Improvements in Power System Integrity Protection Schemes

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Abstract

As the existing transmission system infrastructure is challenged to support loads beyond original design limits, the implementation of "wide area" Power System Protection Systems (PSPS) also called System Integrity Protection Schemes (SIPS) are often needed to maintain transmission system integrity. Such a system, with stringent performance and availability requirements, has been designed and installed in the UK (in 2008), and specifically on the Interconnection between Scottish Power and National Grid. The strategy to maintain transmission system integrity is based on the determination of circuit connectivity in the interconnection and, according to pre-defined criteria obtained from different system stability studies, to selectively issue a trip command to Scottish Power generating units in less than 20 ms. This paper starts by presenting the need for the PSPS and the resulting design requirements. It discusses afterwards the architecture that resulted from the requirements and the subsequent implementation and testing issues. Actual operation and performance results, including end-to-end timing tests, will be presented. The paper concludes with a discussion of desired improvements in the architecture and new solutions that are available through the Generic Object Oriented Substation Event (GOOSE), Virtual LAN (VLAN), and priority messaging technologies that are now available through the IEC 61850 communication standard. The following conclusions were found during the project execution at Scottish Power·

Real time control schemes will increasingly play a role in maintaining the security, stability, and integrity of the electric power network. Today's digital relays – in close integration with advanced communication networks – promise to provide solutions for remediation of identified power system problems.· Implementation using commercial IEDs and configured as two identical systems operating in parallel for redundancy, the SIPS meets the performance requirements defined by system studies.

1. Wide Area Disturbance Protection

When a major power system disturbance occurs, protection and control actions are required to stop the power system degradation, restore the system to a normal state and minimize the impact of the disturbance. The present control actions are not designed for a fast-developing disturbance and may be too slow. Local protection systems are not able to consider the overall system, which may be affected by the disturbance. Wide area disturbance protection is a concept of using system-wide information and sending selected local information to a remote location to counteract propagation of the major disturbances in the power system. A major component of the system-wide disturbance protection is the ability to receive system-wide information and commands via the data communication system and to send selected local information to SCADA [4].

The relative importance of each region of vulnerability is called the vulnerability index. A larger value of the vulnerability index indicates that the region is relatively more important and can cause more serious wide area disturbances or has a higher possibility to cause the disturbances than the one with a smaller index.

"A Power System Protection System (PSPS) or Remedial Action Scheme (RAS) is designed to detect abnormal system conditions and take pre-planned, corrective action (other than the isolation of faulted elements) to provide acceptable system performance". Such action includes, among others, changes in demand (e.g. load shedding), changes in generation or system configuration to maintain system stability or integrity and specific actions to maintain or restore acceptable voltage levels [4].

THE GENERATION SHEDDING SCHEME WAS IMPLEMENTED BY SCOTTISH POWER TRANSMISSION TO ALLOW INCREASED POWER FLOWS WITHOUT LOSS OF STABILITY BETWEEN SCOTLAND AND ENGLAND

Power System Protection Systems (PSPS) is a relatively new concept that arrives from the need to supervise critical nodes that have a big influence on Power System performance. These take the form of automatic actions that instigate load shedding in a specific area of the network or reduction of Generation Output in order to prevent instability or overloads in interconnections that could affect the circuit or Power System stability, etc.

The corrective and emergency actions are limited to a finite number of measures. A detailed description of these measures will be provided as implementation issues for different types of disturbances are analyzed.

2. Description of the power system where the PSPS is applied

The transmission systems of ScottishPower Transmission (SPT) and National Grid Electricity Transmission (NGET) are connected by two double circuit 400kV lines. These circuits, as illustrated in figures 1 & 2 are referred to as the East Coast and West Coast Interconnectors. The East Coast Interconnector is equipped with a basic version of the PSPS which has been in service since 2001. Upgrade work to the West Coast Interconnector which uprated the existing 275kV circuit to 400kV operation resulted in the connection of four substations between the two termination points of the interconnector at Strathaven, near Glasgow (SPT), and Harker, near Carlisle (NGET).

Under exporting conditions from Scotland to England, Interconnector faults result in a surplus of generation over demand in Scotland. The transfers between the two systems are therefore limited by the post-fault transient stability limit of the Scottish system.

In order to increase the transfer capability and minimise generation constraints, a scheme to shed generation in the event of pre-defined fault scenarios was identified. The need for the scheme to be in service and the amount of generation to be shed for various contingencies depends significantly on the transmission load flow pattern. Therefore the scheme is capable of being armed to disconnect generation according to the prevailing system status and generation pattern, following line faults or to accommodate planned outages, thus increasing transfer capability.

