Locamation SASensor High-Medium Voltage (HMV) Primary Substation Protection at Caputh Substation
Project ref. NIA_SSEPD_0002

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Executive Summary

Project scope
The SASensor system uses a digital approach to protection and control of our substations, giving a central hardware processing approach in contrast to the individual relaying approach SSE currently practise. This system will allow remote connection to the system to retrieve fault and Maintenance information, and allow for remote programming of settings, reducing the need to travel to site, and improving the overall network for our customers. The SASensor HMV system was deployed at Caputh substation in Perthshire, which has high instances of HV network faults.

Aims

- Proof of concept and testing the reliability of the protection system under a variety of conditions in a service environment.
- Understand how easy the system is to install, operate and maintain.
- Compare the SASensor system with traditional IED solution both technically and commercially.

Activities

- Design, install, test, commission and operate SASensor system in parallel to the existing IED protection.
- Compare performance of SASensor to the traditional IED operation.
- Install SASensor in the PNDC for end to end testing of faults.

Outcomes of the project and key learning

- SASensor performed very well under end to end performance testing at the PNDC (see Appendix V). Pre-trigger digital fault recording identified a fault before it became a disruptive failure.
- SASensor is marginally cheaper than traditional IED's and much easier, quicker and cheaper to retrofit [see Appendix IV], however further savings may be possible for large scale roll out.
- The SASensor system can be remotely accessed to examine data post fault, reducing outage times. The SASensor system can be remotely upgraded to accept new functionality and management of protection settings etc.
- Effective communication is required for remote access; ADSL connection, GSM modem.
- The SASensor configuration architecture is based on standard panel types which continue with the SSE methodology of reduce engineering / implementation costs and ongoing management costs.
- IED's have limited storage for fault records and the Digital Fault Recording files (DFR's) have a sample rate of less than 2 kHz (4KHz required for pre-fault recognition).
- The limited remote connectivity on IED's are rarely used due to problems with integration into the SCADA systems and the vulnerabilities of the open nature of (for example) the IEC61850 protocols.
- Some "pre-trigger information was generated by the SASensor system which has been translated into reduction in disruptive failures in Alliander. This has led to additional benchmarking with Dutch Utility. Refer to separate report.
- Battery charger needs to be adequately rated.
- Communication links need to installed at each primary substation, ideally [dark] fibre optic cable.
- Training will be required on system operation. The system is simple and easy to operate and will be more familiar and simpler for new Engineers to understand than manual setting of disparate IED's.
- Local data storage is far greater on the SASensor system than with IED's and can be automatically backed up for historical analysis.
- The SASensor system captures the Auto reclose operations and DFR files which therefore enable analysis of network behaviour without the need for comms to the pole mounted reclosers.
- The HMI should be fed from DC in case of substation power outages (use of an inverter).

- Management of IED passwords, configuration files, firmware versions and system setting files etc. can be problematic. Management as well as version control over the firmware / software on SASensor is much simpler and easier than on disparate IED's.
- SASensor may reduce maintenance costs.

Additional learning

- Benchmarking with Alliander;
  - Remote access can save on average 30 minute reduction in HV CML's.
  - Pre trigger DFR's can be used to identify a self-extinguishing fault prior to disruptive failure, reducing CI's by 5%.
- Protection functionality must take absolute priority and not be compromised by any malfunction in analytical layer and have functional and preferably physical separation.
- SASensor simplifies the IT landscape and can be simply integrated into the existing SCADA system, with remote access for diagnostics over VPN.
- The new Open platform enables 3rd party algorithms to be coded on the system, offering additional future flexibility.
- The Locamation solution can help deploy 16 of the 20 key innovations identified in the RIIO top 20 innovations roadmap.

Conclusions

- SASensor is a viable option for roll out.
- SASensor is as reliable as traditional IED's.
- The new SASensor Open platform enables new functionality to be developed by 3rd parties; work with best in class.
- Some functionality is existing and some requires further development. Development can be carried out by 3rd party best in class providers and testing of new functionality can be provided at the PNDC.
- Substantial CI and CML savings can be made using the SASensor system [subsequent benchmarking with Alliander].

Future work

- Recommended for further investigation; consider roll out into Business as Usual.
- Develop front end IT systems to automatically upload and manipulate the raw data for fault location, pre-fault identification, planning and operation to capitalise on the high fidelity data.
- Recommend ongoing analysis of DFR files to identify potential network improvements, possibly by the PNDC or Academia [subsequent benchmarking with Alliander].
- Next step in SASensor Open Platform development: extend the system with (for example) a Linux platform at substation level. This will simplify 3rd party function integration while maintaining reliable SASensor core functionality and enabling the standard SSE cyber security function to be used.
- Integration of protection and ANM schemes [refer to the Digital Substation Platform project].
- Integration of condition monitoring and other analytical applications by best in class 3rd party companies and performance tested at the PNDC.
- ENA assessment of the SASensor system.
- Apply protection functionality on a live network (presently operating in Shadow mode).

1 Project Background

Primary substation protection currently consists of a relay based approach, where each protection function is usually performed by a single relay. This approach requires hardwired copper connections between CTs and relays, with a number of multicore cables required to connect the substation together. At many sites electromechanical relays still exist, while newer installations use modern numerical relays for this task. Development of new protection and control relays are always being delivered by the large developers (ABB, Alstom, Schneider), while more novel techniques may be overlooked. SASensor is a software driven protection system, which does not use a relay based solution to protect the power system. To do this, interface modules are installed on the secondary circuits of current transformers (CTs) and voltage transformers (VTs) to digitise measurements, and the switchgear is controlled by the software through breaker interface modules.

This project looked at the ability of SASensor to protect a primary substation using a digital approach, and provide a finanical comparison between this and carrying out a traditional approach. It will investigate the ability of the system to provide better asset management within a substation, and how OPEX costs differ in comparison with the traditional relay approach.

The project involves a UK deployment of the Locamation HMV SASensor solution which has been successfully deployed in the Netherlands. This system uses a digital approach to protection and control of our substations, giving a central hardware processing approach in contrast to the individual relaying approach we currently practise. This system will allow us to connect remotely to the system to retrieve fault and Maintenance information, and allow for remote programming of settings, reducing the need to travel to site, and improving the overall network for our customers.

2 Scope and objectives

Assess one of the available solutions for alternative protection method at Primary substation level. Outline the required hardware and software required to install system at a local substation, with a high number of faults. Install and commission the equipment, then monitor for 12-18 months. Provide a report on the ability of the system, including a financial analysis of existing systems versus the new technology. The system is currently deployed at Caputh, has no control over the network, but is actively monitoring the network for fault analysis purposes.

This project will look at the ability of SASensor to protect a primary substation using a digital approach, and provide a financial comparison between this and carrying out a traditional approach. It will investigate the ability of the system to provide better asset management within a substation, and how operational expenditure costs differ in comparison with the traditional relay approach, awaiting real faults on the system for the purposes of fault analysis. It is anticipated that by summer 2015 there shall be enough data collected for analysis, note; postponed until end 2016 due to issues with battery charger rating.

