AGILE DIGITAL SUBSTATIONS 2.0
RELEASING THE POTENTIAL OF DIGITAL TECHNOLOGIES

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Optimise your operational costs

Asset managers now have a critical tool that, with less wiring and fewer commissioning tests, optimises preventive maintenance and can extend the lifetime of the entire substation, including third party plant items.

Alstom’s digital solutions:

- Maximise the reliability of your substation
- Operate assets more efficiently and safely close to the limits of the system
- Optimise maintenance, repair and retrofit of equipment with minimal outages

Complete and adaptable solutions

Alstom’s agile digital substation solutions are available for:

- Retrofit and extension schemes, as they reinforce conventional plant and systems
- New substations

The particular solution and architecture can be adjusted to meet your operational needs according to how critical your asset and substation is to the network.

Extensions and modifications are easier, as the substation function is primarily implemented in software, as opposed to hardware.

An investment with many rewards

After more than 15 years of advanced research and projects around the world, Alstom’s digital substations are delivering the great potential of this technology: interoperability, ease of configuration, maximised reliability and availability, real-time performance, Smart Grid communications capabilities and reduced cost of ownership.

Solution continuity from traditional through to the newest digital substations is ensured, thanks to IEC 61850 compliance.

Michel Augonnet
Senior Vice-President, Alstom Grid Commercial Solutions

Extended communication for more accurate substation awareness...

Digital technologies have brought many benefits to the strategic field of transmission networks and specifically in substations. Digital technology at station bus level is widespread today and has also extended to process buses at the primary equipment level. As a company committed to research and a key player in this industry, Alstom has worked with the utility and industry community towards greater standardisation and use of the common standard IEC 61850 since 1995.

Following years of extensive laboratory research, rigorous test platform acceptance programmes and more than 1,000 digital control systems (DCS) installed worldwide, Alstom digital substation solutions are ready for use in an integrated architecture combining cutting-edge hardware, software and communications with technology engineering to IEC 61850 specification standards.

As a global leader in electrical grids, offering a complete range of digital hardware and software, Alstom is uniquely placed to deliver tested, interoperable solutions based on optical fibre and digital communications that will remain sustainable over time and thus provide the significant benefits that systems operators are entitled to expect.

Throughout these pages, I invite you to discover the principles and main benefits of Alstom’s agile digital substations, how the architecture is built and how we can tailor our technology to your needs.

Alstom agile digital substations

- Based on the IEC 61850 unifying communication standard for complete information sharing and interoperability, allowing future modernisation and the integration of new systems
- Digital Control Systems (DCS) connected with the primary bays via a process bus built on redundant Ethernet architectures. Merging and control units collect and translate measurements, signals and commands (I/O) from the primary equipment into sampled values and GOOSE messages and vice-versa
- Digital instrument transformers and DCS-integrated condition monitoring for the substation’s primary equipment can be added, providing superior safety, reliability and substation situational awareness, locally and remotely

Optimise your operational costs

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Complete and adaptable solutions

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- New substations

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The complete digital substation solution
Alstom’s digital substation - the benefits

**Increased reliability and availability**
The extensive self-diagnostic capabilities of digital devices ensure maximised availability of the substation, as well as its full suite of functionalities: any degradation in the performance of an asset is pinpointed in real-time.

The inherent redundancy built into the system can be employed to be self-healing/fault tolerant, and permits troubleshooting without the need for primary system outage.

**Optimised operation of assets**
The intelligence within digital substation schemes allows close monitoring of the load capacity of plant equipment, based on their design ratings. This dynamic load analysis means that lines, cables, transformers and other grid equipment can operate closer to their limits.

**Improved safety**
- Removal of wired cross-site CT (Current Transformer) circuits reduces the risk of fatal injury due to inadvertent opening of the circuit by personnel
- Absence of oil in transformers reduces explosion risks
- Advanced self-monitoring of substation assets ensures that they are operating within safe limits

**Reduced maintenance costs**
The digital substation closely monitors all substation assets in terms of operational conditions, effective load capacity and asset health indicators. Intelligent systems analyse the data and provide recommendations on maintenance and repair actions. This allows a shift to reliability-centred maintenance, avoiding unplanned outages and emergency repair costs.

