Modern substation protection, automation and control systems

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Protection, automation and control (PAC) systems for electrical networks are getting smarter. Advanced communication interfaces and the ever increasing need for information exchange between devices are certainly shifting well-entrenched paradigms. Paradigm shifts create exciting opportunities but also pose significant threats to those not ready to make the necessary adjustments. Communication protocols such as IEC 61850 over Ethernet networks are now being used for real-time protection, automation and control applications and are fast replacing hard-wired interfaces in the substation environment.

This is all unfamiliar and uncharted territory for the control, protection and telecommunications disciplines in utilities. These modern technologies are moving ahead in spite of any resistance to change and it is fast becoming a reality for utilities to address the shortcomings in skills within their organisations and to adapt their structures and philosophies accordingly. This paper describes the NamPower experience in the implementation of the IEC 61850 Standard for its protection, automation and control systems over the past five years. It addresses the challenges that engineering personnel encountered and the paradigm shifts and adjustments they needed to make in order for the implementation of this standard to be a success.

Why migrate?

Firstly, the question to ask is why? Why would a utility decide to implement a solution that is a paradigm shift in the way to protect, automate and control a substation? This is the single most important aspect about deciding to implement the IEC 61850 standard.

Technological disruption

The migration by a utility to a design, integration and operational model that is fundamentally different in its approach to the incumbent technology must be carefully considered. Utilities have been faced with fundamental technological migrations in the past. The migration, for example, to numerical protective relaying was as disruptive in its time as migration to IEC 61850 PAC systems today. The migration to an IEC 61850 based PAC solution with the belief that such a modern standard would solve all of a utility’s operational issues is of course, unfounded. The reasoning for migration must focus, amongst others, on multiple aspects such as sound technical reasoning, financial implications, and operational concerns.

The impact to the organisation must be evaluated in terms of:

- Fit: Does it fit the business model? More specifically, will the technology improve efficiency and system performance?
- Cost: Is the technology worth the price? Will the cost of the technology be viable with respect to the promised benefit?
- Skill: Is the new technology fundamentally intuitive? Are there suppliers already proficient in the new technology? Is the organisation proficient in the new technology or will there be a need for training and skills development?
- Risks: Is the new technology sufficiently mature or are there areas that are still in their infancy which may inhibit a successful implementation?

A frank contemplation of these questions will allow potential pitfalls to be addressed as they become evident and will ensure a single-mindedness in achieving the organisational targets. Only then can the institution of a new technology have minimal disruptive effect. For example, the migration to numerical protective relaying was not trivial as the incumbent philosophies needed to be carefully addressed. Once the migration had begun, the benefits of the newer technology became more apparent and in time became de facto. In this context, IEC 61850 is much more than a standard, it is in fact a philosophy on how to protect, automate and control substations in modern utilities.

Technological considerations

For NamPower, the benefits of the IEC 61850 approach over the existing solutions were technically sound. The underlying fundamentals on which the technological architecture is built had been well proven in the industrial automation arena. Furthermore, the traditionally conservative approach taken by power system engineers was clearly evident in the selection of technologies used to define the standard. The entire standard was either based on or derived from proven solutions. Whereas the application of these technologies to the power system industry may be innovative, the underlying technologies are well proven considering:

- The bulk of the standard is based on EPRI’s utility communications architecture (UCA) initiative which proved to be successful in establishing direction and momentum in the industry toward abstract modelling and interoperability.
- Industrially hardened, switched Ethernet was already proven in the industrial automation arena where existing Fieldbus and Control bus standards have an Ethernet derivative e.g. Modbus TCP, Profinet, EtherNet/IP.
- The manufacturing messaging specification (MMS) as a communications infrastructure with flexible modelling characteristics was also well proven in manufacturing environments in devices such as numerical controllers, programmable logic controllers and robotics.

It was therefore NamPower’s and TAP’s opinion, that solutions built on IEC 61850 would provide a solid grounding for the implementation of 21st century solutions for the protection, automation and control of NamPower’s new green field substations and for the refurbishment of its existing substations. In addition, this paves the way for the development of NamPower’s smart grid – a unified, fully interoperable, communications-enabled electrical system aiming at revolutionising the traditional power system through the introduction of condition monitoring and intelligence [1]. From a technology perspective, the following summary of technological enhancements was experienced by NamPower:

- Improved access to pertinent and relevant information
- Ability to describe the information embedded in the substation fully including asset management details
- Ability to describe the substation information descriptively and not in abstract terms
- A better platform for innovative automation solutions
- A foundation for wider area protective solutions, easier extensions and functionality without the need to install dedicated signalling cables
- Reduced need for expensive I/O modules in IEDs for inter-device signalling
- Less wiring due to the virtualisation of signalling provided by Goose with
the added benefit of constant signal availability monitoring.

- Easier factory acceptance testing due to the improved simulation capabilities provided by the IEC 61850-based solutions.

The technology obsoleted the need for RTU hard-wiring and RTU serial communications for SCADA purposes and the transition to IEC 61850 PAC systems made possible solutions that were either impossible or too complex to implement in the past. It must be made clear that risk mitigation was always a consideration in the implementation of the new PAC systems in that any potential failure of the system would not place the electrical network under undue risk. Bay protection systems were designed to still operate as always. The loss would be the utilisation of the communications assisted protection solutions, busbar protection tripping, substation interlocking and automation features. Thus system integrity was maintained and not sacrificed in any way for n-1 conditions.

