IMPLEMENTATION OF A SYSTEM INTEGRITY PROTECTION SCHEME (SIPS) IN THE CHANNEL ISLANDS

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ABSTRACT

Channel Islands Electricity Grid (CIEG) is a company that is jointly owned by Jersey Electricity PLC (JE) and Guernsey Electricity Ltd (GEL). CIEG oversees the operation and management of several high voltage electricity cables which connect the islands of Jersey and Guernsey to the electricity grid on mainland France, and by which electricity is imported into the islands. The connection to the French grid is through a 90kV network operated by Reseau de Transport d'Electricite (RTE), France.

Both JE and GEL have operated automatic load shedding (ALS) systems for many years. In general, both systems were primarily developed to protect against faults or trip of on-island generating plant, and the possible need to trip (shed) customer load circuits to cover for the loss of generating capacity.

As the CIEG grid has developed, it was clear that a new scheme was required to protect the network against overload conditions (that may typically arise due to a fault trip on other circuits or generation plant in either island). Such overload conditions may need to be removed by shedding of load on Jersey and Guernsey in order to prevent damage or cascade tripping (which in extreme cases could result in collapse of the CIEG grid network). Circuit overload capabilities, both magnitude and duration, should be considered before any load shedding actions are initiated. Hence CIEG looked for a proposal to provide a System Integrity Protection Scheme (SIPS) to supervise the grid cables and circuits, and to provide load shedding functions as may be required in response to fault or trip of any circuit. As speed is a concern, it was needed to design a system with the capability to respond and trip in less than 120 ms.

The technical details adopted for the design of the hardware and software of SIPS are reported in this paper. The criteria applied for ensuring as far as possible security and dependability of operation of SIPS are described, and the operational results of the first eighteen months of operation are reported also. The paper also presents the RTDS studies of the power system, to validate the correctness of operation of SIPS which includes modelling process description and the analysis tests results made in different power system topology and power flow conditions.

THE ELECTRICAL SYSTEM

A simple geographic representation of the CIEG grid network, also showing possible future developments to the network, is shown in Figure 1. A simplified conceptual representation is shown in Figure 3. and the operator HMI interface is shown in Figure 2.

The system implemented fulfils the technical requirements (point 3) of the CIEG functional specification.

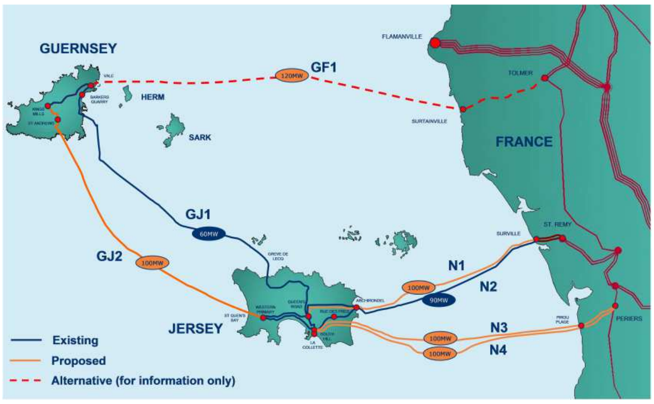

Figure 1. Electrical Grid. Existing and Future Grid

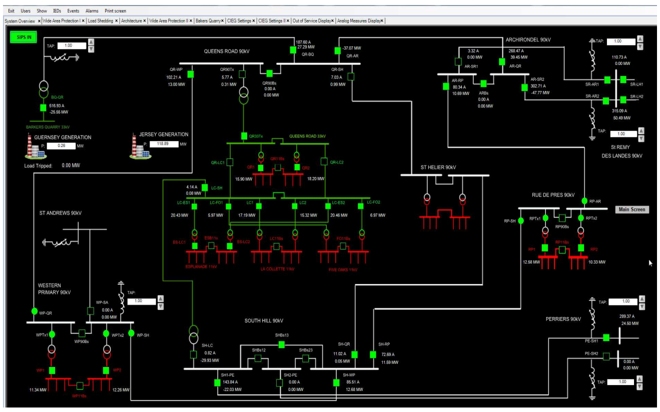

Figure 2. HMI. Electrical Network Overview

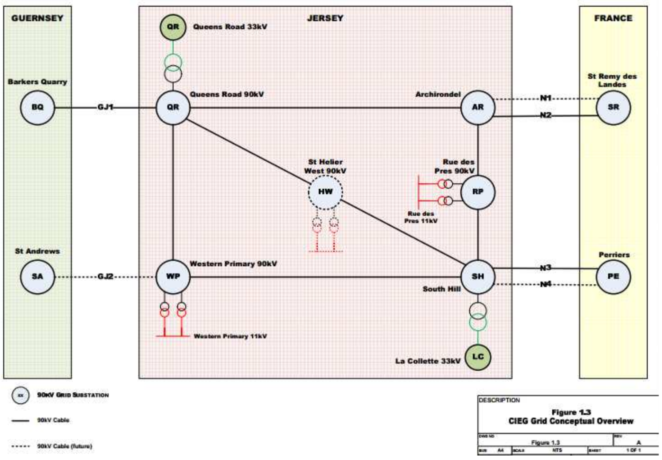

Figure 3. Conceptual representation of the Electrical Grid

The overall functional requirements for the SIPS can be broadly categorized into three main areas, as follows:

- Response to faults/trips on the 90kV CIEG grid, which may require load shedding response.
- Response to faults/trips of Jersey Electricity generating plant (effectively replacing the existing JE Automatic Load Shedding System).
- 'Wide area network' protection and switching operations in response to network failure, and post-fault automated switching.

The functional requirements may additionally be affected by the overall configuration of the CIEG network, if the network is operating as a meshed/interconnected network or if the network is electrically segregated into distinct sections.

The CIEG network comprises the following elements:

- Several parallel submarine cable circuits between Jersey and France;
- A transmission network on/around the island of Jersey;
- Presently a single submarine cable circuits between Jersey and Guernsey (but plans for additional);
- And potentially several parallel submarine cable circuits between Guernsey and France.

OPERATION MODES

There are two basic operating modes, each with distinct operational features that are catered for in the SIPS:

Parallel operation, where multiple submarine circuits effectively share the islands' loads, with an interconnected 90kV network in Jersey;

Split network operation, where there is no interconnection in the CIEG network between adjacent sections of the RTE network, effectively dividing the islands' loads between submarine circuits.

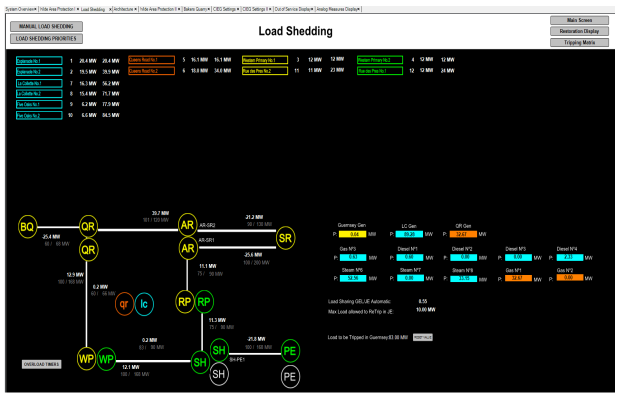

Figure 4. Operator HMI. Example of Split mode.

It must be noted that there are numerous options for splitting the network. The SIPS is fully capable of recognizing any network configuration and responding accordingly. Any load shedding response (for whatever reason) is constrained to the section of network in which the trip occurs. Hence the SIPS knows the status of the overall network, and it can recognize and react accordingly to a split network configuration.

HARDWARE ARCHITECTURE

In Figure 5, we can observe an overview the hardware deployed. It is composed by the following elements:

Outstations: collect operating information (analog and digital) relating to the substation plant at each location, and provide that data to the master system, also implement any relevant output decisions made by the master system at their respective location. Outstations are distributed in all the substations which are affected by the SIPS system. Main geographical locations are France, Jersey and Guernsey.

Dual redundant master system: analyses the network operating data received from the outstations, decide on appropriate responses required, and implement appropriate counteractions (as required). The master system contains the 'intelligence' of the network management system, implementing the functional requirements described elsewhere. The dual redundant nodes are installed in two different locations; La Collette (Jersey) and Vale (Guernsey). Redundancy is based on Hot Standby; the changeover is seamless and occurs within 250ms of loss of the original main.

Communications network: transmits data between the outstations and the master system using existing (CIEG) optical fibre connections between the various sites. System is a self-healing ring, where failure of any communications link will result in data traffic being re-routed to maintain continuous SIPS operation. A dedicated network was installed for the SIPS.

A human-machine interface (HMI): Located in Jersey and Guernsey for operations staff to monitor and control the operation of the SIPS.