This goal was achieved by installing individual schemes for the Strathaven – Coalburn, Coalburn – Elvanfoot, Elvanfoot – Moffat, Moffat – Harker, Strathaven – Elvanfoot, Elvanfoot – Gretna and Gretna – Harker circuits (Moffat is a future substation to be connected at a later date). Each circuit scheme is duplicated and the initial criterion is to detect loss of Power Flow Path (Line End Open or LEO) on one or more circuits. Analogue measurements are not used in the initial scheme.

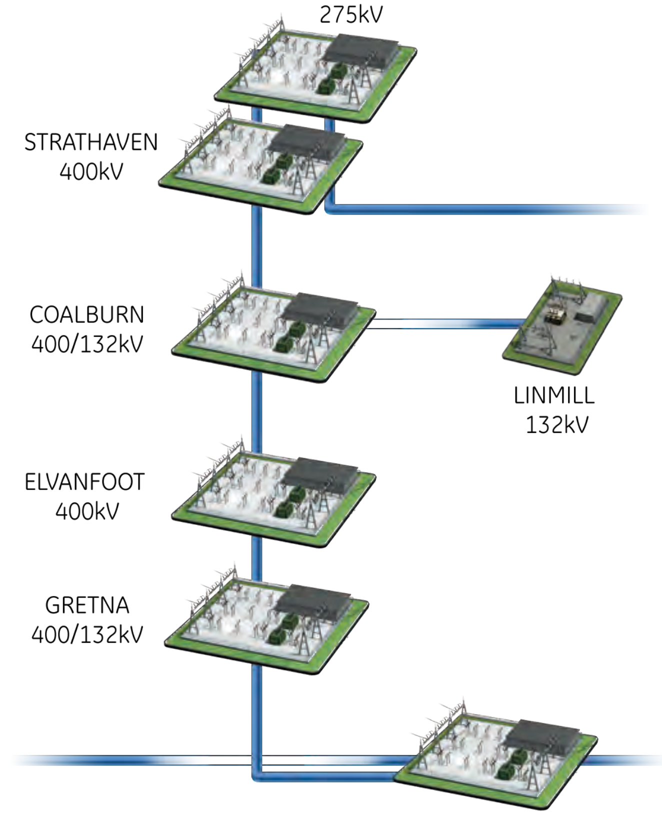

Figure 1.
West Coast Interconnector

The generation shedding scheme was implemented by Scottish Power Transmission to allow increased power flows without loss of stability between Scotland and England.

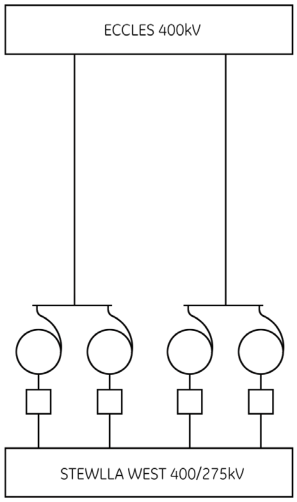

Figure 2.
East Coast Interconnector

3. System requirement

- The maximum permissible time between protection trip relay operation at any remote site and the issuing of a generator trip command at Strathaven 400kV is 25ms, including an assumed communications system latency of 5ms.
- It must be possible to send five commands between sites simultaneously with no loss of performance.
- The inter-site signalling system must comply with PROT-16-009 Issue 1 [7] for Intertripping equipment.

4. System Design

The reliability criteria for transmission planning and operation in Great Britain is the N-d criterion, which requires a transmission system to be developed and operated at all load levels and to meet the most severe double circuit contingency in addition to any scheduled outages. As multiple contingencies are beyond the planned and operational limits of a power system, the occurrence of any multiple contingencies may lead to overloading and cascading trips on the network.

Strathaven 400kV is the scheme 'hub'. Line End Open decisions are made at each site (two feeders and a bus coupler or four feeders depending on the substation) and signalled individually to Strathaven 400kV. The overall scheme logic is performed at Strathaven 400kV and the Operational Trip decision made at Strathaven 400kV is signalled to generators using existing signalling equipment (HSDI-3).

Logical Combinations of circuit breaker position and trip relay status provide Line End Open tripping initiations. In order to minimize the operating time of the scheme, protection operations are considered as Line End Open. The circuit breaker positions are monitored to capture manual opening or the operation of circuit breaker fail protection of an unmonitored circuit, which causes the monitored circuit breaker to open.

Once the scheme performance requirements had been established, SPT developed the concept of employing IEC61850 GOOSE to collect the signals for processing in scheme logic. The scheme logic was agreed with NGET and the logic was then implemented in the GE UR IEDs.

5. Physical Architecture

Having done the engineering analysis as to the device inputs and outputs, communication requirements, and system controller requirements, the final step in the implementation process was the development of the physical architecture. This drawing shows the number of devices required per substation, I/O requirements, communication channels and redundancy, system and device redundancies, time synchronization, controller locations, HMI facilities, etc. This physical architecture allows for a final review before sending the system out for final design.

