

Institution: University of Aberdeen
Unit of Assessment: 15
Title of case study: MW size DC/DC converters and DC circuit breakers
<p>1. Summary of the impact</p> <p>The power systems laboratory at the University of Aberdeen has developed new converter topologies that have applications in connecting MW size DC power sources with DC transmission/distribution grids. These converters resolve very challenging questions of fault isolation on high-power DC networks. Scottish Enterprise funded a proof of concept project which developed a prototype, and confirmed the feasibility for various applications with interconnecting renewable power sources. Impact from the research is ongoing. Initial impact has been on public policy and services, where policy debate has been informed by our research evidence; and where decisions, regulations or guidelines have been informed by our research. Impact has also been generated for practitioners and professional services, where both a professional body and a company have used research findings in the conduct of their work, their practices have changed, and new or improved processes have been adopted as a direct result of research findings.</p> <p>The technology has attracted the attention of George Adamowitsch, European Coordinator for the working group for offshore and onshore grid development. He has described the Aberdeen research in his annual report to EU parliament in 2010, and the lead academic, Professor Dragan Jovcic, now sits on the Working Group for onshore/offshore grid development, developing plans for the European DC supergrid. In addition, this research has contributed to Working Group B4.52 of the International Council on Large Electric Systems (CIGRE), and their major technical brochure "HVDC Grid Feasibility study". Finally, the research has been analysed by the French power company RTE (Réseau de Transport d'Electricité). As a result of the research findings the company has adapted their approach to the planning of major offshore wind farm developments, resulting in a re-definition of the company research and development strategy.</p>
<p>2. Underpinning research</p> <p>Research for the converter topologies as described was largely undertaken during 2007-2013, and remains ongoing [1-5]. The research was conducted in the main part by the power systems research group at University of Aberdeen, led by Professor Dragan Jovcic (member of staff since 2004). The main focus of research activity relates to the development of DC transmission networks which require substantial technical advances from conventional AC transmission systems. In 2006-2007 it was identified that the crucial components that will become building blocks for DC grids are DC/DC converters and DC circuit breakers [1-2]. The basic DC/DC technologies were developed and tested on simulators in 2007 and these results were presented in applications for further research grants.</p> <p>In 2008 Dr Jovcic was awarded a Royal Academy Global Research fellowship, spending 6 months as a visiting professor at McGill University, Montreal. At McGill University he collaborated with Professor B.T. Ooi, developing some of the technology ideas, and co-authoring several journal publications [3-4]. This theoretical study has set the basic principles of integrating DC/DC converters with existing HVDC systems.</p> <p>In 2009 Dr Jovcic was awarded a Scottish Enterprise Proof of Concept grant for commercialisation of the DC/DC converter. This grant funded the building of basic step-up and step-down DC/DC converter prototypes at 30kW. The prototype has demonstrated the feasibility of DC/DC conversion at high power, with good efficiency and most importantly tolerance to DC faults [5]. Two patents have been filed, with Professor Jovcic named as the sole inventor [6]. As part of the commercialisation process numerous laboratory demonstrations and seminars were held in Aberdeen, attended by many of the major companies engaged in the power industry. The main</p>

Impact case study (REF3b)

findings of the research proved:

1. DC/DC converter controllable power transfer in step-up operation,
2. DC/DC converter controllable power transfer in step-down operation,
3. DC/DC converter capability to operate under solid DC fault at either high voltage or low voltage terminals. This capability was demonstrated in the laboratory at full 30kW power and at 900V DC, attracting the attention of many industry organisations, including the French company RTE (Réseau de Transport d'Electricité).

In 2009 EPSRC funded new research at Aberdeen on the development of DC networks. This project further advanced on the development of fault tolerant DC/DC converters and built a 5-converter DC-grid demonstrator in the Aberdeen laboratory. This DC grid has been operational since 2010 and has demonstrated:

1. The feasibility of connecting two DC lines of different voltage levels and high powers;
2. The capability of the DC grid to ride-through solid DC faults in some segments;
3. Fast power reversal and good stability in DC grids.

The DC grid demonstrator at Aberdeen is among the largest and most versatile laboratory DC grid prototypes in the world. Its properties have been widely publicised in technical publications (e.g. Nature, The Engineer, IEEE), and all major power system manufacturers (ABB, SIEMENS, ALSTOM), and many grid operators (National Grid, SSE), have visited the laboratory. EU commissioner Adamovitsch invited Professor Jovcic to deliver a seminar to his Working Group in October 2010, and again in 2011. The DC grid technologies developed at Aberdeen have been debated within the Working Group, and it was decided to include a section on Aberdeen DC grid work in the 3rd annual report to EU parliament.

In 2010, Dr Jovcic was awarded a prestigious Starting Grant by the European Research Council, under the IDEAS FP7 programme. This was for theoretical research which examines DC hubs capable of connecting multiple DC lines of different voltage levels. This research is ongoing, but has already attracted industry attention and developed industry thinking with respect to their own research & development programmes.