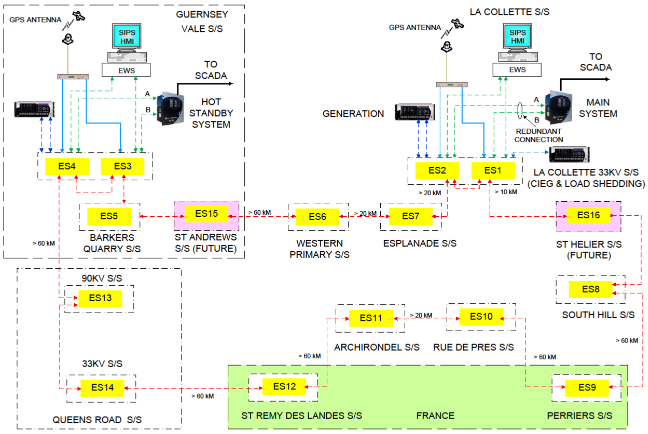

Figure 5. Hardware Architecture implemented

Information flow

Analog and digital values are transmitted in IEC 61850 GOOSE packets from each outstation to each the main stations (primary and secondary/backup control centre's). Analog values typically include Amps and MW from each end of the 90kV circuits as well as for generators. Digital values include circuit breaker status and trip signals.

All the data collected from outstations is transmitted to the Master stations. The Master stations execute the algorithms and make the decisions in order to maintain the stability of the grid. When the algorithms determine that actions should be taken then they send the outputs in GOOSE to the outstations, where those actions are executed. Algorithms will execute mitigating actions for an event based on the pre-disturbance state of the power system,

FUNCTIONS IMPLEMENTED

The overall functional for the SIPS can be broadly categorized into three main areas, as follows:

Response to faults/trips on the 90kV CIEG grid

The CIEG 90kV network is designed to be capable of operating at near full load capability in order to make optimum use of the cable investment. Consequently, a trip on any of the 90kV circuits at periods of high load has the potential to induce overload conditions on adjacent circuits. Such overload conditions could potentially result in overload tripping of adjacent circuits and ultimately the collapse of the entire CIEG grid.

Load shedding response may therefore be required to protect the grid from the original overload condition, and maintain the stability of the grid with minimum load shedding intervention – better to shed a small number of customers than to compromise the entire grid.

Many of the CIEG circuits have significant short-term overload capability, and SIPS takes this into account in order to minimise load shedding response whilst still safeguarding the system.

Response to faults/trips of Jersey Electricity generating plant (effectively replacing the previous JE Automatic Load Shedding System)

When operating in 'island mode' (not connected to France) a generator trip in Jersey could result in overload or excessive load pickup on other generators, hence load shedding may be required to protect against generator overload or cascade tripping. A rapid load shedding response would be required in order to protect against such a situation. Note that in Guernsey the existing load shedding system provides this functionality independent of SIPS.

'Wide area protection' (WAP) functions:

Where a fault/trip on a CEG circuit requires a dynamic trip response elsewhere on the CIEG network in order to maintain grid stability, then SIPS is required to execute such responses based up pre-configurable scenarios. Such dynamic trip functionality had previously been implemented using a complex system of protection relay and teleprotection signalling which was difficult to maintain and diagnose. The configurable SIPS scenarios are simple to understand and modify, whilst providing resilient and reliable WAP responses.

The functional requirements may additionally be affected by the overall configuration of the CIEG network, if the network is operating as a meshed/interconnected network or if the network is electrically segregated into distinct sections.

SIPS Operational requirements

i. 120 ms Response time
ii. HMI / Settings fully configurable
iii. Power Directionality
iv. Priority selection
v. WAPS scenarios configurable
vi. Trip Prediction allowing operators to take actions before a real fault occur.
vii. Cost effective Redundancy without duplications in devices

a. Measures checking taking alternative paths when Local values are suspicious/faulty.
b. Algorithms to take alternative paths when a single node fails (Eth Switch / IED).

viii. Hot-stand by in Control Central units with a 250ms in a switchover.

ix. Ready for complex network topologies (i.e. Meshed grids).

Facilities are provided to permit CIEG engineers to manually override or block the automated sequences described above, hence preventing the associated switching operations. This may be required for example where 'normal/planned' switching operations are in progress, where the automatic responses may be unnecessary or undesirable.

Any of the initiating signals may be manually blocked by CIEG engineers using the SIPS HMI. In this case, an alarm is generated to the alarm list, and a clearly visible indication remains on the SIPS screens to indicate blocking is in force.

ADDITIONAL FEATURES IN MASTER STATIONS

In addition to the arming, target selection, and breaker logic analytic calculations for each of the outage contingencies, the master stations run application analytics to support system operation. These include:

Master Controller in Service/Out of Service: when 'Out of Service' the Master stations will not send any trip orders but continue monitoring the system and executing the results showing them in events and alarms list.

Power measurements: during a widespread power system disturbance, there may be considerable transient power disturbances measured for any generator or grid circuit. To prevent inaccurate decision making based upon erroneous transient analogue measurements all power is damped in such a way as to eliminate incorrect SIPS response that may otherwise arise under transient fault conditions.

Monitoring communications availability and providing statistics for each link.