In addition, the physical architecture provides a mechanism for future explanation and operator training.

In line with standard practice in the GB Transmission system, a duplicated scheme is provided:

- Each scheme (System 1 & System 2) is a full communication scheme where the final trip decision is based on circuit status from remote sites gathered using the IEC 61850 communication protocol and using a Master IED to provide the scheme logic with a link to the trip system.
- Each system is also a hybrid communication/hardwired scheme where the final trip decision is based on circuit status from remote sites gathered using conventional IED relay contacts and opto-inputs.
- Plant status inputs to each system are provided by four auxiliary contacts, two of each state, and the scheme logic checks for discrepancies. Only if the four contacts are in the correct states will the plant status be recognised.
- The Direct and Remote I/O communications both employ 32-bit CRC and comply with international standards for protection communications.
- There are extensive isolation facilities which are supervised and annunciated. These use interfaces familiar to operations staff, namely switches and removable links.

The relays used in each substation were IEDs with the following capabilities:

- Protection: Out-of-step tripping, Power Swing Blocking, Under- & over-frequency, Rate of change of frequency, Sensitive Directional Power, dP/dt, dV/dt, Overcurrent, Under- & over-voltage.
- Control: Open pole detection, Synchrocheck, Programmable Logic Control, Add, Subtract, Compare, Select.
- Communication: Peer-to-peer via Ethernet, Peer-to-peer via SONET, G.704, RS422, C37.94, Fiber, Flexible communications. Architectures, Telemetry with 8-bit resolution, Respond to remote & local data.
- Monitoring: Synchrophasors (PMU – only in the Main 1), Metering of Voltage, Current, Power, Frequency, Energy, SOE, DFR, etc.