3 Success criteria

Caputh Substation Locamation SASensor Installation Key Performance Indicators

1. Evaluate SASensor's ability to perform under a variety of fault conditions (10 system faults).
2. Proof of stability for faults beyond the first pole mounted recloser and proof of clearance for faults close into Primary substation (10 system faults).
3. Identification of fault current on individual feeders when faults occur.
4. SSE Power Distribution to improve understanding of commercial and technical aspects of system deployment (installation, design, commissioning and maintenance) with existing practices.
5. Evaluate the event recorder data to see if proactive maintenance of switchgear can be performed via condition based monitoring.
6. Evaluate system for business roll out.

4 Details of the work carried out

4.1 Method trialled

SASensor HMV system was installed in parallel to the existing IED's with all functionality enabled, but without connecting the interaction to the primary equipment. This creates an evaluation setup where the full system functionality can be evaluated with and the captured data can be compared between the SASensor system and the IED's.

An ADSL line was connected into the substation in order to access the equipment remotely down a VPN tunnel.

The primary switchboard was selected at Caputh, which has high instances of network faults; network diagram below, see Fig1.

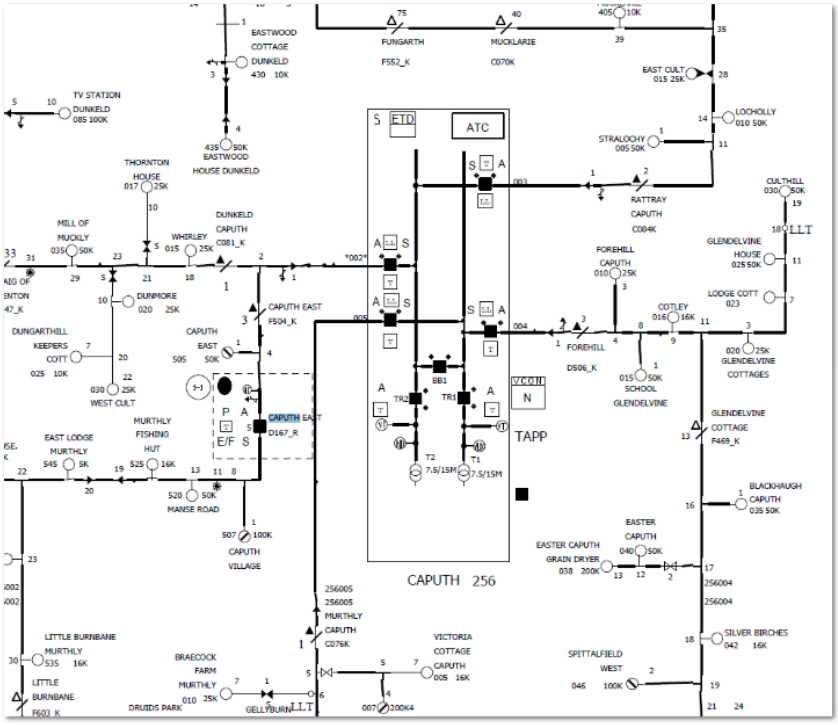

Figure 1: Network Diagram

The architecture of the SASensor system is shown below in Fig 2.;

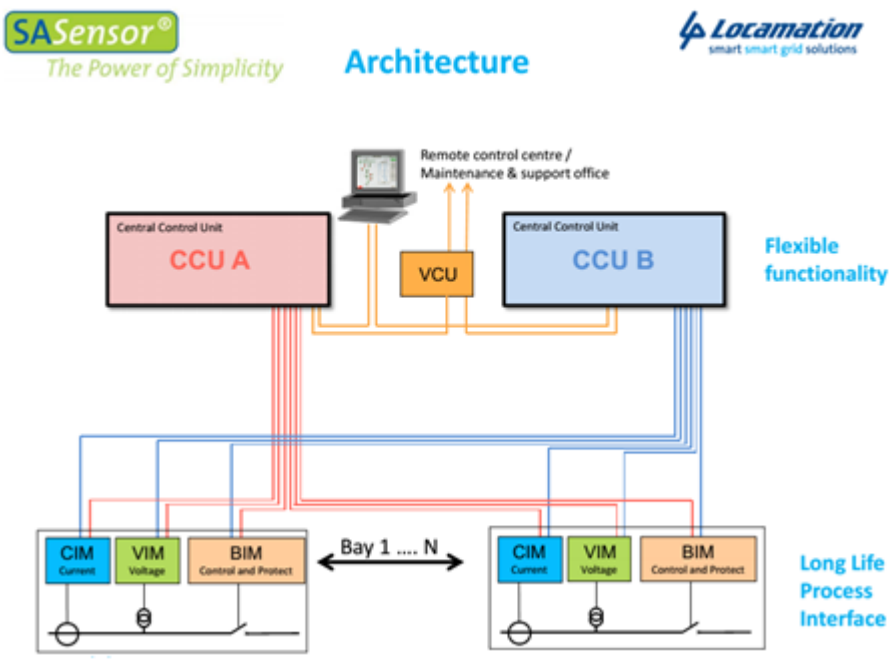

Figure 2: SASensor Architecture

4.2 Trialling methodology

Set Up - The SASensor system was retrofitted into the substation see photos Photographs 1 – 4 below. The outputs from the VT were connected to the Voltage Interface Module (VIM), the CT secondary's were passed through the CT's of the Current Interface Module (CIM) and the digital inputs were connected to the Breaker Interface Module (BIM).

These were connected to dual redundant Central Control Units (CCU's) by fibre optic cables.

Photo 1: CIM

Photo 2: BIM

Photo 3: CCU

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Photo 4;Installation on Caputh switchboard

Data collection - Event recording is standard on the SASensor system. This was compared to fault records and data stored within the IED's. The system was connected to SCADA by DNP3.

Analysis - Comparison and analysis of the 2 sets of results were compiled by Locamation. Each phase of the project was subject to analysis;

- Engineering
- Installation
- Commissioning
- Operation
- Other

4.2.1 Performance testing at the PNDC –In addition to the trial at Caputh, a SASensor system was installed at the PNDC so that it could be subjected to a number of performance tests, operating on real network faults. Refer to Appendix V.

5 The outcomes of the project

5.1 Caputh substation

- **Engineering**
  - Continue with the methodology of creation of standard panel configurations to minimise engineering, installation, commissioning and management. The configuration of the SASensor system is already built with panel standardisation in mind.

