Specification, Engineering and Testing aspects of digital substations :
At its core, a digital substation focuses on converting binary status and analog measured data into digital data
At the substation level, everyone agrees to improve:

- the situation awareness
- the renewable integration capacity on the transmission grid
- the management capability
- the HV & LV assets management
- the performances
- the resilience,
- the cybersecurity
- the use of FO
- the maintenance strategy
- the interoperability
- ...

The solutions to achieve the goals are completely different depending on the user's vision.

When it comes to primary equipment like a Gas Insulated Substations (GIS), the specifications are very different. They can be based on the needs to reach or based on the international standard or both. The IEC61850 station bus is now deployed on a large scale in the control panel. The IEC61850 has introduced for a couple of years the process bus concept that allows digitizing the exchange between the protection relays, the control and the HV equipment. Although, the process bus is the backbone of the Digital substation, the users are not at the same degree of maturities on this concept for the Control & Protection. Where is digitization performed with or without redundancy? At the Intelligent electronic devices (IED) located in a control building with a conventional HV or in the HV apparatus itself by integrating IED and replacing conventional Instrument transformer by Low Power Instrument Transformer (LPIT).
The Digital Substations can be split in three categories:

- The first stage is to keep all conventional principles as inductive CT & VT and protection CB tripping by wires. However, upper level communication between IEDs (protections devices, meters,…) is made using 61850 Station Bus. The monitoring solution can be fully digital. The testing facilities and associated process can stay conventional
- The second stage is the integration of the process bus for replacing conventional VTs & CTs by LPITs, all IEDs should be synchronized and compatible with the standard IEC61869-9. Even if though testing facilities can be the same, new smart tools are available as IEC61869 generator.
- The last stage consists in locally integrating a computer Switchgear Control Unit (SCU) to locally operate/trip the CB. No more "conventional wiring" between Circuit Breaker & protection devices. The protection device will send a GOOSE command to trip the CB. The monitoring solutions are digital. At this stage the testing facilities is fully digital
  The Fiber Optic (FO) is the preferred media, it allows to mix several information types and to implement several new functionalities.

1 Digital Specification: Usually based on the conventional ones.
1-1 Digitization of Instrument transformer
For instrument transformer, when the IEC61869-1 ED2 will be available, the general requirements for all type of instrument transformer will be covered. The user could use a complete set of documents and choose the right categories, ratings,…to specify its need. In case of LPIT, the digitization of the exchanges with the HV apparatus is not sized anymore by the copper wires capabilities so several aspects of conventional specification disappeared while new ones appear. The main specifications are listed in the following table:

Environmental conditions	Normal
	Special
Ratings	Voltage and Current ratings
	Dielectric ratings
	Rated frequency
	Output ratings
	Rated Accuracy class
Design and Construction	Liquid
	Gas
	Solid materials
	Temperature rise of parts
	Earthing
	Electrical continuity
	External insulation
	Mechanical
	Multiple chopped impulses on primary terminals
	Internal arc fault protection
	Degree of protection by enclosures
	Electromagnetic Compatibility (EMC)
	Corrosion
	Markings
	LPIT secondary terminals
	EIT secondary signal noise
	Fire hazard
	Pressure withstand
	Failure detection of EIT
	Vibration
	Storage climatic conditions
Tests	Type test
	Routines tests
	Special tests
	Commissioning tests
	Sample tests
Rules for transport, storage, erection, and maintenance	
Safety	
Influence of products on the natural environment	

1-2 Digitization of HV apparatus

Regarding primary equipment, the digitization of the exchanges impacts the interface between the HV apparatus and the control. In majority of the GIS substation below 145 kV, the conventional logical function fitted in the GIS bay cubicle is replaced by automatism in the computers with protection and trip functions. The cubicles of the substation are similar and can be de-standardized very late in the project. Most of the substations are remotely operated. There are nevertheless cases of redundancy by conventional scheme to manage. Above 245 kV, a multitude of solutions are specified. From a conventional one, computers located in the control room connected to a conventional LV scheme by hundreds copper wires to the last tendency to integrate computers in the GIS bays as the 145 kV with FO interfaces.

1-3 Specification of monitoring

Massive introduction of real or virtual sensors for feeding asset management tool

In case of Gas Insulated Substations (GIS) the online monitoring solutions is required in most of the cases. There are different physical constants to record such as gas pressure, density, temperature, humidity but also dedicated functions as partial discharge monitoring. The introduction of digital sensors started fifteen years ago, based on their data, virtual sensors have been developed to deal with users' specifications. IED is installed in the primary equipment for managing the sensors, performing computation, and sharing data through IEC61850 Ed2 with a model closer to the reality. The model of monitoring can be specified by using the technical report IEC TR 61850-90-3:2016 © IEC 2016 developed inside the TC57 WG10. An updating report will soon be available.

2 Engineering

In a conventional substation, the limit of scope between primary and secondary equipment is well known, the electrical terminals are the limit. Even though for any additional functions or modifications, several drawings should be updated. This scope of work is admitted and in the best case, the electric diagrams of the cubicle are modified at factory and in the worst scenario a rework is mandatory on site with all its constraints. The LV schemes is evolving several stages from "as manufactured" to "as build" when the last modifications are confirmed by a site acceptance test.

For Digital Substations, the limit of scope should be defined at early stage. Who is responsible for what? The IEC61850 is a complex standard, it is well known by the Automation engineers but partially known by the primary equipment users. The IEC61850 part 4, System and Project management is a part that describes the Engineering, System life cycle and quality assurance phases.

3 Test

The purpose of the testing is to prove that the system functions as specified, all the IED connected shall be "conformance tested". For the functional tests, the principle is the same as conventional substation in easy way, all tests of Protection can be done without injecting any analog signal on the terminal block, Goose & SV test devices are available.

The verification of the primary equipment is necessary. As described in the IEC61869-1, the LPIT is divided in 5 main blocks. There are Primary sensing element, primary converter, transmitting system, secondary converter and merging unit. In agreement, to the technology theses blocks can be integrated in at least two or three elements, the HV sensor, the primary converter, and the Merging unit. The requested accuracies are mainly 3P for protection and 0.2/0.2S for metering. This can be reached by the same primary sensors for currents from a few A to several kA. The calibration of the different parts should be done at factory, the calibration factors are saved in the sensor itself for ensuring a replacement of any devices without recalibration at site. The test at site is limited to a verification and a functional one.

The Primary Convert, the IEDs in charge of the LPIT primary sensor digitalization is equipped with analog testing plugs. That new generation of devices induces a new "way of testing" the conventional one with signal generator but a new one based on new features with the test mode functionality. Nevertheless, the primary equipment allows to inject voltage and current as done with a conventional method.

4 Conclusion

A digital substation isn't built in a day. The journey typically begins with the upgrade of a single analog relay to a multi-function digital device. The actual technology provided by the manufacturers allows users to drive change at the speed he wants, but the time is running fast!