3. References to the research**Key journals on underpinning research:**

1. **Jovcic**, D. "Bidirectional high power DC transformer" *IEEE Transactions on Power Delivery* Vol. 24, issue 4, October 2009, pp 2276-2283.
2. **Jovcic**, D. "Step-up DC-DC converter for MW size Applications" *IET Power Electronics*, Vol. 2, issue 6, November 2009, pp 675-685.
3. **Jovcic**, D. and Ooi, B.T. "Developing DC transmission network using DC transformers" *IEEE Transactions on Power Delivery*, Vol. 25, issue 4, October 2010, pp 2535-2543.
4. Robinson, J., **Jovcic**, D. and Joos, G., "Analysis and Design of an Offshore wind farm using MV DC grid" *IEEE Transactions on Power Delivery*, Vol. 25, issue 4, October 2010, pp 2164 -2173.
5. Hajian, M., Robinson, J., **Jovcic**, D. and Wu, B. "30kW, 200V/900V thyristor LCL DC/DC converter laboratory prototype design and testing " *IEEE Transactions on Power Electronics*, 2013, DOI: 10.1109/TPEL.2013.2260564

Key patent:

6. **Jovcic**, D., "Power Converter" *UK patent office, PCT Patent application no PCT/GB2009/051141, 9 Sept. 2008*

4. Details of the impact

The impact of the research so far has been twofold: informing European policy and guidelines in terms of European offshore electricity grid transmission networks, and leading to practitioners in industry changing their development strategies as a direct result of new research.

The research findings of the Aberdeen group on offshore grid development using DC/DC transformers have been directly cited in the European Coordinator's 3rd Annual Report submitted to the EU parliament, "*Projects of European Interest: Connection to offshore wind power in Northern Europe (North Sea – Baltic Sea)*" (2010) authored by the EU Co-ordinator George Adamowitsch. Since 2010 Professor Jovcic sits on the EU Working Group for Onshore/Offshore Grid Development, part of the Energy Infrastructure Package - North Seas Countries' Offshore Grid Initiative. This group is developing plans for HVDC inter-connection systems for the European supergrid. Specifically, the group was appointed by the EU parliament to deal with the regulatory, economic and planning law challenges involved in linking the offshore wind capacities with the European high-voltage network. The DC transmission network requires a significant investment in the order of £50-100bn, with construction commencing around 2020. The Aberdeen DC grid prototype has provided early stage demonstration of technical feasibility and cost-effectiveness of the underlying technologies for DC grid to the Adamowitsch group. Source to corroborate 1).

The professional association the International Council on Large Electric Systems (CIGRE by its acronym in French) established a Working Group B4.52 in 2009 looking at an "HVDC grid feasibility study". Professor Jovcic is one of the two invited members from UK. The group completed its work in 2012, and has prepared a technical brochure (no 533, published in April 2013). The Aberdeen DC grid work contributes significantly to the brochure, with Professor Jovcic being the author of a main chapter and several appendices. As a result of the findings of this working group, 5 new working groups on DC grids were established by CIGRE in 2011. Professor Jovcic is one of two UK members in new WG B4.58 "Devices for power flow control and methodologies for direct voltage control in a meshed HVDC Grid", where he leads the topic on DC/DC converters. CIGRE brochures have traditionally been very influential in industry and frequently provide background for many standards. Source to corroborate 2).

As an example of direct industrial impact, Aberdeen's research findings have been analysed by the French power company RTE since late 2011. RTE are interested in DC grids as the means to connect numerous offshore wind farms in the Mediterranean and the North Sea with the French electricity transmission system. DC grid concepts developed in Aberdeen have directly influenced the RTE DC grid strategy, and as a result the company have adapted their approach to the planning of a major offshore wind farm development. While the original approach was based on using DC Circuit breakers for DC grids, the development strategy has expanded towards developing DC grids based solely on DC/DC converters. The company have therefore decided in 2012 to invest in an 18 month project at Aberdeen to study the suitability of Aberdeen DC/DC converters for the French DC grid topologies. The initial findings have demonstrated technical feasibility, and the cost comparisons are also encouraging. As a result the company is re-considering its DC grid development strategy with a programme installation date of 2020. Source to corroborate 3).

The breadth of impact on the engineering community has been large since highly influential science journal *Nature* writes about Aberdeen DC grid research and also other popular articles like *The Engineer* have published similar articles. Sources to corroborate 4) and 5).

5. Sources to corroborate the impact

1. Adamowitsch, George, European Coordinator working group for offshore and onshore grid development. The Third annual report, Annex 6, is available online: http://ec.europa.eu/energy/infrastructure/tent_e/doc/off_shore_wind/2010_annual_report_en.pdf. December 2010 (*PDF document describing research which influenced discussions within the EU WG*). The secretary of the Working Group who is a Policy Officer at the European Commission can corroborate the impact statement.

2. CIGRE B4.52 “HVDC Grid Feasibility study,” CIGRE Brochure 533, April 2013. B4.52. *The Convener of WG B4.58 and Secretary of WG B4.52 who is Lead Engineer at ABB AB in Sweden, can corroborate D Jovcic’s contribution in both WG54.52 and B4.58.*
3. The Deputy Head, Substation Department, RTE/CNER can corroborate impact on RTE.
4. *Publicly available article in Nature to corroborate wide breath of impact on engineering community:* Macilwain, Colin, “Supergrid,” *Nature* **468**, 624-625 (2010) | doi:10.1038/468624a
<http://www.nature.com/news/2010/101201/pdf/468624a.pdf>
5. *Publicly available article in Nature to corroborate wide breath of impact on engineering community:* Wagner, Siobhan, “Building a supergrid for Europe,” *The Engineer*, 2010
<http://www.theengineer.co.uk/in-depth/the-big-story/building-a-supergrid-for-europe/1005262.article>