- **Installation**
  - The installation was carried out by SSE Contracting, with the Distribution Major Projects Field Unit providing the operational assistance required to install the system. The CCU cabinets were installed in the corner of the control room, the VCU cabinet was wall mounted and all associated interface units were placed within the existing switchgear and relay panels. A

dedicated computer was used as the Human Machine Interface (HMI) on site to allow local access to the CCU and wider system.
- Individual DC miniature circuit breakers were installed at each position where one or more interface units were going to be installed within existing panels. This allowed for isolation and safe installation of the equipment, without interrupting any existing switchgear supplies.
- Fibre optic cabling was used on site to connect all of the interface units to the CCU, VCU and HMI. This was run within copex tubing to provide a more robust protection layer to the fibre optics.
- Once the CCU, VCU and HMI were all powered up, outage were taken on each individual circuit to connect the CTs through the CMUs. This could not be done with the circuits in service, and backfeeding of the network was essential. The BIM and VIM units could be installed without backfeeding the circuits.
- A 48V battery charger was sourced to power the VCU and CCU cabinets from PE systems at the request of RTS to keep all items associated with the RTU on a positively earthed battery charger.
- Overall the installation of the system was straight forward, and connecting all of the units together via the fibre optics was easy. A couple of issues were picked up during the commissioning of the equipment. The installation of the full system took approximately two weeks, and an additional week was required to connect the CIM units.
- Getting an ADSL connection to the site proved to be more difficult. It took BT over 6 months, and several visits to get a cable installed into the substation, and get suitable hot site isolation equipment for the site. This was all going on while the SASensor system was put into service, although no remote access could be made to the site during this time.

- **Commissioning**
  - Locamation provided all the necessary commissioning resource to get all of the equipment on site up and running. This took one day to get all of the equipment communicating with the HMI via the CCU cabinets. All of the software had been prepared before arriving at site, and minor modifications to the arrangement were required only. As this was provided from the R&D supplier there is not a complete knowledge on how the system works, and training would need to be rolled out by Locamation to SSEPD engineers who would be looking to carry out different tasks on the equipment e.g. settings changes, fault record retrieval, signal modifications etc…
  - Problems were identified with some of the fibre optic cabling, which appeared to have been damaged during the installation. This highlights the care that must be taken during the installation period. New fibre optic cabling was sourced after the commissioning and connected to the system without any issues. Again this shows the flexibility of system when replacing a damaged item of the control system.
  - The remote connection could not be commissioned at the same time due to delays in the installation of the ADSL link. After it was finally connected the connection to the remote system was relatively simple, and only required minor changes on site after discussion with Locamation.
  - One issue of note during the trial period was that the 48V battery charger sourced to run the VCU and CCU cabinets was not suitable for the load requirements. This was an oversite by the SSEPD installation team, and was remedied by supplying the CCU from the existing 110V battery charger on site, as it should have initially been done.
  - Apart from some minor issues the system was relatively easy to commission and has happily worked in the background of the existing control and protection system to provide fault analysis.

- **Operation**
  - Please see attached comparison report in Appendix II. Conclusions and summary provided below;

    From Caputh comparison report;
    - On 14/01/14 we noticed a pre-trigger from the DFR files of approximately 330 Amps on the red phase of bay 2, then 6 hours later the yellow phase of Bay 2 tripped on fault @350A.

- 2 events need more evaluation. Some data files are missing from the IED's.
- SASensor captured all of the Digital Fault Recording [DFR] files which can be used for analysis of the faults.
- In all other events, the SASensor system has the same reaction as the conventional equipment, or has more information available. However:
- The logging from the conventional equipment is very limited in time.
    - The history for the conventional equipment only shows events for the last 3 months.
    - Both CCU's have more that 50% of free space available for additional logging. Based on the trial, it is estimated that the CCU'scan locally store approximately 2 years of network data. In any eventuality, the data can be automatically backed up on the SAServer, assuring that no data is lost.
- The existing SASensor configuration does not have sensitive earth fault protection, but the CCU has captured the data for this. The available 3rd party function (provided by Locamation's partner Protrol) would have handled the SEF correctly and possibly the traditional earth fault application would have operated normally if the settings were set a bit more 'tight'.

- **Operation Other**
    - SSEPD need to define the core protection functions required to ensure that Algorithms either exist or can be added to the platform. Some of these are in the development roadmap, but other functions may require adding. The PNDC could provide external support to develop these.

- **Comparison with IED solution**
    - Installed SASensor system is marginally cheaper than equivalent system with IED's, but additional savings could be made under roll out.
    - The SASensor system is easy to use and communicates directly with the SCADA over DNP3 without issue. SASensor simplifies the IT landscape and can be simply integrated into the existing SCADA system, with remote access for diagnostics over VPN.
    - The SASensor system comes in 5 basic device forms; CIM VIM BIM CCU and VCU's, making stock management much simpler and cheaper. Functionality is all software based. Version management ensures that all systems are upgraded to the latest version of operating system and new functionality can be remotely upgraded.
    - IED's have limited storage for fault records and cannot provide highly accurate DFR's which can be analysed to identify fault location and pre-triggers – refer to separate report..
    - The limited remote connectivity on IED's are rarely used due to problems with integration into the SCADA systems and interoperability between manufacturers using IEC61850 protocols. Protection settings can be remotely checked on the SASensor system which reduces travel to site and duplication errors.
    - SASensor can be upgraded with new protection, control and analytic functionality which can be uploaded remotely as new requirements emerge.

- Vendor Lock in
    - Whilst the SASensor is a proprietary design, it can host 3rd party algorithms, as well as communication to industry standard devices including IEC61850.

- Communication
    - Ensuring good communication to the substation was problematic. SSEPD need to consider a solid communications infrastructure programme in order to maximise the value of the system and information.

- Maintenance of primary plant
    - SASensor has built in breaker fail protection, which can form part of a Condition Based Maintenance strategy.

  - A Trip timing testing algorithm is under consideration on SASensor at the PNDC as a core research project, which can reduce maintenance operations within SSE and identify sticktion in mechanisms, driving condition based maintenance procedures.
  - The system can host other Condition Based Maintenance techniques, including partial discharge monitoring (new low cost solutions are being developed in the marketplace) and Smart Cable Guard.

- **Reliability / availability**
  - SASensor is a dual redundant system; if one of the CIM's or VIM's fail (these are high reliability design) then the system will continue to function normally, taking references from the other panels. There is a dual CCU, which both operate as masters.

5.2 Additional learning

Some "pre-trigger information was generated by the SASensor system which has been translated into reduction in disruptive failures in Alliander. This has led to additional benchmarking with Dutch Utility.

Refer to separate report.

- Other
- Battery charger needs to be adequately rated.
- Communication links need to installed at each primary substation, ideally [dark] fibre optic cable.
- Training will be required on system operation. The system is simple and easy to operate and will be more familiar and simpler for new Engineers to understand than manual setting of disparate IED's.
- Local data storage is far greater on the SASensor system than with IED's and can be automatically backed up for historical analysis.
- A SASensor system has been installed at the PNDC for performance testing; report attached.
- The SASensor system captures the Auto reclose operations and DFR files which enable analysis of network behaviour without the need for comms to the pole mounted reclosers.
- The HMI should be fed from DC in case of substation power outages (use of an inverter).

5.3 Technology Readiness Level (TRL)

Technology readiness level has increased from 7 to 8 during the project; the system is already in commercial use, however there is continuous system function improvement and expansion.

5.4 Business Benefits

- Business benefits (Refer to attached presentation see Appendix III).
  - The headline values from Alliander for the benefits case are;
    - Use of high fidelity DFR files for cable fault reduction using pre-trigger information and automated distance to fault; 30 minutes reduction in average travel time per fault ; 5% reduction in disruptive failures – refer to separate report.
    - Remote interrogation of substation data, protection settings etc.
  - Other business benefits are identifies in Appendix I.

