tripping (short-circuit, overload, earth fault), thereby allowing the operator to take the necessary actions.

The **fault tracing function** can also be applied, just as in medium voltage systems.

The example illustrated in the next figure depicts a future low voltage network with distributed generation.



5. “Smart” substation components

If a fault occurs, the service can be restored within a short time since the circuit-breaker functions in the selective mode by detecting and eliminating the fault. The information is propagated by the communication system, while the operator can re-configure the LV network in the remote mode, by re-supplying the users from another supply source.

Air circuit-breakers also have advanced protection functions, such as directional protection and selective short-circuit protection: this allows the circuit-breakers to be coordinated with each other, thereby reducing the part of the network subject to outage.

Further functions include local control for load management, as described below:

- load disconnection and re-connection: the Emax2 circuit-breaker acts as a predictive local controller so as to maintain the power within preset limits. The function is based on mean power calculation at adjustable intervals (e.g. 15 min.), which can be synchronized with the reference signal. Load disconnection and re-connection in sequence (in order of priority) occurs on the basis of the total power/energy measured and on the estimation of period-end energy consumption.
- connection and disconnection of local generators: Emax2 limits the power exchanged with the network. In the case of local generation (e.g. photovoltaic), the power exchanged is the difference between consumption and local production: if the PV power produced drops, the difference increases and the loads are disconnected. Vice versa, if the PV power increases, the difference reduces and the loads are re-connected;
- management of storage systems: when power consumption is high, the storage system (or local generator) is connected. Vice versa, when power consumption drops, the storage system is disconnected or put in stand-by and system recharging begins. A mixed generator/load scale of priorities can be defined.
- demand side management coordinated with renewable sources: the total load on the load side of the Emax 2 Power Controller is kept within the programmed limits. These limits are stored inside the circuit-breaker and can be adjusted in the remote mode via a communication system. The Public Utility Company can therefore monitor the mean consumption of each group of loads without having to monitor each load individually.

All the measuring sensors and the calculation processor are integrated into the Emax 2 circuit-breaker, while the commands are implemented by other circuit-breakers, contactors or generic command contacts.

The key features of the circuit-breakers described are:



Emax 2 air circuit-breakers

Rated current: 400 – 6300 A

Breaking capacity: ≤ 200 kA

Rated alternating voltage: ≤ 1000 V

Protection unit: Ekip-Hi-Touch

Values monitored: I, U, P, Q, E

PQ measurements: average hourly values, harmonics and THD, voltage interference statistic (transient voltage dips, overvoltage, voltage variations, ...), device for storing events, ...

Communication protocols:

- serial (Profibus, Modbus RTU, ... via RS485)
- Ethernet (Modbus TCP, IEC 61850, ...)



Tmax XT2 – XT4

Rated current: 100 – 250 A

Protection unit: Ekip-e

Values monitored: I, U, P, Q, E

Communication protocols: serial (Modbus RTU via RS485)

Sensors and electronics inside the circuit-breaker.

5.10. Low voltage measuring instruments

Low voltage instruments designed for installation in low voltage industrial secondary distribution switchgear are ideal for completing ABB apparatus and enable the switchgear to be configured as an integrated system of functions.

ABB offers the following instruments:

- DMTME multimeters in both modular and switchgear-front versions;
- M2M and ANR network analyzers for monitoring network quality;
- MID certified electricity meters for monitoring the power consumption of individual loads and the installation;
- TMD control units for monitoring the temperature of the windings and power transformers.

DMTME instruments are digital multimeters that measure (in root-mean-square value) the main electrical parameters in 230/400 V.A.C. three-phase networks.

DMTME multimeters allow the functions of voltmeter, ammeter, power factor meter, watt-meter, varmeter, frequency-meter, active power meter and hour counter to be performed by a single instrument.

Several multimeters and other digital instruments can be connected to the network via the RS485 serial port using the Modbus RTU protocol.



The M2M network analyzer measures the main electric parameters in three-phase and single-phase medium and low voltage networks in true root-mean-square value (TRMS).