Capturing events, values, and decisions in the controller needed for post-mortem analysis of operations or failure to operate, including trigger events.

Resilience, Redundancy and Diagnostics: SIPS is highly important to CIEG, failure to operate or spurious operation could result in expensive and highly disruptive damage to plant and equipment, or in unnecessary disconnection of electrical supply to many customers. As a rule, failure of any single outstation node, or communications to any outstation does not render the SIPS system inoperable. Where a failed node is used for data gathering only, it is generally possible to estimate the state of the overall network using information gathered from adjacent nodes, to allow continued analysis of the network to a reasonable degree of accuracy. Where a failed node would be used to output a load shedding response, then the master system recognizes that node as being unavailable, and selects alternative responses from healthy nodes.

Software Design & Implementation Approach

- Software design supports additions of functions and modules without redesign of other functions and modules.
- Software design supports expansion of processing capacity without redesign of functions, modules.

SYSTEM CAPABILITY

The initial system provides sufficient expansion capability to increase future circuits, cables and loads.

INTEROPERABILITY WITH EXISTING SYSTEMS

Interoperability with grid protection is limited to contact inputs and outputs in outstation devices and peer to peer communication through IEC61850 protocol to the Master stations.

The SIPS Master Station provides data communication interfaces to existing CIEG SCADA systems using DNP3 and Modbus protocols.

FACTORY TESTS AND COMMISSIONING

This type of SIPS is complex to test due to the requirement to recreate the network dynamic conditions which generate the signals (voltages and currents) and test the closed-loop response to the different algorithms within the master. Therefore the proposal for the FAT was to use a Real Time Digital Simulator (RTDS) as the main tool for testing all scenarios. These tests not only provided the end client with the confidence that the system operated correctly but highlighted additional unforeseen scenarios and the necessity for design enhancements to the original project scope. RTDS testing enabled the client to put the SIPS system into service with a reduced commissioning time and minimum disruption to the operational network.

Modelling

The model was prepared to emulate the real power system as closely as possible. The main HV CIEG system contains as follows: 4 submarine cables (90kV), 10 transmission lines (90kV, 33kV), 6 diesel generators in Guernsey, 4 diesels generators in Jersey, 3 steam generators in Jersey, 3 gas turbine generators in Jersey, 13 loads, 5 shunt reactors and 8 transformers.

RTDS simulator creates the opportunity to do many comprehensive "real" time simulation tests, but the same as all devices, it has some limitations, and therefore some simplifications were necessary. Nonetheless the completed RTDS model provided a very accurate representation of the dynamic characteristics of the CIEG grid, including dynamic load flow modelling in response to trips of CIEG cables or generators. Generator models incorporate AVRs and Governors with primary and secondary regulation.

Tests

To validate the model correctness, several tests were performed. The tests focused on overview model functionality such as power system stability in response to a load shed, additional load connection and effectivity of primary and secondary regulation when the CIEG system works connected to France or in island mode.

During FAT testing of the SIPS itself, extensive scenario testing was performed to verify all aspects of the SIPS performance under a wide range of credible operating conditions. This was essential for verification of SIPS performance, since 'real-life' testing on the operational grid would not be possible.

Example of Load Shed Test

In this test 20 MW load is shed. To check the system response, generated active power P, frequency f and P flowing through indicated lines are measured. The results can be seen in Figure 6.

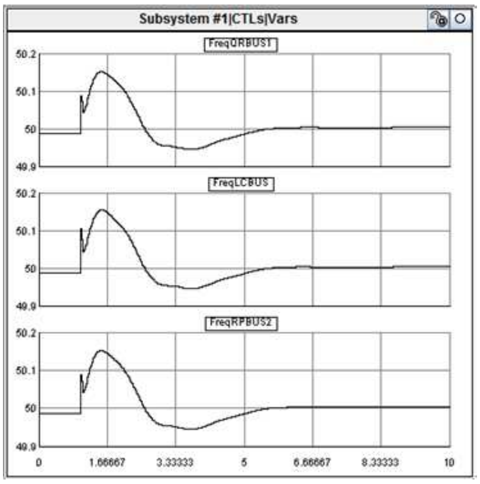

Figure 6. Frequency after load shed

Commissioning and In-Service Operation

Due to the extensive FAT testing the SIPS commissioning was limited to proving of I/O wiring and data mapping plus very limited repeat of SIPS core functionality. SIPS entered full service in November 2015.

Since commissioning SIPS has performed reliably and without unwarranted intervention or action. SIPS has also been required to operate 'in anger' on one occasion as a result of a trip of one of the CIEG cable circuits. Further enhancements to SIPS functionality are planned to be implemented in Autumn 2017.

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