**Investment optimisation**
The capital cost of investment projects is reduced on many fronts:
- Savings on time needed to engineer and install substations
- Reduced real-estate needs
- Copper cabling is cut by up to 80% through the use of optical fibre
- Asset optimisation tools allow faster targeting of weak areas needing reinforcement, allowing reduced operational costs

**Easier renovation and extension of existing substations**
Interoperable solutions and the use of fibre optics instead of copper wiring reduce the duration and costs of unavailability of substations during the refurbishment of secondary equipment. This also applies to extension works.

**Standardisation and interoperability**
Being IEC 61850 compliant, Alstom’s digital solutions and substations are designed to be interoperable with other vendors’ equipment, with a strong degree of standardisation at the interface level of secondary equipment.

**Improved communication capabilities**
Data exchange between intelligent devices, intra and inter-substation, is optimised through Ethernet communications. Smart local and wide area control units allow data exchanges between voltage levels within substations and between substations. Direct inter-substation communication without the need to transit via a grid control centre reduces the response times, enabling fast, real-time applications.

**IEC 61850: a crucial technology enabler**

Modern sensors and other Intelligent Electronic Devices (IEDs) must be connected to communicate within the substation and over the greater grid system. In the past, there were many different protocols requiring much effort to make them communicate with each other. Insufficient standardisation, fear of degraded reliability and lack of return on investment slowed down the emergence of the fully digital substation. But today, the IEC 61850 standard makes it possible to facilitate interoperability between different equipment and suppliers.

Introduced in 2004, the IEC 61850 standard is accepted across the world, as its main objective is to ensure interoperability between equipment coming from various suppliers. IEC 61850 continues to evolve and encompass the needs identified by the industry’s user group (UCA UG), ensuring that it caters to all substations needs. IEC 61850 is rapidly being enriched as new application areas are continually added, most notably IEC 61850-8-1 and IEC 61850-9-2.

This permits full digitisation of signals in a substation so that large amounts of data can be managed and communicated for the real-time management of a modern power grid - a smarter grid

**IEC 61850**
IEC 61850 is the international standard for Ethernet-based communication in substations. It is more than just a protocol, it is a comprehensive standard designed for utilities, to deliver functionality that is not supported in legacy communication protocols.

IEC 61850 defines a domain specific data model (data and services) supporting all functions required in substations. These unique characteristics can significantly reduce costs associated with designing, installing, commissioning and operating power systems.

IEC 61850 is designed for interoperability and longevity, removing the dependence on one supplier and one generation of IEDs.

IEC 61850-8-1
IEC 61850-8-1 is the relevant standard for the station bus. It defines the means to generate and present reports which may be subscribed to by other devices and HMIs (Human Machine Interfaces) as well as the way to communicate peer-to-peer. The latter is achieved by the exchange of GOOSE messages between devices on the LAN (Local Area Network).

IEC 61850-9-2
IEC 61850-9-2 is the part of the standard that brings digital instrument transformer technology into play, breaking the constraints of conventional CTs and VTs. It is particularly important for the process bus, as it describes how analogue signals such as phase currents and voltages can be exchanged as sampled values.

Denis Chatrèfou
Alstom Grid Research & Development, Digital Substation Coordination

“As a driving force in the development of the standard, Alstom is proactive in the support, maintenance and development of IEC 61850 and its components. We have developed an integration platform for interoperability tests of digital systems in their real configuration before installation in the field. We will continue to work to make sure that this standard delivers its potential benefits to transmission and distribution system operators. We will also endeavor to develop technologies and solutions that are instantly interoperable with other vendors’ equipment and compatible with future generations of software and hardware.”
The architecture of Alstom digital substations

Alstom’s digital substations rely on the latest DS Agile digital control system that provides the complete architecture, connecting all components, together and with the operator interface, through an IEC 61850 Ethernet network.

DS Agile digital substation solutions are highly scalable in terms of equipment, functions, architecture and services.

The digital substation architecture can be divided into three levels:

1. The station control area
   Communication within the substation and control system, coordination with the substation operational functions and the station-level support functions.

2. The protection and control level
   Protection and control of substation equipment includes IEDs traditionally called “secondary equipment” (protection, measurement devices, bay controllers, recorders...).