The main features of the product are:

- multi-language display;
- remote monitoring of electrical parameters via Modbus RTU, Ethernet TCP/IP and Profibus DP protocols;
- compact overall dimensions;
- bidirectional energy reading, allowing the amount of produced and consumed energy to be cost accounted;
- measurement of energy consumption in kg of CO₂ and in Euros;
- measurement of the maximum demand for the purpose of monitoring power consumption;
- measurement of the harmonic distortion rate (THD) in absolute and percentage value for voltage and current;
- autodiagnosis function;
- programmable digital alarms for setting alarm thresholds or pulses.

5. “Smart” substation components

When increasingly advanced analysis functions are required, use of ANR network analyzers allows the network parameters, information and alarms to be measured, recorded and the data to be directed towards remote supervision and monitoring systems.

The key features are:

- measurement, recording and analysis of over 60 electrical parameters;
- voltage and current measurements in root-mean-square value with class 0.5 accuracy;
- remote monitoring of measured data in different modes: programmable analog outputs, digital outputs for commands, pulses and alarms, acquisition of non-electrical parameters and/or states;
- communication protocols such as: Modbus RTU, Profibus DP, Ethernet Modbus TCP/IP.



TMD-T4/96 temperature control units

Used for monitoring the temperature levels and ventilation functions of electric machines, transformers, motors, etc. Preventive temperature monitoring allows outages and overloads to be avoided. The temperature is read by probes of the PT100 and RTD type. Two alarm levels (alarm-trip) can be set for each measuring range. These levels switch output relays for the purpose of remote signalling should a critical temperature level be reached.

In addition, these control units can store data such as maximum values, number of trips and can monitor ventilation inside the switchgear. The temperature values and alarm states can be remoted via RS485 serial output using the Modbus RTU protocol.



ABB's vast range of modular electronic energy meters is outlined in the table below. Energy meters can be usefully employed in civil/service-providing and industrial facilities. Certified in accordance with the European directives, ABB's meters can be installed where energy must be metered for "fiscal" purposes.

A typical example of the former case can be found in shopping centers, where local energy consumption can be measured and a consumption log created, as well as remote management of the building and integration into a supervision system using the Modbus RTU protocol.

Single-phase energy meters		Three-phase energy meters	
ODINSingle	DELTAsingle	ODIN	DELTAplus
			
Direct measurement up to 65 A	Direct measurement up to 80 A	Indirect measurement up to 65 A via CT (5/5-900/5 A/A)	Indirect measurement up to 80 A via TA (1-999 A)

6. Conclusions

To briefly outline the issues described in the previous chapters as to configurations and products, the following three solutions can be considered:

Solution	Apparatus	Functions	Customer benefits
Monitoring Control	<ul style="list-style-type: none"> - Motor-operated switch-disconnectors - Fault indicators 	<ul style="list-style-type: none"> - Remote signalling of apparatus status - Fault signalling - Monitoring of substation conditions - Remote control of apparatus 	<ul style="list-style-type: none"> - Diagnostics and supervision - Isolation of faulty segment and network re-configuration - Remote configuration of the network
Monitoring Measurement Control	<ul style="list-style-type: none"> - Motor-operated switch-disconnectors - Current and voltage sensors in a high accuracy class - Measurement management device 	<ul style="list-style-type: none"> - Accurate medium voltage measurements 	<ul style="list-style-type: none"> - Power flow measurement and management - Monitoring of voltage stability measurement in the presence of distributed generation.
Monitoring Measurement Control Protection	<ul style="list-style-type: none"> - Circuit-breaker - Current and voltage sensors in a high accuracy class - Protection relays 	<ul style="list-style-type: none"> - Logic selectivity of the protections 	<ul style="list-style-type: none"> - Least number of outages in the event of faults - Integration of renewable energy sources

ABB can develop further secondary substations solutions together with the customer. Examples of components and structures can be examined in the ABB Smart Lab of Dalmine, where qualified technicians can provide solutions to even the most complex requirements.



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