How does this improvement in technology assist to achieve the objectives of improving reliability, flexibility in network topology and efficiency, while reducing the total cost? This article focusses on “smart” grid solutions and in particular transmission grids and “smart” substations.

What is smart grid?
The term “smart grid” has been in use since about 2003. People say that the smart grid will be able to gather and act on information, such as customer and supplier behaviours, in an automated fashion, to improve efficiency, reliability, economics and sustainability of electricity supply. People talk about smart meters, active demand side management for load adjustment, etc., which all tend to focus on the customer end, which might be a good thing, but is probably a long way off.

There are many definitions of smart grid, but the common element is the application of digital processing and communications to the power grid, making data flow and information management central to the smart grid. Reliability demands will drive automation investments.

Smart transmission grid
China took a different approach to its smart grid, which is more transmission oriented; and invested in intelligent infrastructure and automation improvements in all transmission substations above 500 kV and large generation facilities. These improvements include a wide area management system (WAMS) using phasor measurement units (PMUs) across the network, power stability control system PSCSTM and smart substations. China focussed on the supply side to create a stronger grid.

All new transmission substations in China are required to adopt IEC 61850 process bus (to date there are over 500). There is a target of 38% all 110 kV and above substations to be upgraded to IEC 61850 process bus by 2015 and 65% by 2020.

NR Electric is a significant contributor to the Chinese smart transmission grids with its integrated secondary system, with over 45% protection market share above 220 kV, its WAMS solution, its PSCS solution and now more than 250 smart substations with full fibre connections.

China now has the second largest power grid in terms of generation capacity. It is extremely complex and interconnected with various voltages up to 1000 kV AC and 800 kV DC distributed generation of all types and transmission technology including AC, LCCHVDC and VSCHVDC. Yet, with all of this complexity, the Chinese power grids are extremely stable and reliable and improving each decade through the improved co-ordination of the whole network to improve stability and efficiency. The resulting reduction in power blackouts has been significant.

Objectives
The objectives of the smart transmission grid are:

- **Reliability**: Fault detection and self-healing (automatic correction) to prevent rolling blackouts or voltage reductions (brownouts) so that there is no need for a technician to intervene to correct a fault. The result is improved power quality.
- **Flexibility in network topology**: To enable bi-directional energy flows and hence improve capability to interconnect systems. Early network were radial and most of the current network infrastructure is not designed to allow many distributed feed in points. The smart grid must manage these situations to give stability and interconnectedness.

There are three transformations that need to take place for smart transmission grids to deliver maximum value to the utility:

- Improving infrastructure by introducing intelligence in the IEDs and the primary equipment to strengthen the grid
- Introduce a digital layer to improve the automation system
- Business process transformation to realise savings in the utility operations

The key technologies that go into the smart transmission grid are:

- Integrated communications based on the IEC 61850 standard
- Investment in automation, which includes measurement and sensing
- Distributed intelligent agents (control systems) for rapid diagnosis of and precise solutions to specific grid disruptions or outages
- Analytical tools (software algorithms, high speed computing)
- Operational applications (SCADA, substation automation, demand response)
- IEC 61850

The IEC 61850 standard is the result of years of work by electric utilities and vendors of electronic equipment to produce standardised communications systems. IEC 61850 is a series of standards describing client/server and peer-to-peer communications, substation design and configuration, testing, environmental and project standards.

The IEC 61850 standard provides an internationally recognised method targeted towards the interoperability between IEDs from different vendors.
It has built in capability for high-speed control and data sharing over the network, eliminating most dedicated control wiring as well as dedicated communications channels between substations.

NR protection relays, bay control units and substation automation systems that are completely compatible IEC 61850 and certified by KEMA for level A IEC 61850 conformance test. NR also provides solutions that allow the migration of conventional substation automation systems to the new standard.

The communication profiles included in the IEC 61850 standard include:

- Buffered and un-buffered reporting
- File transfer
- Timestamps
- Logical note name prefixes
- Generic object oriented substation event (GOOSE) communication

NR Electric has participated in (and passed) a number of interoperation tests in Indonesia and China:

- Indonesia: In July 2012, the Indonesia Electricity Corporation’s Jawa Bali Transmission and Load Dispatching Centre and Research and Development Centre conducted IEC 61850 interoperation tests. The participants were NR, ABB, Alstom, Schneider, GE and Hyundai. Interoperations tests between IED devices and HMI software of these manufacturers was tested. NR’s IED devices (protection, control and measurement devices) passed the interoperation tests with the HMI software from ABB, Alstom (E-terra) and Schneider (PACIS). The NR HMI software also passed the interoperation tests with IED devices from ABB, GE, Alstom and Schneider.

- China: During 2005 and 2006 the State Grid Dispatch Centre organised six interoperation tests, each with between eight and 15 manufacturers taking part, including NR, ABB, Siemens, SEL and Areva.

Smart substations

Smart substations comprise the intelligent primary devices and networking secondary devices based on the IEC 61850 protocol.
Compared with conventional substations, the communications interfaces and protocols are changed at the bay level and the station level; however the major difference is the introduction of the process bus in the smart substation. Intelligent primary devices, merging units and optic fibre connection substitute the traditional CT/VT, primary devices and conventional copper cabling.

Smart substations introduce the GOOSE scheme which enables the replacement of traditional binary inputs and outputs by digital models. All of the communication is by optic-fibre, which significantly reduces the amount of copper cabling required.

