Testing a Digital Substation in a Power system with an RTDS

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Abstract

Digital Technology at station bus level is today widely spread and has also extended to process bus at the primary equipment level. An analogue merging unit takes analogue inputs from instrument transformer sensors (CTs and VTs) and outputs sampled and time-stamped digital data onto the IEC 61850 9-2LE process bus. This provides safer and more economical cross-site communication using fibre optics and allows the primary and secondary plant to be decoupled.

As part of the qualification of an analogue merging unit (AMU) a system wide test requirement was identified. This was to confirm that the IEC 61850 9-2LE streams from several AMUs could be sent to the correct destinations and there would be no impairment of the protection operation. This required a model of a representative power system with a typical mix of Protective devices. The chosen system had two transmission lines, a power transformer and a busbar with distance protection on one line, current differential protection on the second line, transformer differential covering the transformer and busbar differential protection. Additional protective devices were deployed at the remote line ends to complete the protection schemes. In total, ten logical nodes were active feeding data to six protective devices.

The system was modelled using the RTDS® Simulator system installed within AP Labs at Stafford, United Kingdom (UK). Analogue feeds for current and voltage were provided to a total of ten AMUs each providing one of the logical nodes in the system. All the IEC 61850 9-2LE signals were sent to a switch and the six protective devices were also attached to the same switch. There was no separation of the data streams by the use of different virtual networks. The streams intended for the remote line ends were included in this data concentration to represent other connections that were not modelled. The operating times of all the monitored protective devices were measured and recorded.

A series of system disturbances were applied, checking the operation of all of the protection in the system. This checking was amplified by the close interaction of the elements included; for example an internal line fault was also an external fault for all the other protective systems.

This style of system wide testing can, currently, only be carried out with the use of a real time simulator. The RTDS® system installed in AP Labs, Stafford, UK could also have provided some of the IEC 61850-9-2LE streams and interfaced through GSE streams in place of the AMUs and conventional connections used.

Background and Test Requirement

Whilst planning the tests required to ensure correct product operation before the launch of an analogue merging unit (AMU), a need was identified for a system level test. This was to ensure that there were no measurable impacts on the operation of the protective relays when fed from AMUs connected in a similar manner to a typical substation. A particular area of concern was that the same logical node needed to connect to more than one protective relay through a switched network with other traffic also present.

The basic conversion process provided by the AMU was not the major concern, as a number of other tests had already been carried out on the product as part of the normal process of product development and certification. Some of these tests had already utilised the RTDS® installation in APLabs, Stafford UK, including some that used the ability to input the sample stream that the AMU was generating from an analogue signal generated by the same RTDS® case. Other tests had also looked into the impact of errors in the IEC 61850 9-2 data stream input into the protection functions. To support this requests were made to RTDS Technologies Inc. for enhancement of their GTNET IEC61850 9-2LE output component so that a number of common communication errors, including packet loss and out of order reception, could be simulated.

The previous test systems used in ALSTOM Grid for product qualification mainly concentrated on one protective function (e.g. distance protection) and were not suitable for the system wide test required. However, a similar test system had been prepared previously to allow the approval testing of several protective relays in one test session. This system was selected and adapted to meet the new requirement.

System Modelling

Utilising the same protective functions as those ordered for a significant digital substation product, the modified system would need to have suitable locations for distance and current differential line protection, transformer differential protection and busbar differential protection. The system chosen has two transmission lines and a power transformer with a total of three ideal sources as shown in the following diagram.