6 Performance compared to original project aims, objectives and success criteria

The project succeeded in proving the digitised approach to a central solution protecting the whole switchboard and provided access to accurate fault data for remote diagnostics.
A large number of DFR files have been generated during the trial, the contents of which could be analysed to generate more insight into network behaviour; initial analysis has identified situations where network failures have occurred.

In addition, use of the pre-trigger function has identified where a number of faults could have been identified before disruptive failure, refer to the analysis report in Appendix II.

The platform can be remotely managed and upgraded to accept new functionality as requirements emerge.

Table 1 - Extent to which objectives have been met

Objective	Met?	Commentary
Current policy is to use individual relays to protect the power system from faults. This leads to vendor lock in as well as entrenching systems that are not flexible or interoperable. The proposed project uses a digitised approach where a single processing unit protects the entire substation. It gives remote access to fault information, which may assist in a reduction of customer minutes lost during power cuts, and provides information which can be used to determine whether maintenance of plant and equipment is required.		SASensor is a viable option, it is simple to use, simplifies the substation and IT architecture and is suitable for future upgrading and produces significant business benefit.
The project involves a UK deployment of the Locamation HMV SASensor solution which has been successfully deployed in the Netherlands. This system uses a digital approach to protection and control of our substations, giving a central hardware processing approach in contrast to the individual relaying approach we currently practise. This system will allow us to connect remotely to the system to retrieve fault and Maintenance information, and allow for remote programming of settings, reducing the need to travel to site, and improving the overall network for our customers.	✓	Training on the system will be required, especially with respect to how the layers of the system are built.

Table 2 - Extent to which success criteria have been met

Objective	Met?	Commentary
Evaluate SASensor's ability to perform under a variety of fault conditions	✓	Protection operated successfully at Caputh and bench testing continues as part of the DSP project.
Proof of stability for faults beyond the first pole mounted recloser and proof of speed for faults close into primary s/s	✓	Additional testing underway at the PNDC for increased functionality. The SASensor system captures the Auto reclose operations and DFR files which enable analysis of network behaviour without the need for comms to the pole mounted reclosers.
Identification of fault current on individual feeders when faults occur under a variety of fault conditions.	✓	On 14/01/14 we noticed a pre-trigger from the DFR files of approximately 300 Amps on the red phase of bay 2. 6 hours later the yellow phase of Bay 2 tripped on fault @350A.
SSE to improve understanding of commercial and technical aspects of system deployment (installation, design, commissioning and maintenance) with existing practices	✓	Business case positive.
Evaluate the event recorder data to see if proactive maintenance of switchgear can be performed.	✓	DFR files produced during fault conditions and pre-trigger files generated. TTT project in consideration at PNDC.

7 Required modifications to the planned approach during the course of the project

- There were no major changes to the planned trialling methodology, however, following the results obtained on identification of pre-faults and remote access, benchmarking was carried out with Alliander to validate the results.
- A SASensor system is being installed at the PNDC and additional reliability testing will be carried out on the SASensor system.
- Delays incurred due to installation of ADSL line by BT.
- CCU initially fed from an undersized 48vDC battery charger which needed to be replaced.

8 Significant variance in expected costs and benefits

Table 3 - Project costs

Item	Forecast	Actual	Variance (£k)	Variance (%)
Project Management	24.02	17.87	6.16	34.35
Equipment	85.93	84.43	1.50	1.78
Installation & Decommissiong	37.09	30.87	-3.78	-12.23
Total	137.04	143.16	-6.12	-4.27

- The benefit of the project has met expectations. With the potential reduction in CI and CML penalties however, the business benefit is substantially greater.
- Additional business benefits have been identified, but left out of the headline benefits for now pending further investigation (see Appendix I). The platform has the potential to enable other technologies under development, including radiometric fault location Active Network Management schemes, Real Time Thermal Ratings, Condition Monitoring etc.
- The Locamation solution can help deploy 16 of the 20 key innovations identified in the RIIO top 20 innovations roadmap; see below.

RIIO-ED1 primary output	Top 20 innovations for RIIO-ED1
Connections	Active network management - community demand management
	Active network management - generator constraint management
	Demand-side management - thermal energy storage
	Dynamic circuit thermal rating
	Fault current limiters
	Local smart EV charging infrastructure
	LV solid-state voltage regulator
	Static synchronous compensators (STATCOMs)
Customer Service	Advanced distribution automation - network reconfiguration
	Weather impact and response modelling tools

RIIO-ED1	Top 20 innovations
Environment	Bidirectional hybrid generation plant
	Wood pole alternative
Reliability	Automatic demand response with commercial customers
	Energy efficiency approaches
	LV network modelling
	LV network monitoring
Safety	Arc suppression coil and residual current compensation earthing
	Conductor sag and vibration monitoring
	Live line tree felling
Social Obligations	Enh.supply monitoring and supp. for vulnerable customers

key
Criteria for this project
Other areas for integration onto the platform (out of scope)

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9 Lessons learnt for future projects