3. The primary equipment process level
   Acquisition of voltage, current, status and condition signals, consolidation, processing, and transmission of digital data via optical fibres: intelligent primary devices (electronic power and instrument transformers, circuit-breakers, disconnectors) and optic fibre can replace traditional CT/VT systems and conventional cable wiring.

Figure 1: Generic overview of a digital substation
on those measurements (pressure or temperatures in GIS switchgear, current and voltage measurements) via a “process bus”.

Most important is that smart devices and systems within the substation, (protection relays, recorders, phasor measurement units, bay controllers, wide area controllers) can immediately process this data. By subscribing as clients to this data flow over an Ethernet process bus, the information from the “eyes and ears” of the power system is distributed and communicated much more efficiently to the bay level than in conventional hardwired schemes.

The process bus is also the link by which the primary equipment information from out in the yard travels back to the substation control room.

In a fully digital architecture, control commands are also routed to the primary devices via the process bus.

The process bus, therefore, enables time-critical services.

2. The protection and control level

Between the process bus and the station bus are devices identified as “secondary equipment”.

In the digital substation, these devices are IEDs (intelligent electronic devices), interacting with the field via the process bus; with other peer devices in the bay; with other bays, and with the digital control system via the station bus. They are designed to provide the Smart Grid applications demanded by utilities via real-time and secure equipment. They provide interoperable solutions, stability applications, wide area protection and control plans, and more globally, substation situational awareness.

Key components are:
- protection relays, bay controllers
- measurement and recording devices
- time synchronisation units
- Ethernet network and switches
- substation proxy
- control room user interface
- security applications
- control/relaying panels

IEC 61850 communications enable complete integration between devices. It ensures optimal use of the information for the continuity and reliability of electrical grid operations in secure access situations.

3. The station control area

The digital substation station bus is much more than a traditional SCADA bus, as it permits multiple clients to exchange data, supports peer-to-peer device communication and links to gateways for inter-substation wide-area communication.

The IEDs perform their time critical functions such as protection, point-on-wave switching supervision and other tasks via direct interaction with the process bus.

Additionally, other clients in the substation may require information-sharing of some or all of this data. For example, protection and control schemes may be distributed amongst multiple IEDs.

There is also the need to distribute the information to local or remotely-stationed control operators so they can visualise the operational status of the substation in real-time. This requires substation HMIs, proxy server links to remote HMIs and control servers. One or more workstations can apply the instructions assigned by regional dispatchers, or can be used as an engineering workstation for IED configuration, or for local concentration and archiving of power system data. On-line condition monitoring may have specific workstations for alerts and to manage the database history of each primary device.

Using industry norms and enabling technologies to their fullest, Alstom’s global experts now bring the digital substation to the market. Whether for incremental refurbishment, or complete green-field installations, Alstom has the equipment, the system delivery capability and project management expertise to be operational first time and on-time. The component parts of this offer are detailed in further sections:
Digital instrument transformers

Decades of extensive research by Alstom has delivered proven digital instrument transformers, designed to be accurate, intelligent, safe, cost-effective – and very importantly – core-less.

The root of many of the limitations of conventional instrument transformers is their reliance on an iron core. The core is a source of inaccuracy, due to the need to magnetise it, but not to overflux it. In the case of conventional CTs, achieving the low-level accuracy and dynamic range to satisfy both measurement and protection duties is a challenge. Conventional VTs may experience ferroresonance phenomena resulting in thermal overstressing.

Instead of an iron core, the translation from primary to secondary measurement uses optical, Rogowski or capacitive technology, with the optimal choice for AIS (Air-insulated Switchgear) and GIS (Gas-insulated Switchgear) driven by the size of the respective digital measurement device, which allows footprint optimisation for the substation.

A wide array of sensors monitor conditions in real-time thanks to multiple applications: diagnostic analysis, asset management and condition-based maintenance.

