Institution:
University of Manchester

Unit of Assessment: UoA13b Electrical and Electronic Engineering

Title of Case Study:

Synchronised Protection of Electrical Power Transmission Networks

Summary of Impact

Manchester research on differential protection, synchronised using the global positioning system (GPS), has opened up a radically new approach to protection and integrity of electrical transmission networks. The research has led to updating of international technical guides and international standards. In the UK, National Grid has implemented policies based on the research, which will save about £0.5m per annum in substation upgrade costs. The market for GPS synchronised differential protection products is £400m pa globally. This figure represents the "insurance premium" against the avoided cost of a power system failure, estimated in a report on the North-East USA blackout to be $6bn in economic cost and 11 directly attributable deaths.

Underpinning Research

Impact is based on research that took place in Manchester from 1993-date, with the first major publication in 1997 [1]. The key researchers were

- Prof P A Crossley (L and SL 1993-97, Reader 2000 - 02, Prof 2006 - date);
- Prof R N Allan (Prof 1993- 2001);
- Dr H Li (RA 1996, L 2001, SL 2011 - date)
- Dr M Panteli (PhD 2009 – 13, PDRA 2013 – date)

PhD students and year graduated: Castro (graduated 1997), Pugh (1997), Southern (1997), Sherwali (1997), Tan (2000), Kangvansaichol (2004), Hor (2005), Villamagna (2005), Ashwal (2011), Li (2012), Anombem (2012), Panteli (2013), Du (2013).

GPS time signals became available for civilian use globally in the early 1990s. Recognizing the usefulness of these signals, the aim of the research was (and continues to be) the design of algorithms, prototype devices, concepts and operating strategies that enhance the reliability of the protection systems used on electrical transmission networks using GPS time signals.

The key insights from transmission network protection research at Manchester were:

- The first to propose and demonstrate the use of the GPS time signal to synchronise feeder differential protection [1, 4].
- Formulation of a quantitative methodology for calculating the reliability of integrated control and protection [2].
- Formulation of a strategy for wide area synchronised differential protection to avoid the reliability and selectivity problems of conventional "back-up" protection [3, 5].
- The development of a quantifiable methodology for reliability assessment of System Integrity Protection Schemes (SiPS) [6]

References to the Research

The research was published in internationally leading journals, and especially the IEEE Transactions on Power Delivery, the leading journal in power system protection and control.

Key Publications

1. H Y Li, E P Southern, P A Crossley, S Potts et al (Alstom):- A new type of differential feeder protection relay using the Global Positioning System for data synchronisation, IEEE Trans. on Power Delivery, Vol 12, No.3, 1997, p1090 – 1099. *(IEEEXplore citations = 281)* DOI:

10.1109/61.636902
2. L R Castro, P A Crossley, J Goody (National Grid), R N Allan:- Impact of functional integration on the reliability of substation protection and control systems, IEEE Trans. on Power Delivery, Vol 16, No 1, Jan 2001, p83-88. *(IEEEXplore citations = 179)* DOI: 10.1109/61.905599
3. J C Tan, P A Crossley, I Hall (National Grid), J Farrell (Scottish Power), P Gale (Hathaway):- Sequential tripping strategy for a transmission network back-up protection expert system, IEEE Trans. on Power Delivery, vol. 17, no. 1, pp.68-74, Jan. 2002. *(IEEEXplore citations = 43)* DOI: 10.1109/61.974189

Other Publications

4. E P Southern, H Y Li, P A Crossley:- A differential feeder protection system - the need for time synchronisation, 1st Precise Measurements in Power Systems Conference, Arlington USA, November 1995.
5. N.Villamagna, P A Crossley: A CT saturation detection algorithm using symmetrical components for current differential protection, IEEE Trans. on Power Delivery, Vol 21, issue 1, Jan 2006, pp 38-45. (IEEEXplore citations = 22) DOI: 10.1109/TPWRD.2005.848654
6. M Panteli, P A Crossley: Assessing the Risk Associated With a High Penetration of System Integrity Protection Schemes, presented at the IEEE PES Innovative Smart Grid Technologies (ISGT) Conference 14-17 Oct. 2012

Details of Impact

Context

The impact of protection measures needs to be seen in the context of the cost both financial and human when the power system fails. The cost of a wide area blackout, caused by protection mal-operations and human errors, is immense, e.g. the NE USA blackout (2003) directly caused 11 deaths and cost the US economy $6bn [A] and the Indian blackout (2012) affected 700 million people [B].

National Grid own and operate an increasingly stressed transmission network in the UK, which is expected to become less stable and more congested as fossil fuelled and nuclear power stations are retired. The solution is multi-faceted, but transmission utilities are helping to address their problems by exploiting research at Manchester on high reliability protection and control.