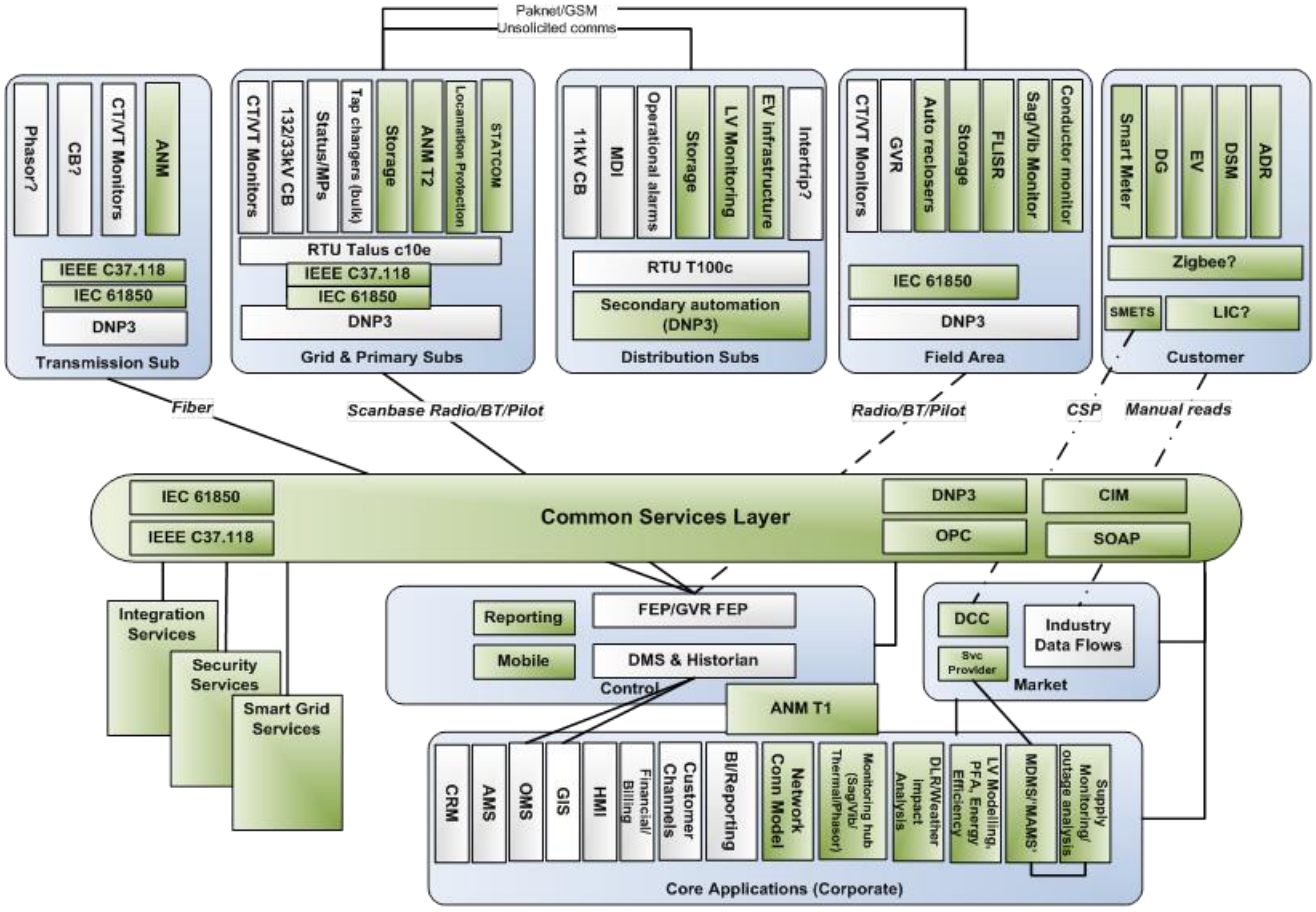
- Immediate recommendations
  - Upgrade the SASensor system at Caputh to include the high impedance arcing earth fault algorithm by Protrol and the new SASensor Open Platform.
- Bench study on the DFR files to identify potential network improvements.
- Further investigation on how to include fault prediction and location into BAU.
- Generation of new functionality in conjunction with PNDC and other technology houses.

- Future requirements – Digital Substation Platform project
  - The system was analysed to determine if new functionality (ANM, Condition Monitoring) can be incorporated on the platform as part of the Digital Substation Platform project. Feedback from the SSEPD / Locamation / SGS working groups as part of the Digital Substation Platform project;

    - The Protection Engineers requested that non-core functionality (protection) should have separate hardware in case of and that no failure of any applications can affect core functionality.
    - An industry standard OS is required to host corporate Cyber Security software programs; initially firewalls but with increasing requirements for Cyber immune systems in the future. This could be hosted on a substation computer or included within the SASensor system itself.
    - ANM algorithms can be coded onto the SASensor Open Platform (SGS “Connect” was coded easily for example), however, SGS requested a standard OS build environment in order to easily manage product upgrades for new connections and system changes in the future.

10 Planned implementation

- The Locamation solution is a viable option for adoption into BAU. Potential implementation may be considered for;
  - Roll out of SASensor across all primary switchboards.
  - Roll out of SASensor across switchboards with high instances of cable failures and high densities of populations.
  - Roll out SASensor across all new switchgear and for protection upgrades.
  - Roll out SASensor when ANM functionality is employed.



11 Project replication and intellectual property

The following tables list all physical components and knowledge required to replicate the outcomes of this project, showing how the required IP can be accessed by other GB DNOs. Further detail relating to any knowledge item is available from SSEPD on request through futurenetworks@sse.com.

Table 4 - Components required for project replication

Component	Products used in project or commercially available equivalents
Artos Operating System, SASensor Software Suite And SASensor Hardware	Locamation SASensor HMV system. IP owned by Locamation

Table 5 - Knowledge products required for project replication

Knowledge item	Application	IP ownership and availability
Understanding on how centralised protection systems can increase performance of the DNO and identify risks and benefits.	Roll out of SASensor HMV Protection system.	SSEPD

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Appendix I
Benefit analysis

	Item	Application	cost benefit	Description	Existing solution	Saving
Network Performance	**1**	Failure prediction and prevention	high	Use of pre-trigger Enhanced DFR capture identifies failures prior to interruption (sse Caputh results).Alliander only take action when they receive 2 SASensor pre-trigger alarms. Within 10 days before we adding an extra measurement (Smart Cable Guard); less than 10 days is too short for the organisation to react. From analysis of 2012 when both of these criterias were met 50% of the pre-trigger faults which prior had a self-restoring short circuit, a disruption could have been prevented."	Reduce the number of interruptions in pre extinguishing faults by up to 50%. Benchmarking from Alliander; 5% reduction in all cable failures.	Assume 1,000 cable faults per year = cost of 50 interruptions
				Pre-trigger alarms used on other DNO ohead line networks	Need to understand impact on overhead line network, but this could be substantial.	tba
	2	CI CML reduction	high	Use of dial in from Control centre to access trip history, settings and upload Enhanced Digital Fault Recording (Enhanced DFR) files. All sites are generally within 4 hours drive of the local office.	Benchmarking with Alliander, reduction of travel of 30 minutes per fault on average. Additional savings in manpower (travel time), travel etc. are not included for simplicity.	Reduction of 30 minutes per HV fault on average.
	3		high	Additional savings by remote interrogation of the Enhanced DFR files; 1) Determine distance to fault; This is a simple impedance calculation carried out to determine distance to the fault. This requires detailed information on the cable type (and impedance). 2) Determine fault type; manual analysis of the DFR file will show how the fault propagated etc. Research has been carried out to determine the type of fault from the shape of the waveform. Location of cable faults may be difficult to analyse under BAU due to the varying types of cable and uncertain cable routes. Analysis of the DFR files could be particularly useful for identification of intermittent faults which represent a significant portion of Customer Interruptions especially on overhead lines, where moisture can cause a flashover in an insulator which blows out and clears during fault conditions making tracing of the fault difficult.	Additional data available to analyse intermittent faults. Target 50% reduction in intermittent faults.	50% reduction in intermittent faults