- **Optical sensors use the Faraday effect.** A fibre optic loop sensor carrying a polarised light beam encircles the power conductor. This light will experience an angular deflection due to the magnetic field, generated by the primary current flow. The sensor’s intelligence is to accurately determine the primary current based on the real-time optical measurement.
- **Rogowski sensors dispense with the conventional CT core** and instead implement windings as tracks on a multi-layer printed circuit board. Four quadrants of the board are clamped together to form a toroid around the primary conductor. The sensor output becomes a low-level voltage measurement, which can be accurately correlated to the primary current.
- **Capacitive dividers dispense with the conventional VT core.** Capacitors are built from slimline film stacks for AIS sensors or printed circuit board electrodes laid on the interior of the enclosure for GIS sensors.

### Alstom’s offer...

#### Measure

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>AIS</th>
<th>GIS</th>
<th>AC</th>
<th>DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Sensor</td>
<td>Flexible, portable optical current sensor</td>
<td></td>
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<tr>
<td>Rogowski Sensor CT</td>
<td>Rogowski core for current measurement</td>
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<tr>
<td>Capacitive Sensor VT</td>
<td>AIS voltage transformers</td>
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</tbody>
</table>

**Customer benefits**

- Enhanced safety: no risk of explosion, no wired CT secondary circuit running cross-site
- Measurement precision coupled with protection dynamic range
- No saturation, ferroresonance or unwanted transients
- Long-term accuracy
- Outstanding seismic resilience
- Unparalleled reliability and availability with full self-diagnostics
- Lightweight, compact and flexible
- Minimal inventory, near-zero maintenance
- Harmonic monitoring
- Online condition monitoring
Alstom’s offer...

Convert

Alstom’s digital substations minimise the amount of electronics residing in potentially harsh outdoor environments. The primary converters convert analogue signals from the primary equipment into digital signals. Primary converters can be installed either directly in primary plant hardware or in cubicles.

Digital controllers (Switchgear Control Units) are the fast, real-time interface to switchgear, mounted close to the plant which they command. They replace the hardwiring of inputs and outputs with an Ethernet interface to the yard and also support condition monitoring features.

Merging units perform all the digital data processing necessary to produce a precise, time-aligned output data stream of sampled values according to the IEC 61850-9-2 standard. This processing includes tasks such as sampling, analogue to digital conversion, scaling, precise real-time referencing, message formatting and publishing.

The design may vary with the applied technology of the instrument transformers (eg: optical, Rogowski, voltage dividers, or conventional wound instrument transformers), the switchgear type, mounting space available and also with the preferred substation communication architecture.

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>DS Agile SCU</td>
<td>Switchgear Control Unit: Processes the I/O signals from/to the primary switchgear as IEC 61850-8-1 GOOSE messages</td>
</tr>
<tr>
<td>Reason MU320</td>
<td>Standalone integrated merging unit: Digitising of conventional 1A/5A and 100/5/10V analogue secondary circuits, plus GOOSE 1/0 for binary control of switchgear</td>
</tr>
<tr>
<td>MU Agile XMU 800</td>
<td>Digital merging unit: Interfaces with the different primary converters for DIs in the field, also compliant with IEC60841-4 for legacy DIs</td>
</tr>
<tr>
<td>MU Agile XMU 900</td>
<td>Modular merging unit: Interfaces with digital and conventional instrument transformers</td>
</tr>
<tr>
<td>MU Agile COSI</td>
<td>Modular merging unit: Interfaces with COSI optical CTs and conventional or capacitive VTs</td>
</tr>
</tbody>
</table>

Digital pioneers in the field

With multiple reference sites in different countries, Alstom has been involved in the development of the various components of the digital substation for many years. We have gained precious experience in our IEC 61850 projects that puts us in a strong position to meet the demands of utilities for instantaneous operability and backward compatibility of multi-vendor equipment.

Customer benefits

- Interfaces with all types of power system current and voltage sensors, whether digital instrument transformers (DIT) or conventional CT/VT
- Ensures accuracy of protection applications up to highest fault currents and X/R ratios
- Ensures measurement accuracy