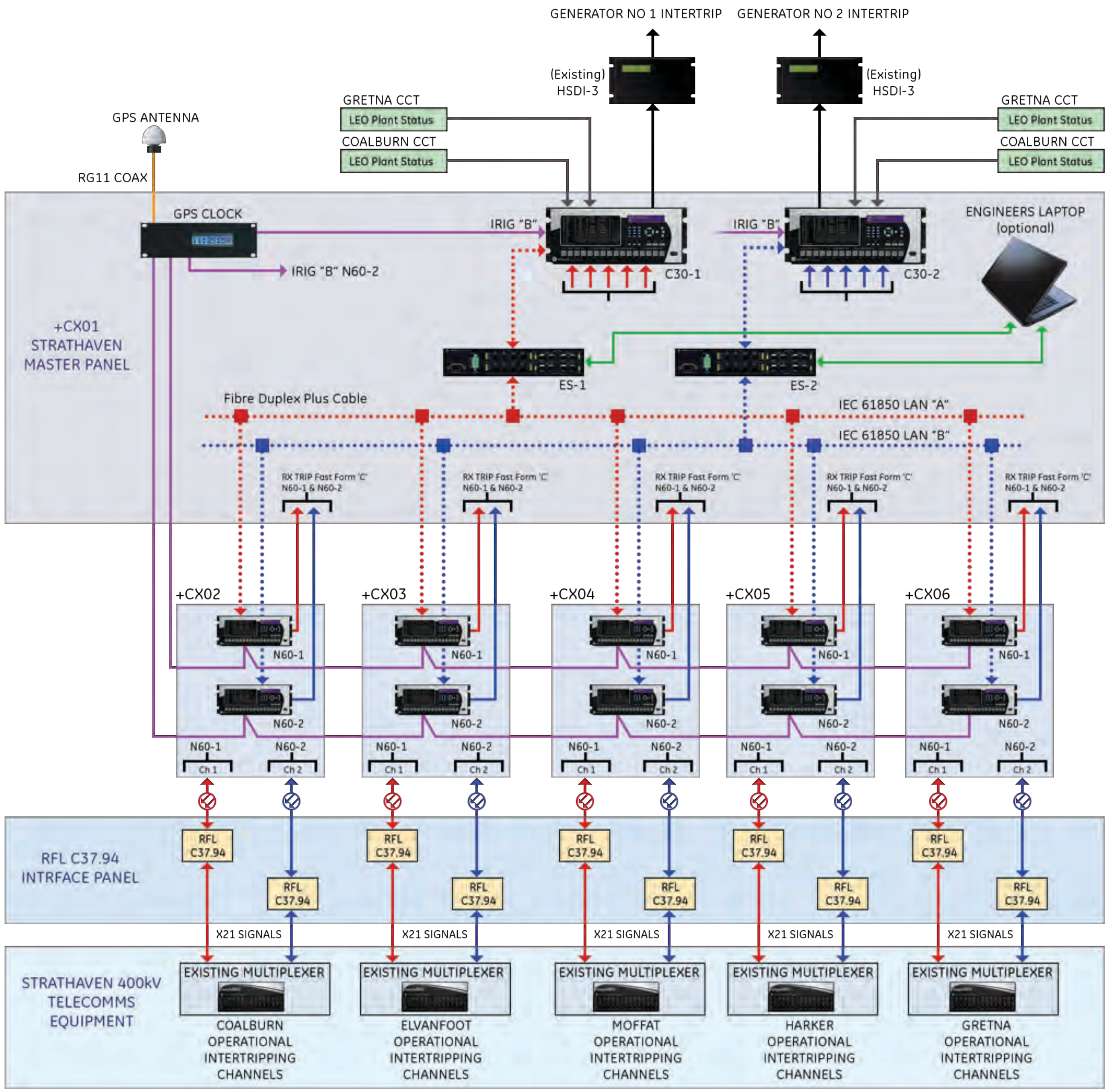

Figure 3.
Physical Architecture. Wide area generator rejection scheme.

The Master IED used at Strathaven has only Control & Communication features.

The system is designed with 10 IED units for System 1 and 10 units for System 2. Only System 1 has PMU capability. The CT and VT inputs are available at the relay panel terminal blocks but are not yet connected to the primary plant. The PMU capability has been provided to facilitate future development of the scheme and to support SPT's future wide area monitoring strategy.

The IEDs were used on the 400kV operational intertrip system for the West Coast Interconnector between Scottish Power and National Grid.

The IEDs transmit line end open signals via direct I/O from remote substations to receiving IEDs at Strathaven substation using C37.94 communication system in a redundant scheme.

At Strathaven all IEDs are connected via hardwire and Ethernet to the Master IED unit. Each IED sends signals via hardwire and remote I/O (GOOSE).

Combinational logic is used in the Master IED to route the signal through to the HSDI voice frequency intertrip equipment to trip the selected Scottish generators.

This is the first system in the UK to be in service and tripping at 400kV using IEC 61850. It has been in service since July 2008.

The system is being extended this year with a completion date of October 2009, by adding a further panel with IEDs to permit the tripping of additional Scottish generators. A Master IED which will act as a SCADA interface unit will be also added. This will take IEC 61850 commands from the Operational Control Centre (OCC) via a

Microsol RTU with an IEC 61850 interface card. It is a trial installation to observe the merits of IEC 61850 SCADA control. ICD files will be developed for this task.

6. System performance

The reliability criteria for transmission planning and operation in Great Britain is the N-d criterion, which requires a transmission system to be developed and operated at all load levels and to meet the most severe double circuit contingency in addition to any scheduled outages. As multiple contingencies are beyond the planned and operational limits of a power system, the occurrence of any multiple contingencies may lead to overloading and cascading trips on the network.

REAL TIME CONTROL SCHEMES WILL INCREASINGLY PLAY A ROLE IN MAINTAINING THE SECURITY, STABILITY, AND INTEGRITY OF THE ELECTRIC POWER NETWORK

There are three tests that are performed, namely:

- Scheme Checks
- Logic Tests
- End-to-End Tests

Total trip time was less than the expected : On average, the total trip time was always less than a cycle (20 ms) using hardwire inputs/outputs or using GOOSE (IEC61850) for final trip schemes.

7. Implementation issues / New solutions

With the C37.94 communication system, each measuring relay had one C37.94 – 64,000 bps port which was configured to transmit information on detection of a Line End Open condition.

As stated above, the Control Engineer's decision to 'arm' the system is based on prevailing generation patterns and network conditions. The system's scheme logic includes the flexibility to accommodate system outages. Commands from the OCC modify the scheme logic to allow the scheme to respond to changing network connectivity and generation patterns.

8. Operational experience

The system has been in service for almost two years now and has had no false operations, it has not been called upon to operate, and correctly did not operate during a recent trip-out of the plant.

9. Future enhancements

The potential, to improve power system performance using smart control instead of high voltage equipment installations, seems to be great. The first step should aim at achieving the monitoring capability, e.g., a WAMS (Wide Area Measurement Systems). WAMS is the most common application, based on Phasor Measurement Units (*).

Since this system has been installed, a new solution space has been made available through the communication capabilities of the IEC 61850 GOOSE to transmit and receive Digital and Analog Signals.

(*) Phasor Measurement Unit (PMU) – Device that records phasor quantities and accurately references them to a standard time signal. (See IEEE Standard 1344-2006 for more details.)

10. Conclusions

- Real time control schemes will increasingly play a role in maintaining the security, stability, and integrity of the electric power network. Today's digital relays – in close integration with advanced communication networks – promise to provide solutions for remediation of identified power system problems.
- Implemented using commercial IEDs and configured as two identical systems operating in parallel for redundancy, the SIPS meets the performance requirements defined by system studies.

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