	5		high	Potential opportunity to host the radiometric fault location of overhead lines onto SASensor platform. The time stamped GPS coordinates could be automatically exported to a data analytic layer for triangulation. This type of hardware architecture should make the integration of this technology commercially viable and enable identification of faulty assets and fault location via GPS location. The spread of SASensor systems could provide blanket coverage although aerials range is uncertain, but 22km – 70km is likely. (lower cost repeater units could always be added).	Application in development under NIA project with other DNO.	Information not available
	6	Reduction in reinforcement	medium	Use of Real time thermal ratings on overhead lines. Well established algorithms available free from Cigre, particularly useful for windfarm integration..	RTTR can provide an increase in up to 113% of normal rating, but is normally constrained by primary assets. Very useful technique to prevent high cost of public opposition to new windfarms etc.	Information not available
	7		medium	Use of Real time thermal ratings on underground cables. Many cables are only under thermal stress for a small %age of the time, although traditional static ratings would identify a need to reinforce circuits. Due to the thermal lag of the cables, higher power can be transmitted over short periods of time. algorithm provides a 2 hour and 12 hour maximum loading.		Information not available
	8		medium	Use of Real Time Thermal Ratings on Transformers. Thermal rating algorithm exists (EA Technology) but not deployed, taking readings from the WTI information, circuit loadings and ambient temperature. Many transformers were over designed so rapid improvement of Load Index could be achieved using thermal modelling.		Information not available
	9	Active Network Management	high	Host ANM schemes. Although ANM schemes can be coded to work on the SASensor platform, a standard Linux development OS provided to enable hosting and commercial integration of proprietary ANM schemes, decentralised or providing an interface to a centralised system.		Information not available
Asset Performance	**10**	Condition assessment	low	Use of Enhanced DFR files to identify re-strikes across vacuum bottles to meet the needs of BS6626. Vacuum bottles were first introduced en mass in the far East where failure rates are increasing.	The phenomenon has been identified, but research work in very early stages.	future development only
	11		medium	Adoption of trip timing testing onto SASensor platform with real time register files uploaded to Linux platform for manipulation. Presently done manually. Automatic identification of rogue CB's prior to failure.	Project presently underway at the PNDC.	Reduction of 30 minutes per panel CB's operated every 2 years, profiling carried out every 4 years and maintenance every 8 years.
	12		medium	Partial discharge monitoring of switchgear. New, low cost solutions are being developed in the market. Linux platform can host the data.		Information not available

13		high	Cable PD Monitoring. Smart Cable Guard is commercially available. It is employed within Alliander when pre-triggers are identified, to monitor the circuit and pinpoint potential failure sites - and system faults to a high degree of accuracy. PD Monitoring can also be deployed on critical circuits.	Reduction in failures of up to 50% (see item 2 above)	see 1 above
14	Protection	high	Checking of protection settings is presently carried out manually during site visits by protection Engineers, however, SSE have identified a number of protection setting failures which are likely to increase as the network becomes more dynamic.	Reduction of 1 visit to site per annum. What are the associated costs in setting based failures.	Reduction of 1 site visit per annum.
15		low	Use of adaptive protection for better management of the networks. The landscape is unclear as to the speed of introduction, however, the system is capable of multiple settings.	not costed	Information not available
16		medium	Reduced ongoing management costs, rationalisation of stock levels and training. As the system is modular with software driven functionality, a minimal stack holding od CIM VIM VCU and CCU only required. BBES have provided a fully serviced solution to SSE and BBES for over 15 years with very high reliability. A similar arrangement could be considered for a SLA.	not costed	Information not available
17		low	SASensor is a full dual redundant system. Dual redundancy ensures high availability. If a CIM fails, then the system will notify the failure but will continue to function normally, using calculated values from the other CIM's. If a VIM fails then it will use data from other VIMs on the switchboard.	What are the failure rates of the existing systems and how does reliability / availability compare wih SASensor?	Information not available
18		low	Breaker fail protection is inherent in the product.	need to quantify how many failures could this prevent and what are the costs?	not costed
19		low	Flexibility to accommodate emerging requirements. High impedance arcing earth fault algorithm available from Protrol on SASensor platform for example, but any protection function can be coded - refer to Protrol website (Locamation Technology partners).	What are the requirements for SEF; network performance or safety? How is this monetised?	not costed
20	Hardware reduction	high	An additional Remote Terminal Unit not required, which need to be retrofitted to existing non automated sites.	c£25k per site	£25,000 / site
21	Tap Change control	medium	From the DSP project, ATC control is standard on the SASensor platform, eliminating the need for replacement ATC relays on site.	2 relays required per substation. Assume ATC required on 20% of sites.	Cost reduction of c.£2k per pair of transformers as part of introduction of a voltage management scheme.
22	New connections	low	Network planning. Existing algorithms available to determine the level of Low Carbon Technologies from weather and load patterns. High quality data from SASensor can provide accurate system information for analysis to speed up new connections.	Hosted on a centralised PC.	not costed

	23	Life Cycle costs	high	Separation of hardware and software functionality reduces life cycle costs and upgrades.	SASensor system is approximately 30% cheaper than equivalent system with IED's. System upgrade after 10-15 years is c. 40% of the cost of upgrading IED's.	not costed
Manpower reduction	**24**	Copper theft reduction	medium	Linux platform can host intelligent algorithms being developed under LCNF / NIA to determine intruders. Combined with substation cameras, which can also be integrated, this can reduce travel to site and reduce theft (generation of automatic alarms).	size of hardware may need to be determined if loaded with lots of applications. Rugged industrial computer could be used to manage programs	not costed
	27	Standardisation	medium	Standardisation; training and competence. Reduced number of disparate devices especially for new employees (large scale recruitment planned in the industry).	Reduction and simplification of training, especially new Protection Engineers.	not costed
IT	**28**	Cyber security	medium	System provides a reduction in attack vectors and a separation of protection and analytics platforms. The Linux platform can host corporate CS software, (eg industrial defender) and emerging Cyber Security analytics from new entrants (eg ViaSat). Corporate Enterprise licenses can form economies of scale and be upgraded as new threats occur.	Reduction in software licenses. Reduction of risk.	not costed
	29	Device management	high	Dutch working groups have identified escalating costs for device management, firmware management, management of Config and setting files. (refer to report). Version control and software upgrades can be easily managed.	What are the anticipated costs from the IT business for management of these issues. What are the savings using SASensor?	not costed
	30	Simplification of IT architecture.	high	What are the associated costs to introduce a system to manage the data from IEC61850 architecture Vs SASensor architecture? Does the SCADA system need an upgrade to cope with the large volume of data and performing an analytic layer?	What are the projected costs associated with integration of IED devices / IEC61850. How will the traffic be managed? How will the data be manipulated centrally, stored and at what granularity? What is the reliance on communication technologies and what are risks are there of a centralised Vs Decentralised system?	not costed

	31	Data management	high	As a decentralised system, SASensor will continue to operate algorithms even when communication is lost and has the ability to upload historical data when comms are restored or during off peak times. Assume an Ethernet connection into each substation. Lessons learned from 220 data collection points only with basic data in the Thames Valley Vision project; over 250 million data points streamed per day - over 350 million half hourly calculated data points per day - 6TB of SAN storage provisioned - 0.5GB of data gathered per day at a cost of £5.20 - Data transmission costs £91.66 per day	SASensor stores all system information locally and backed up on a server. Information is consolidated for SCADA but held locally and backed up on a server, with algorithms identifying events and reporting by exception. What is the reduction of data transmission and storage costs?	not costed
	32	Data mining	low	Use of accurate system data, Enhanced DFR files etc. can be used for big data mining and determine network improvements.	What cost savings / network improvements could this provide?	not costed

Appendix II Comparison report between SASensor and Micom operation at Caputh

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SSE – Caputh

Comparison SASensor - conventional

Date: 2015-06-04
Author: René Wassink, Locamation
Name: 20150604rjw SSE Caputh comparison.docx

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1. Introduction

The intent of this document is to provide a comparison between the SASensor pilot system and the conventional equipment, as is installed at the SSE substation location 'Caputh'.