<table>
<thead>
<tr>
<th>Customer benefits</th>
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</thead>
<tbody>
<tr>
<td>ENERGINET.DK (DENMARK)</td>
</tr>
<tr>
<td>Supply of COSI optical digital instrument transformers and MiCOM P546 process bus line differential protection</td>
</tr>
<tr>
<td>Digital instrument transformers plus MiCOM P546 line differential, for line to cable transition stations in hybrid circuit applications at 400kV. Environmental “beautifying” project associated with the undergrounding of circuits.</td>
</tr>
<tr>
<td>RTE (FRANCE)</td>
</tr>
<tr>
<td>Saumade - 220 kV GIS substation with hybrid sensors, merging units and distance protection</td>
</tr>
<tr>
<td>Digital instrument transformers based on Rogowski coils and capacitors, connected to merging unit and interfacing digitally with distance protection relays provided by Alstom and a third party.</td>
</tr>
<tr>
<td>GETCO (INDIA)</td>
</tr>
<tr>
<td>Jambua AIS Substation</td>
</tr>
<tr>
<td>220 kV COSI-CT based on optical sensor technology (Faraday effect), connected to the merging unit and interfaced digitally with Alstom distance protection by IEC 61850-9-2 process bus.</td>
</tr>
</tbody>
</table>

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Alstom's offer...  

Protect

Digital protection relays

MiCOM P40 Agile is a complete range of IEDs designed for digital substation architectures. The full range of transmission protection is included, from the simplest back-up device, to subcycle tripping main protection schemes. In a fully-digital architecture, the relays receive currents and voltages as IEC 61850-9-2 sampled values and issue trip or alarm signals using IEC 61850-8-1 GOOSE. The flexibility of MiCOM allows you to adopt new technology tailored to match your pace of change – from initial station bus digital integration, up to full station and process bus schemes.

Measurement and recording devices

The Reason RPV311 is the perfect digital fault recording (DFR) solution to analyse power system fault waveforms, power quality and network oscillations which could threaten grid stability. It includes a synchrophasor feature (PMU) to measure and communicate real-time power system vector quantities using IEEE C37.118 for use in stability and wide area automation schemes.

The following table indicates the typical relay and recorder selections, and their main functions:

<table>
<thead>
<tr>
<th>Device</th>
<th>Principal Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>MiCOM Alstom P41, P44</td>
<td>Numerical full-scheme distance protection with integral teleprotection</td>
</tr>
<tr>
<td>MiCOM Alstom P466</td>
<td>Subcycle distance protection with one or two breaker reclosing and alternative algorithm principle to P44/4</td>
</tr>
<tr>
<td>MiCOM Alstom P466</td>
<td>Line differential for 2 or 3 terminal lines with subcycle detection and one or two breaker reclosing</td>
</tr>
<tr>
<td>MiCOM Alstom P466</td>
<td>Transformer differential for up to 5 ends with advanced loss-of-life thermal monitoring</td>
</tr>
<tr>
<td>MiCOM Alstom PT4</td>
<td>Digital busbar protection for centralised or smaller schemes up to large decentralised bus configurations</td>
</tr>
<tr>
<td>MiCOM Alstom PT4</td>
<td>Transmission line terminal IED for backup, reclose and breaker fail management</td>
</tr>
<tr>
<td>Reason RPV311</td>
<td>Multifunction digital fault recorder with PMU, for process bus, conventional and hybrid CTVT applications</td>
</tr>
</tbody>
</table>

Also available, the MiCOM P847 discrete phasor measurement unit offers industry-leading accuracy and dynamic response to frequency excursions where a decentralised alternative to the RPV centralised solution is preferred.

The Reason RT430 grandmaster clock provides the precision IEEE 1588 reference for merging units and phasor measurement units in the substation.

Alstom’s protection IEDs extend their supervision facilities to check the plausibility of the incoming sampled values from the process bus. This addresses the fact that the traditional task of current and voltage sampling is now external to the device, and is connected via Ethernet. The supervision compensates for any latency or mismatch in the network, provides ride-through intelligent compensation in the event of several missing samples or jitter, and blocks/alarms if the quality of incoming data compromises the secure and reliable operation of the IED.

Customer benefits

- Proven algorithms of conventional applications remain unchanged, no need for reapproval
- Time-critical performance is maintained irrespective of the architecture, number of functions enabled, or extent of logic programmed
- Safer test and maintenance operations for technicians – no wired CT secondary circuit exists
- Accurate measurement capabilities – as accurate as the incoming -9-2 data itself
- Station bus communication redundancy available: PRP (Parallel Redundancy Protocol) and RSTP (Rapid Spanning Tree Protocol)

Over a quarter of a million Alstom MiCOM P40 relays protect critical infrastructures worldwide

MiCOM IEDs

MiCOM P40 Agile

Reason RPV311 Digital Fault Recorder with Phasor Measurement Unit (PMU)
Alstom’s DS Agile solution is the latest generation of substation Digital Control System (DCS). It relies on fast Ethernet networks with IEC 61850 communication standards and offers topology-oriented automation combined with electrical security to minimise outages.