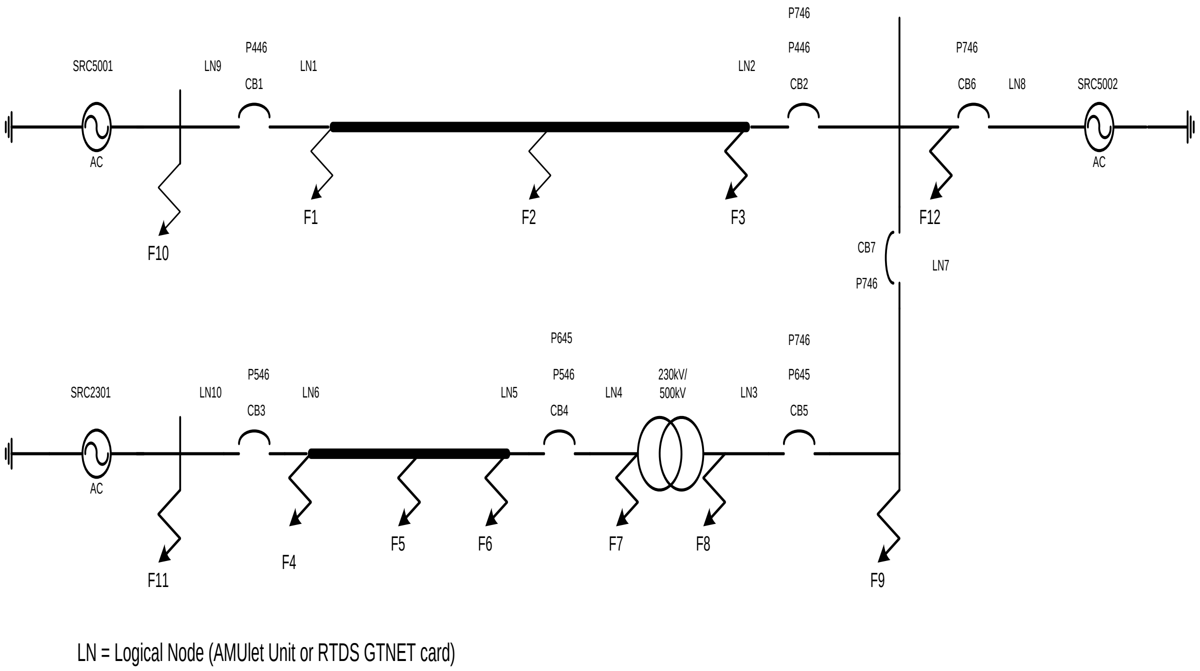

Figure 1 – Test system

The ALSTOM product codes above each circuit breaker indicate the protection function or functions active for that breaker. P446 is a distance relay, P546 is a line differential relay, P645 is a transformer differential relay and P746 is a busbar differential relay. Each logical node identified in the diagram required an AMU, with the four nodes on the left hand side of the diagram present to provide the signals to the remote line ends to complete the distance and line differential schemes. As the busbar protection does not require voltage signals, not all the logical nodes present in the busbar at the right hand side are connected to AMUs.

To reduce the demand for high current drive to the AMUs, the 230kV and the right hand 500kV sources have a relatively low fault level (4.5kA and 14kA respectively), but the other 500kV source has a high fault level (57kA). This gives a range of fault currents in line with the range commonly seen in similar systems. The 500kV line was 300km long and the 230 kV line was 75km long; the transformer was a YNd unit rated at 500MVA with 15% leakage reactance. As the test was aimed at the interaction between the AMUs and the protective relays, no VT or CT modelling was introduced other than an ideal ratio. All circuit breakers were modelled with a two cycle operating time plus the additional delay inherent in waiting for the next current zero before the poles separated.

The fault locations were chosen to provide a range of internal fault conditions for each protection, noting that internal faults for one protection function were also external faults for all the other protection functions.

No distance aided schemes or intertrip signals were included except for the intertrip inherent in the current differential protection functions. This caused significantly delayed clearance at one end of the protected zone for many of the faults particularly for the distance protection. This difference between fault clearance at each end increased the chances of any effect from the AMU converted signal and the digital communication system being observed in the operation of the protection functions. All tripping was three pole.

Communication Layout

All the IEC 61850 9-2LE outputs from the ten AMUs measuring the ten logical nodes identified in the diagram were connected to a switch after conversion from the optical media supported by the AMU to the copper media supported by the switch. The copper ports from the six protective relays were also connected to the switch. Including the signals from the remote ends was intended to represent some of the additional signals that would normally be present in a typical substation.

The AMUs each require a 1pps (pulse per second) optical synchronising signal, this signal is available from the RTDS® system but only on four output ports. A small unit was constructed to take a single optical input signal and repeat it on multiple outputs so that all the AMUs and the protective relays could be synchronised.

Tests and Results

An exhaustive selection of internal faults for each protection function was arranged. External faults were, generally, automatically included as an internal fault for one protection function was also an external fault for all the other functions. The exceptions were the remote busbars where no protection was deployed. Faults on the busbar at the left hand side of the 500kV line were left on so that the delayed zone 2 at the other end of the line would operate, checking the backup function provided by this zone, In total over 400 different faults were applied to the system.

These different faults were programmed using the scripting facilities provided by the RTDS® simulator so that they could be run without manual intervention.

The RTDS® system was also used to time the interval from the fault inception to all the protection trip outputs which was a total of 27 operating times. These times were written into a file that was then processed by Microsoft Excel to produce a final document. As we had acquired the individual phase operating times, we could predict the single phase operating decisions and, therefore, gain an indication of the expected single phase performance. No auto-reclose was considered as there was insufficient time to decide on and configure an appropriate set of schemes.

All the protective relays operated within the normal range of times expected from previous testing of similar products using conventional inputs when the faults were within the protective functions operating boundaries. Some faults were deliberately placed outside the distance resistive boundary, and the relays concerned also operated without any significant change from the results expected from a conventional input relay. In addition the wide range of external faults applied while testing each function showed complete stability for all units under test.