The use of sampled values makes the current/voltage sampling on the primary side easier and more reliable. The signals are sampled, converted to optic signals and transferred to the protection and control IEDs via optic-fibre. This can reduce the instrument transformer insulation requirements and also reduces the electromagnetic interference that copper analogue systems are susceptible to.

Scheme 1: IEC 61850 only at the station level

Scheme 1 is the most similar to a conventional substation, with the IED installed at the bay level and communicating with the station level via IEC 61850. This model can solve the intercommunication and information interoperation problems between IEDs in conventional substations. The interlocking GOOSE signals and co-operating signals between the relays can be realised by the network at the station level as well.

By installing the IEDs in outdoor cubicles near the primary equipment, copper wiring can be minimised, with fibre-optic cables from the IED to the station level. This reduces the construction time and cost (about 10% for new build and 40% for maintenance/upgrade) for smart substations and also reduces the outage time (by about 50% for secondary system retrofit), especially with relocated outdoor control and protection cubicles. The smart substation also becomes much more easily extendable and maintainable. Design and engineering work is also reduced by about 40%.

The automation products are used at the station level and include SCADA systems, database systems, gateway systems, RTUs, GPS receivers, protocol converters, bay control units, ethernet switches, etc.

Scheme 2: IEC 61850 at the station level and process bus

Scheme 2 introduces the independent process bus at the bay level. IEDs can
be installed anywhere in the substation. Large amounts of copper wiring between the IEDs and primary devices because merging units, intelligent control units and protocol converters convert the signals to fibre-optic at the bay level.

NR’s PCS series of protection, control and management IEDs are intelligent electronic equipment which are fully compliant with DL/T667-1999 (IEC 60870-5-103) and IEC 61850 (including GOOSE). They support both electromagnetic as well as electronic CTs and VTs and are widely applied in smart substations.

**Scheme 3: Smart Substations with full digital information exchange**

Scheme 3 introduces electronic CTs and VTs, where the outputs are digital and sent to the protection and control devices via fibre-optic cable.

The operation of a smart substation relies on a reasonable communication framework. Communication in and between the process bus, bay level and station level is accomplished by high-speed ethernet network. The communication protocols of the station level network, the process bus GOOSE network and sampled values network are independent and have different tasks:

- **MMS network data at station level**: MMS is the communication bridge between SCADA, dispatching centres and IEDs at the bay level. The interlocking GOOSE is also implemented in this layer. High-speed Ethernet switches are required to process the message priority and realise the GOOSE scheme between the relays.

- **GOOSE network in the process bus**: Needs high reliability and real-time performance. GOOSE network in the process bus can be configured together with the sampled values network or independently.

- **Sampled values network**: Transmits high volumes of data (CT and VT measurements) and needs real-time, stable and reliable data transmission.

Fig. 4 shows the full arrangement of a scheme 3 smart substation. The advantage of this scheme is the good communication quality and the simple network structure. The reason to configure the sampled values network and the GOOSE network together in the process bus is due to the different nature of their data flows: sampled values have large but continuous data flow, while GOOSE has small and intermittent data flow. The selection of which configuration to use may be based on the cost/benefit analysis at various voltage levels.

**Smart substation products**

NR has developed a full range of products for smart substations, including intelligent control units, merging units, electronic CTs and VTs, etc.

Intelligent control units convert analogue signals (e.g., status of primary devices) into digital data signals and sends this to the protection and control devices via the GOOSE network. At the same time the tripping and closing commands from the protection and control devices will be converted to analogue signals to control the primary equipment.

Electronic CTs and VTs can be applied to GIS and AIS substations at all voltage levels. The output (for protection and measurement)
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Fig. 8: NR smart substation for CLP, Hong Kong.

Fig. 9: NR Smart bay for national grid, UK.

is digital and is communicated via fibre-optic cable.

The data captured by the electronic CTs and VTs are converted to the standard digital signals by the merging units. The digital signal is compliant with IEC60044-8, IEC61850-9-1, IEC61850-9-2 protocols and will be sent directly to the protection devices or the sampled values network in the process bus.

The SCADA HMI and database software is used to configure the smart substation using ICD files, SSD files, SCD files and CID files.

Case study: Smart substation for CLP, Hong Kong

NR Electric installed a smart substation for the Hong Kong Eastern Road Substation, which has electronic CTs and VTs integrated into the GIS switchgear. The merging unit, intelligent breaker controller and bay control units are integrated into one device and located in a cubicle in the switchyard. Communication is via peer-to-peer for the sampled values and LAN for the MMS and GOOSE.

Case study: Smart bay for national grid, UK

NR Electric installed a smart bay for the national grid in the UK. The solution has conventional primary equipment and copper wiring between the primary equipment to the outdoor cubicles, which house the merging units and intelligent breaker controllers. The protection and control IEDs are located indoors and the communication between the outdoor cubicles and indoor panels is via fibre-optics.

Conclusion

NR Electric has a complete integrated secondary system, including control and protection IEDs, substation automation products and smart substation products that has been successfully used in over 250 smart substations in China. Therefore, the smart transmission grid is already a reality. The successful implementation of these products and systems into the Chinese power grid has contributed towards improving the efficiency and reliability of this extremely complex power grid.

References

[3] Information from NR Electric Company
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