DS Agile can be tailored either to single substations or to an inter-connected system across multiple substations using wide-area communication.

### Substation automation

**Situational awareness**

In the context of power grid substations, situational awareness means monitoring and understanding the state and the environment of the substation in real-time, and being able to precisely anticipate future problems in order to take corrective actions in advance.

DS Agile v6 offers local and wide-area situational awareness, allowing dynamic management of power flows, and the optimum condition-based management of substation assets.

DS Agile is able to integrate, process and display through clear and intuitive dashboards a large array of monitored parameters, such as:
- Condition monitoring data for all primary and secondary equipment and auxiliary systems in the substation
- Environmental and weather conditions
- Thermal (infrared) camera imaging
- Wide area state (surrounding substations)
- Cyber- and physical intrusion

The complete situational information provided by DS Agile constitutes an invaluable tool that simplifies and optimises the substation operators’ decision-taking.

### Wide area automation and communication

The digital substation benefits from a wide-area network interface, receiving and responding to the data from its extensive array of sensors and IEDs. It can be integrated as part of the grid operator’s wide area control system and defence plans, as the data from Phasor Measurement Units (PMUs) is concentrated and relayed from the substation to the control centre and analysed by online stability solutions to track current oscillations and anticipate incidents.

Alstom’s digital substation sensors and control systems work seamlessly with its software platforms for grid operator control rooms, allowing a real-time data exchange both at the substation operational data level and at the asset management data level. This substation/control room communication introduces smart grid and microgrid capabilities to the network, bringing synergy between field equipment operation and network management systems.

The networks can be local to the substation or they can interconnect several dispersed substations, all being linked together and to the grid control room via gateway solutions.

Inter-substation or inter-voltage level automation exchanges GOOSE messages for:
- Logic selectivity
- Auto-reclose and fault location
- Automatic setting of the relays

### Cyber security

The digital substation brings increased cyber security capabilities, as intrusion protection and protection against virus attacks are integrated in switches and IEDs. DS Agile includes specific solutions to increase the cyber security level in the substation.

The system hardening strategy includes:
- Reduction in the substation attack surface
- Intrusion protection: antivirus & whitelisting
- Access point through firewall and ‘jump box’
- Improved authentication, authorisation, auditability in all sub-systems

A number of standards apply in this area, typically: NERC CIP, IEEE 1886, IEC 62351, ISO/IEC 27002, ETSI and CEN-CENELEC.
Online condition monitoring and asset management

Online condition monitoring functions are essential for power transformers and all primary switchgear.

Physical parameters are continuously monitored and real-time measurements are combined and compared to models in order to generate specific recommendations for operations and maintenance, as well as alarms when necessary.

Expert software provides additional advance warnings, automatic diagnostics and maintenance suggestions, boosting the efficiency of asset management. An interface with an asset management system yields additional features such as remaining lifetime or dynamic rating capabilities.

This architecture gives operational and maintenance teams an overview of the condition of all substations in real-time, so they can make appropriate strategic asset management decisions.

Customer benefits

- Reduced unscheduled outages and repair times
- Reduced routine maintenance costs
- Increased equipment life expectancy
- Frees-up skilled personnel for remote diagnostics & operation centres

Alstom’s agile digital substation offers unprecedented performance using intelligent primary systems and tailored automation solutions.
Digital retrofitting and extension of substations

Alstom’s engineering teams can interface with any system, whatever its age or generation. We provide stage-by-stage extensions, whilst keeping the remaining circuits safely in service. Alstom has developed simple tools that enable operators to manage their substations easily and safely whilst identifying problems quickly. We provide a fully documented solution with clear instructions on interconnecting, testing and commissioning. Moreover, extension and retrofit solutions in the future will not require the original manufacturer to be involved, as everything is designed for interoperability.