1.1. Overview

The SSE substation Caputh is a 33/11 kV substation, where (in this report) the focus is on the 11kV installation. The installation consists of 2 incoming bays, 1 coupling bays and 4 outgoing feeders.

All bays are equipped with CIM & BIM interface modules. The incoming bays also have a VIM to measure the voltage signals. The conventional equipment is equipped with Micom relays from Alstom.

1.2. Data overview

This report handles 131 DFR files, 13 events of the SASensor overcurrent protection and 25 events from the conventional equipment, and is based on:

- SASensor log information, as retrieved during an on-site visit to Caputh on 26-2-2015
- Log information from the Micom relays, as was made available by SSE. The data was interpreted with the "Micom S1 Agile" software from Alstom (version 1.2.0)

1.3. Remarks

The information is not fully consist between SASensor and the conventional equipment

- The settings of the overcurrent protection (hereafter: ptoc) were not set on the CCU-B system. Therefore, all ptoc related information is taken from the CCU-A system
- The settings of the DFR recording were not equal between the A and B system. Therefore there sometimes is a discrepancy between both CCU systems.
- The DFR pretrigger setting was set to 0 ms on both CCU's, which causes that some DFR's miss information at the beginning of the recording
- There was no DFR recording installed on the incoming bays. Result is that there can be a ptoc logging without the corresponding DFR record.
- Some settings were missing for the neutral current part of the ptoc settings. This causes that some signals were seen by the Micom, but not by SASensor.
- It seems like the Micom relays only create a disturbance recording when the corresponding bay was given a trip command. The result of this is the SASensor system has more DFR recordings available than the Micom relays
- The log information of both SASensor systems from 2014-06 until 2014-10. The exact status is not clear at this moment, but is requested to SSE.

20150604rjw SSE Caputh comparison.docx

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2. List of information

The table below shows the availability of which information on which date. The next chapter will go into detail in this.

Date	DFR	ptoc	Conventional
17-11-2013	X		
19-11-2013	X		
5-12-2013	X		X
24-12-2013	X		
8-1-2014	X		X
2-2-2014	X		
5-2-2014	X		X
14-2-2014	X		
20-2-2014	X		
23-2-2014	X	X	?
5-3-2014	X	X	?
13-4-2014	X	X	?
24-6-2014	X		X
26-7-2014			X
3-9-2014			X
16-9-2014			X
19-9-2014			X
2-10-2014			X
4-11-2014		X	
9-11-2014	X		
13-11-2014		X	X
15-11-2014	X	X	X
18-11-2014	X	X	X
3-12-2014	X		
4-12-2014	X		
8-12-2014		X	X
11-12-2014	X		
9-1-2015	X		X
14-1-2015	X	X	X
16-1-2015			X
29-1-2015		X	X
31-1-2015	X	X	X
6-2-2014		X	X
18-2-2015	X		X
25-2-2015		X	X

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3. Evaluation

This chapter goes through some details of the most recent events. The goal is to explain the behaviour of both systems to verify correct behaviour.

3.1. 2015-02-25, 18:33

The Micom of TR1 shows an overcurrent. The CCU shows the same response of the overcurrent protection function. There is no DFR recording available because that was not configured on the incoming bays.

3.2. 2015-02-18, 11:02

The events of the Micom of Bay 003 indicate an unbalance, but there is no disturbance record. There are no settings for the neutral current in this bay in CCU-A, so there is no reaction from the ptoc. However, there is a DFR recording which shows a 130 A peek signal in phase 3 of bay 3. The time and duration correspond with the Micom information.

3.3. 2015-02-06, 15:35

The Micom of TR2 shows an overcurrent. The CCU shows the same response of the overcurrent protection function. There is no DFR recording available because that was not configured on the incoming bays.

3.4. 2015-01-31, 23:11

The events of the Micom of bay 002, TR1 & TR2 indicate a start of the fault, but don't indicate a trip of the circuit breaker. There is no disturbance recording found in the Micom relay. The CCU responds in the same manner, showing a current unbalance. There are multiple DFR records:

1) 23:11:58: an overcurrent of 700A top on phase 2 for 4.5 cycles. Then the signals return to normal
2) 23:12:08: a phase-phase fault of max 3900A top between phases 1 and 2. The signals return to normal after approximately 4 cycles
3) 23:12:18: a phase-phase fault of max 3700A top between phases 1 and 2. The signals return to normal after approximately 7 cycles.
4) 23:14:38: a phase-phase fault of max 3500A top between phases 1 and 2. The signals return to normal after approximately 7 cycles.
5) Next day, 00:10:33: a phase-phase fault of max 3500A top between phases 1 and 2. The signals return to normal after approximately 7 cycles.

3.5. 2015-01-29, 17:34

The Micom of TR2 shows an overcurrent. The CCU shows the same response of the overcurrent protection function. There is no DFR recording available because that was not configured on the incoming bays.

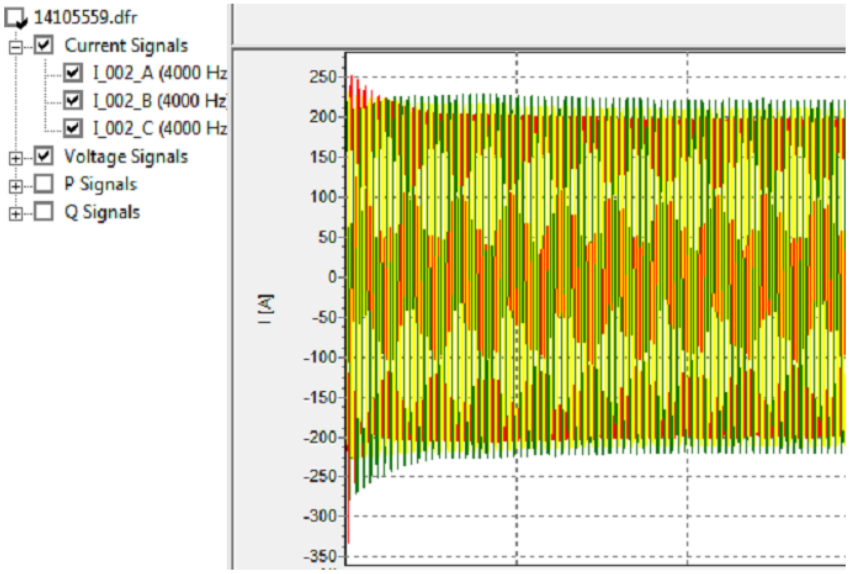
3.6. 2015-01-16, 9:40

The Micom of bay 002 shows two short start signals on sensitive earth fault protection. The CCU did not react, which indicates that there was a short spike in the current which did not meet the CCU trigger levels.

3.7. 2015-01-14, 19:02

The events of the Micom of bay 002 indicate an unbalance. There is no disturbance record of the Micom. The CCU shows the same events, but has also created a DFR recording. This shows an unbalance of approximately 3 cycles of phase 2. After the disturbance, the signal is restored to normal.