Pathways to Impact

To ensure the widest application of the research four strategies were adopted:

1. Signing of a licensing agreement between Alstom Grid and the University to ensure confidential information was made available to help Alstom develop a commercial GPS synchronised differential protection device.
2. Input to industry related journals, conferences, and international bodies. Two international organisations critical in the power systems area are the Council on Large Electric Systems, (CIGRE) and the International Electrotechnical Commission (IEC), which produce the international technical handbooks and standards used by industry globally.
3. Provision of skilled engineers and researchers. Six of the PhD students and Postdoctoral researchers involved in the research subsequently joined Alstom or National Grid, which has helped these companies to commercially exploit the research outcomes and develop products based on the research.
4. Investment by the University in a protection and control test facility used by industry to evaluate new products. The facility allows evaluation of time-synchronised protection with merging-units and Ethernet communications, and evaluation of wide-area time dissemination systems for use with protection and control.

Reach and Significance of Impact

1. International Standards and Policy development

Prof Crossley was the convenor of a CIGRE working group that used this research to help prepare the technical brochure, effectively the engineers' working practice guidance document, on the life-time management of relay settings (CIGRE 539 GT B5.31). The approved version of this document was published in June 2013 [C] and this guide is now influencing global protection strategy and helping manufacturers deliver what utilities require.

IEC61850 is the international standard for digital electrical substations. The standard has developed over time and its extension to protection and control was enabled by the implementation of time synchronisation envisaged in this research. The IEC61859 standard was updated to include the model for time synchronisation in July 2011 [D]

In the UK, National Grid have utilised the Manchester concepts to change the National strategy on integrating the Control and Protection functions within a substation (2002-2010) and to influence policy on the Architecture for Substation Secondary System (AS^3) (2010-date). This policy defines the functional architecture for all new protection and control systems used on the GB Transmission Network. National Grid's price control agreement with OFGEM allows expenditure of £334.3m over the RIIO period 2013-21 [E].

2. Industry Uptake and Product Development

Most important transmission lines in the developed world are protected by a combination of differential and distance protection, and the former often uses GPS for time synchronisation. The major manufacturers have developed products to meet the demand for such systems (e.g. Alstom MiCom P594 GPS Synchronising unit; Toshiba Line Differential Protection GRL100; GE L90 Line Current Differential System [F].

Electrical equipment installed on the Power System typically has a life of 40-60 years. As a consequence the rate of uptake of new developments can be relatively slow in terms of the number of units installed. Nevertheless the global market in 2010 for GPS synchronised differential feeder protection was worth more than £400M per year, with the largest user being China State Grid [G].

3. Use of IEC61850 in substations

Industry has further developed the concepts originated in the research to produce products of higher added value through the implementation of centralised time servers which are synchronised with GPS and distribute the time signal across Ethernet networks [H].

National Grid has implemented GPS synchronisation within IEC61850 within the AS^3 development as part of their research and development with the low carbon network fund provided by OFGEM. The project estimates a potential saving of £0.5m per year as the system is rolled out to refurbished and newly built AS^3 substations [I]. With the UK representing circa 5% of the global market this would suggest a global market for substation upgrading of £10m per annum.

4. Mitigating Risk

At the end of the day the real value of all protection and control systems is not in the value of systems implemented but in the costs avoided by prevention of failure as shown by the $6bn economic loss in the US blackout [A] and 700.000 people affected by the India blackout [B]. The cost of the systems implemented can be viewed as the insurance premium and their effectiveness is measured by the lack of interruption of power supplies. In the developed world most consumers now have the expectation of power supplies being permanently available as they have rarely or never experience a power network failure.

Sources to Corroborate the Impact

A. North American Electricity Reliability Corporation report on the 2003 NE US Blackout http://www.scientificamerican.com/article.cfm?id=2003-blackout-five-years-later

B. Report on the power blackout in India http://www.theguardian.com/world/2012/jul/31/india-

blackout-electricity-power-cuts

C. CIGRE 539 GT B5.31 report Technical Brochure Oct 2012

D. IEC 61850-7-1 ed 2.0 the update to IEC 61850 that introduces the model for time synchronisation as proposed in this research.

E. OFGEM RIIO-T1 Final Proposals for National Grid p64 table of approved expenditure for electricity transmission

F. Major manufacture product brochures showing a selection of current products for differential protection from Alstom, Toshiba and GE.

G. Internal note demonstrating the justification of the global differential protection market

H. Product brochures for Ethernet based time synchronisation systems Siemens technical brochure Efficient Energy Automation with the IEC 61850 Standard Application Examples P32 and GE Protection & Control Journal P10.

I. National Grid Innovation Funding Incentive Annual Report 2011/12 showing the cost savings of implementing AS^3 protection schemes. P151