Financial impact

The benefits that get punted by the industry according to the adoption of IEC 61850 include potential cost savings due to the reduction of cabling, reduced engineering and reduced commissioning time. In the NamPower case, there was a scheme development cost that was assembled for the migration to IEC 61850 looked historically to the initial resistance that was encountered during the migration to numerical protective relaying a number of years ago. The lessons that were learned at that time were incorporated. Staff training was seen as the essential ingredient to success. Skills development was encouraged through theoretical training and detailed factory acceptance testing which allowed staff to become intimately familiar with the technologies and the newly designed schemes in a risk-free environment.

Implementation strategy

The following basic steps were followed for the implementation of the IEC 61850 standard for the NamPower’s PAC systems:

- A technical champion was appointed who recognised and drove the process for the new PAC systems despite the learning pains, the need for different skills and approaches, and the inevitable glitches.

- A detailed specification was developed in partnership with experienced consultants to describe the requirements for the new NamPower PAC systems. The specification covered the requirements for the substation PAC equipment as well as the communication systems. An open tender process was followed and an engineering company was appointed for the provision of the new PAC systems.

- A project team was then appointed consisting of effective project managers and a technical team. System design and application design was performed by the technical consultant, PAC systems engineering was done by scheme manufacturer, and the utility’s engineers were responsible for installation, FAT and SAT testing, commissioning and system maintenance.

- Part of the design work included:
  - The development of protection systems for EHV, HV and MV feeders, transformers and reactors.
  - The development of communication systems to provide reliable, safe and secure infrastructural support for the PAC systems that depend on it.
  - The development of system management requirements including security, performance, and other aspects necessary to effectively manage and engineer the equipment and communication networks.

- Due to time constraints the initially designed schemes which were intended to be prototypes were installed for proof-of-concept purposes to discover what is involved, map the potential “minefield” and identify the risks, get a handle on how to deal with discrepancies, and determine the real cost-benefits. During the project, there were naturally mid-course corrections and reassessments of engineering solutions. Review and comment on documentation, which is a vital step to ensure the equipment and systems were developed as specified.

- Scheme designs were then “frozen”, IED firmware versions were locked down, and the project moved to factory acceptance testing (FAT) with protection settings, scheme logics,
device configurations, and so on, in order to test the full functionality of the substation automation system. To do this a simulator was developed for the project to mimic primary plant control and indications, • After successful factory acceptance testing, the prototype schemes were installed and integrated with actual primary plant for the project. All functional and interlocking tests were repeated with actual primary plant, • After successful commissioning of the project, changes were proposed for other production projects that were in the pipeline as part of a continuous feedback system to improve the reliability and security of the PAC systems.

Implementation experience
The engineering and commissioning time spent initially was significantly more than would have been spent on legacy systems and solutions. This can be attributed almost completely to the time and energy it took for the technical personnel to design and engineer new solutions and philosophies based on the standard and to make the paradigm shift. In NamPower’s case significant reductions in engineering and commissioning time were only observed with the 7th substation project that was based on this standard.

Operational and maintenance benefits
Here simplicity lies within the complexity of the solution. In the NamPower case, all new IEC 61850 protection and control schemes are fully automated and interlocked, both for air insulated as well as gas insulated plant. To achieve this it meant the wiring back, testing and checking of all plant indication and control signals, from equipment and bay level (process) up to substation level (HMI, etc.). The benefit of doing this is full control of the plant, including the continuous feedback of plant status from all levels and the control of the plant from multiple levels. Plant alarms, indications and interlocking messages are updated in real time and displayed to operators at various levels.

Operator safety and overall system integrity can be achieved with a certain level of automation. Pre-defined switching sequences such as live busbar change-over and the placing of feeders on transfer for maintenance purposes were also automated at substation level, which led to a significant reduction in cumbersome and risky operating instructions and processes. In other words the operating and maintenance effort has become much simpler, but the consequent engineering effort is significantly more complex.

Conclusions
The IEC 61850 standard has been designed with extensibility and scalability in mind. Originally developed to define communications within electrical substations, IEC 61850 has recently been extended to cover smart grid relevant aspects such as communications between substations, hydro-power plants and distributed energy resources (DER) [2]. The standard is supported by vendors worldwide – on both sides of the Atlantic. It is the opinion of the authors that this standard is here to stay and is not subject to a life cycle of say 20 years after which it will be replaced by another standard (with the associated refurbishment of substation protection and control equipment and costs that would be incurred by a utility). We further predict the future of protection, automation and control philosophies to encompass solutions where hardware will become less relevant and where software will determine a device’s or system’s capability.

From a financial perspective, the viability of a migration project may be considered questionable when the capital cost of migration is evaluated. Care must be taken to consider operational and overall lifecycle costs of the new systems when performing cost-benefit analyses.

The key success criteria for NamPower can be summarised as follows:
• Establishment of a strong technical team of utility engineers and experienced consultants,
• Meticulously define a proper system specification. Here the Latin phrase festina lente “hasten slowly” would be appropriate in describing how we believe utilities should undertake this phase,
• Training and skills development underpin the success of implementation. The overall project success hangs in the balance if adequate investment is not made in skills development. Furthermore, the financial and operational impact of not investing adequately in skills development will be felt for many years,
• Advantage should be taken of factory acceptance testing, not only for system verification but also to provide opportunity for staff to familiarise themselves completely with systems in a risk-free environment,
• A process of continuous improvement should then be followed as an organisational philosophy from this point onwards.

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References

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