Prior to this event (10.55) the CCU triggered on an unbalance in phase 1 as can be seen below.



3.8. 2015-01-09, 4:25 & 10:34

The events of the Micom of bay 002 indicate twice an unbalance in the current. There are no disturbance recordings. The DFR files show an unbalance of approx. 40 A, which is smaller than the setting of the ptoc of the CCU, which did not react.

3.9. 2015-01-09, 1:03

The events of the Micom of bay 005 show a short overcurrent situation, but there is no disturbance recording. There are multiple DFR recording created with very short overcurrent recordings (< 30 ms). The overcurrent is too short for the ptoc to react.

3.10. 2014-12-11, 16:46

The DFR file shows a small increase of the unbalance current in bay 2. This unbalance is not large enough to start the overcurrent protection function. The setting of the Micom is slightly larger than the DFR trigger setting so that the Micom does not show any event.

3.11. 2014-12-08, 19:30

The Micom of TR1 shows some events of a phase-phase fault. The CCU ptoc function gives the same reaction. There is no DFR recording available because that was not configured on the incoming bays.

The event log of the Micom does not seem to be complete as this does not show all event which would correspond to this type of fault.

3.12. 2014-11-18, 13:30

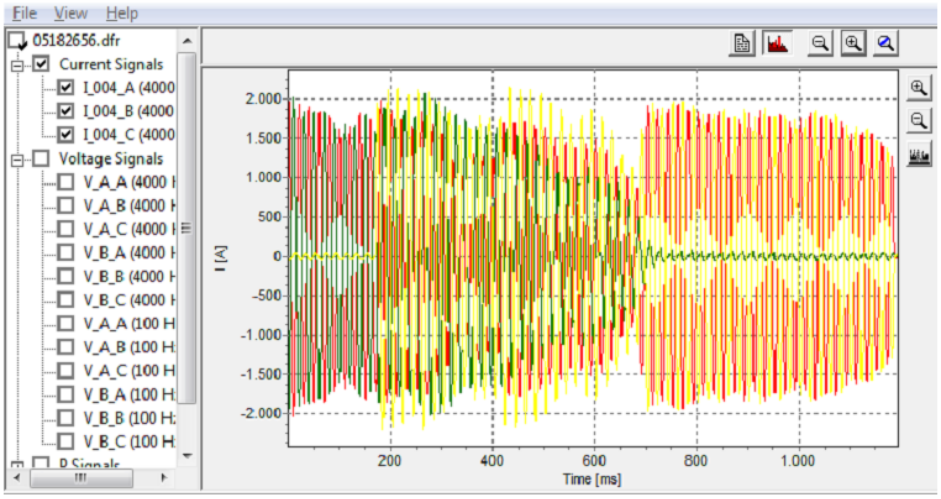
The events of the Micom of bay 005 indicate an unbalance and overcurrent situation for approx. 60 ms. This was picked up by the ptoc. There is no disturbance record available from the Micom, but there is a DFR recording which shows a high current in phase 2.

3.13. 2014-04-13, 20:55

The DFR recording shows a phase-phase fault of max 2kA top value. It appears that the short-circuit power comes into Caputh via bay TR1, and leaves again via bay TR2. The CCU also indicates that there was no trip signal from the conventional equipment. Locamation suggests evaluating this event in more detail, if possible together with SSE.

3.14. 2014-03-05, 18:26

The DFR recording shows the graph as can be seen below.



The trip command of the SASensor ptoc function seems to be earlier than the reaction of the Micom. This event needs in-depth evaluation of both systems.

4. Conclusion

This report has evaluated the major part of the available information comparing the SASensor and conventional systems. Both systems give the same reaction when an overcurrent situation occurs. The Micom gives some additional information in case of a sensitive earth fault, which functionality was not available at the time of commissioning of the SASensor system. However, the SASensor system has more log information and created more additional DFR recordings.

The following items need more attention:

- What was the status of the SASensor systems between 2014-06 and 2014-10? There is no log information available. Questions are asked to SSE
- The behaviour of the conventional protection is not fully understood at the event of 2014-03-05.
- On 2014-04-13, there seems to be no event from the conventional equipment while the DFR shows a high overcurrent.
- On 2015-01-14 the CCU noticed a DFR pre-trigger of approximately 330 Amps on phase 1 of bay 2. 6 hours later Bay 2 tripped on a fault current of 350A in phase 2.

Giving some (additional) attention to the settings regarding the DFR and ptoc functionality will improve the clarity for future evaluations. Some first steps for this were taken during a site-visit on 2015-02-26, for example regarding the DFR pre trigger settings and the ptoc settings of the CCU-B system.

4.1. Recommendations

- Compare the settings between the SASensor and conventional equipment to ensure the same behaviour.
- Upgrade the SASensor functionality by adding the Sensitive Earth Fault application to the configuration of Caputh.
- Very little training was provided as part of the project. SSE found the system easy to navigate and simple to use [source; Digital Substation Platform review panel] however it is identified that a training program would be required as part of a roll out programme.
- The configuration should be equal on both systems. There is tooling available to verify this, but there is a need for more information and/or training on this subject.

Appendix III
Benchmarking with Alliander

20150519 SASensor
at RCC - Ceel Hekelaa

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Appendix IV
Cost comparison with IED's.

Information received from Jason Rose, Business Analyst FN, 18th June 2015

Component	**Price £**	**Qty per substation**	**total**
Micom P142 * 7	£2,500	7	£17,500
C10 RTU	£20,000	1	£20,000
Commissioning	£7,845	1	£7,845
Total			**£45,345**

Component	**List price Euro**	**Price £**	**Qty per substation**	**total**
CIM (1 of)	€ 1,090.00	£894	7	£6,256.60
BIM (1 of)	€ 1,330.00	£1,091	7	£7,637.00
VIM (1 of)	€ 920.00	£754	1	£754.00
CCU (Floor mounted)	€ 6,255.00	£5,129	2	£10,258.00
CPUs/Cards (pentium)	€ 3,230.00	£2,648	2	£5,296.00
VCU (wall mounted)	€ 5,015.00	£4,112	1	£4,112.00
PC (Dell desktop PC met 22inch LCD and SASensor VPN software)	€ 1,425.00	£1,168	1	£1,168.00
Fibre (25m of simplex)	€ 40.00	£33	1	£32.80
Fibre (25m of duplex)	€ 105.00	£86	1	£86.00
Cabinet (2 floor and 1 wall)	€ 5,380.00	£4,411	2	£8,822.00
Simplex Fibre (600m)	€ 932.00	£764	1	£764.00
Duplex Fibre (750m)	€ 3,143.00	£2,577	1	£2,577.00
SASensor Aux (Key & Convertor)	€ 865.00	£709	1	£709.00
Locamation Commissioning (incorrect value).	€ 13,000.00	£4,524	1	£4,524.00
TOTAL				£52,996
price reduction 20%				**£42,397**

Note that further discounts to be agreed for large scale roll out.

Appendix V
PNDC test report on the SASensor system


PNDC_TPC-008_FR01
_Locamation HMV Tes

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