90	19:36:58	07/24/2013	CN2AN	F7F7	0	0.06	0.01	NA	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	0.033	0.033	0.033
91	19:37:55	07/24/2013	AN2BN	F4F11	0	0.06	0.01	NA	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	0.028	0.029	0.028	0.028	0.028	0.027
92	19:38:52	07/24/2013	AN2CN	F4F11	0	0.08	0.01	NA	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	0.028	0.028	0.028	0.028	0.029	0.028
93	19:39:49	07/24/2013	BN2CN	F4F11	0	0.2	0.01	NA	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	0.03	0.031	0.03	0.029	0.028	0.029
94	19:40:45	07/24/2013	BN2AN	F6F7	0	0.06	0.01	NA	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	0.031	0.031	0.031	0.031	0.031	0.031
95	19:41:42	07/24/2013	CN2AN	F6F7	0	0.2	0.01	NA	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	0.033	0.034	0.033	0.035	0.035	0.035
96	19:42:39	07/24/2013	AN2BN	F11F4	0	0.06	0.01	NA	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	0.091	0.091	0.091	0.091	0.091	0.09
97	19:43:36	07/24/2013	AN2CN	F11F4	0	0.08	0.01	NA	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	0.112	0.113	0.114	0.112	0.112	0.113
98	19:44:33	07/24/2013	BN2CN	F11F4	0	0.2	0.01	NA	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	0.231	0.231	0.23	0.233	0.233	0.232
99	19:45:30	07/24/2013	BN2AN	F7F6	0	0.06	0.01	NA	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	0.094	0.094	0.095	0.034	0.034	0.034
100	19:46:26	07/24/2013	CN2AN	F7F6	0	0.2	0.01	NA	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip	0.234	0.235	0.234	0.034	0.034	0.034
101	19:47:23	07/24/2013	AN	F1	0	NA	0.01	NA	0.02	0.02	0.021	0.224	0.224	0.224	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip
102	19:48:54	07/24/2013	BC	F1	0	NA	NA	0.01	0.02	0.02	0.019	0.221	0.222	0.221	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip
103	19:50:26	07/24/2013	CAN	F1	0	NA	0.01	0.01	0.021	0.021	0.021	0.221	0.221	0.222	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip
104	19:51:59	07/24/2013	ABC	F1	0	NA	NA	0.01	0.02	0.02	0.02	0.223	0.223	0.224	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip
105	19:53:32	07/24/2013	BN	F2	0	NA	0.01	NA	0.024	0.025	0.025	0.026	0.026	0.026	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip
106	19:55:04	07/24/2013	CA	F2	0	NA	NA	0.01	0.021	0.021	0.021	0.022	0.023	0.023	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip
107	19:56:37	07/24/2013	ABN	F2	0	NA	0.01	0.01	0.021	0.021	0.021	0.021	0.02	0.02	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip
108	19:57:33	07/24/2013	ABCN	F2	0	NA	0.01	0.01	0.02	0.019	0.019	0.022	0.021	0.021	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip
109	19:59:05	07/24/2013	CN	F3	0	NA	0.01	NA	0.224	0.223	0.224	0.021	0.021	0.021	No Trip	No Trip	No Trip	No Trip	No Trip	No Trip

A small part of the processed file covering the transition from the last tests directed at the current differential to the first tests involving the distance protection is shown above. The pale green colour shows where correct relay operating times were measured for the test condition applied, the blue color shows were correct operation of the function was measured even though that function was not the focus of the test condition. Any operation which was measured to be outside the range expected would have been highlighted in bright yellow, however no such operation was observed.

Conclusions

Testing an AMU creates a number of different challenges compared with those that are well known to engineers experienced in testing protective relays. The AMU does not provide a full protection function, merely the analogue signal acquisition. Whilst measuring the distortions and inaccuracies introduced by the AMU will provide a full description of the performance of the device, the impact of using the AMU with a protective relay is less easy to quantify. As more experience is gained in using AMUs and IEC 61850 9-2 based protection, the issues inherent in the interaction of the two devices will become as well known as those associated with conventional analogue inputs.

Until this experience is gained, there will be a need to test protection schemes for the impact of communication issues in the IEC 61850 9-2 link under realistic operating conditions. When there is a need to also examine the system wide interaction, then a real time simulator is the obvious test tool as no other test tool will permit the rapid and detailed collection of data at the same time from different locations in the network under consideration. The system that is installed in APLabs, Stafford currently has the capability of providing (not necessarily simultaneously) a total of twenty IEC 61850 9-2LE logical nodes at protection rates, ten three phase sets of voltage and current signals, in excess of two hundred conventional binary inputs and outputs and greater than three hundred GSE signals to more than twenty sources or destinations, This capacity allows either several independent tests operating at the same time, or a series of tests involving a large and complex network.