Commentary

Priorities in UK electricity supply research

D. F. Warne*

The ESR Network exists to coordinate and to further R&D collaboration between the UK industry and academic communities in electricity supply issues. A concerted effort has been made to establish how established academic expertise can be related to industrial plant problems and needs, resulting in a matrix that has been refined to identify clusters that may be used to guide future research strategy.

The ESR Network

The UK has a long history of collaborative and co-funded research in the generation, transmission and distribution of electrical energy. This started in the 1920s since when several schemes have provided for combined strategic input and funding from the electricity supply industry, related manufacturing companies and government agencies.

The CEGB (Central Electricity Generating Board) and the Electricity Association operated well-integrated research schemes through their own laboratories and associated universities, but fragmentation of the electricity supply industry following privatisation in the early 1990s made it more difficult to maintain a platform through which pre-competitive research could be stimulated and overseen. ERCOS (the Electricity Research Co-funding Scheme), which provided for 50 : 50 co-funding of research and which was operated by EPSRC (the Engineering and Physical Sciences Research Council) and the supply industry, remained the only effective collective scheme during the 1990s. In 1999 ERCOS was discontinued by EPSRC and it was replaced in 2000 by a managed programme known as ESR21 (Electricity Supply Research for the 21st Century).

Recognising that there remained considerable scope for industry–academic consideration of important research issues, the ESR Network was formed in August 2000 with EPSRC and industry funding to provide a platform for research communication between the supply industry, manufacturers and the academic community. Initially the Network was based around the monitoring and coordination of the 35 projects funded through the ESR21 programme, but recipients of new grants of interest to the industrial membership are continually invited to join, and over 50 grant-holders are now or have been involved in the Network's coordination process. There are now 16 industrial members, which provide the backbone of the Network's funding, with over 40 academic members, and the Network operates independently of any Government funding.

The Network is administered by the School of Mechanical, Materials and Manufacturing Engineering at the University of Nottingham, which hosts the web site (www.nottingham.ac.uk/esrnetwork) and provides the chairman, Professor Tom Hyde. Its activities are overseen and directed by a panel which meets three times a year, comprising all industrial members and three academic members taken in rotation from the membership. DTI (the Department of Trade and industry) and EPSRC are also represented.

The Network also encourages and supports new grants applications to EPSRC and DTI, It maintains links with other consortia, networks and organisations active in electricity supply research and regular reports and presentations are taken from organisations including the Advanced Power Generation Task Forum, UKERC (the UK Energy Research Centre), appropriate SUPERGEN consortia, IET (the Institution of Engineering and Technology) and the Energy Materials Group of the Institute of Materials, Minerals and Mining. Ongoing liaison is established where possible.

A key objective of the ESR Network is the formulation of R&D strategy papers, the purpose of which is to alert funding agencies and the community to the need for coordinated action in a particular area, and to offer guidance on research priorities. The initiation of each paper by a small group of experts is followed by a workshop to which leading UK experts are invited, A final draft resulting from this workshop is then sent to the Network membership for comment and agreement. The result is the nearest that can be achieved to an independent, consensus and authoritative document on the needs and priorities of that area.

Four papers have so far been published on the Network website:

- INSTEPP: 'An integrated approach to structural integrity in electrical power plant'
- PARTICEL: 'Particulates in electricity generating plant'
- TOPSYNC: 'Tools for power system operation in a competitive environment'
- COMET: 'Condition monitoring of electrical transmission and distribution plant'.

Work has started on a fifth paper, SYNTER: 'System integration of non-thermal generation'.

While these subjects were selected by consensus, it is recognised that in the modern climate of limited resources there is a need to select the topics very carefully, and to ensure in the longer term that a rationale exists for creating priorities for the development of such strategy papers. There has also been an overriding concern that an intuitive or unstructured approach might fail to recognise connections between current problem areas and relevant, but apparently unconnected, academic competencies.

The research and development needs of electricity supply are wide-ranging and complex, many relating to the challenges arising from the materials to be used in future plant. Discussions among industrial and academic network members quickly showed there were no obvious or simple existing means to rationalise the

*ESR Network Co-ordinator, email doug.warne@btinternet.com, Internet www.nottingham.ac.uyk/esrnetwork

DOI 10.1179/174892406X191882

priorities. This commentary outlines the procedure adopted by the Network to identify and rank these priorities.

Scope and complexity of electricity supply research

The supply of electricity encompasses a wide range of technologies, from combustion and steam-raising through to the protection and control of power networks and finally to decommissioning, Each presents R&D challenges and each has an associated need for maintenance of skills in the UK.

Some of the basic technologies in key areas have been established for many years. But ever-increasing commercial, environmental and security-of-supply pressures, coupled with breakthroughs in materials, modelling and prediction methods, control algorithms and computing techniques, mean that there is continuous scope for challenging research which can make a real impact. Without prejudging priorities, the following examples convey the breadth of the issues facing the industry and the academic community:

- in combustion not only is there a continuing drive for higher temperatures, increased efficiency and better control of gaseous and particulate emissions, but also a need to cope with increasing diversity of fuels from throughout the world, and with co-firing or re-burn using biomass fuels or waste
- in gas turbines there are numerous research issues, not least of which are the achievement of acceptable and predictable blade life, and acoustically linked instabilities
- the combination of a need for higher temperatures and pressures in boilers, coupled with the reality that even large sets will now rarely operate at constant load over long periods, means that new steels, jointing methods and possibly coatings are required which will withstand more arduous temperature, pressure, creep, fatigue and corrosion duties. Better material modelling methods, possibly in multi-scale from the nano-scale to the macro-scale, will be essential to obtain the best from the new materials in future designs
- the emergence of wind power and other types of distributed generation has highlighted the need for innovation in generator design, power electronics, control and protection to provide acceptable quality of power and to provide ride-through in the case of system faults and disturbances
- switchgear, transformers and overhead lines are critical elements in the supply chain and in the UK the age of much of this infrastructure is such that an increasing number of failures can be expected in the coming years. A programme of refurbishment and replacement will ameliorate many of the potential difficulties, but in the short term there is a need for better means of detecting and characterising incipient dielectric and mechanical failure, and of predicting residual life
- even the basis of power system operation and control is under continuous review and development. Ongoing refinement of the arrangements for managing a private and competitive base of generation brings its own challenges, but overlaid on this is the growth of distributed generation, connected to the system at low voltage. The challenges of managing an increasing penetration of this small-scale generation are immense, Power electronics will be one of the many tools which will be increasingly deployed
- the revival of interest in new nuclear plant and the ongoing issues of life extension, structural integrity and decommissioning in existing nuclear stations bring a wide range of materials problems and reinforce the need for an ever-improving capability to model and assess materials. Certainly there are challenges associated with the management of waste from nuclear plant.

These few illustrations barely represent the range of research challenges but they highlight the difficulty of creating priorities. Each area of industrial need has its own complexities and there will not always be a direct match into the expertise of the academic community, which has its own research agenda of a different and more generic type.

A framework for identifying priorities in research and development must accommodate these nuances, yet provide a rational route to isolate important areas and issues, and then work through all the options.

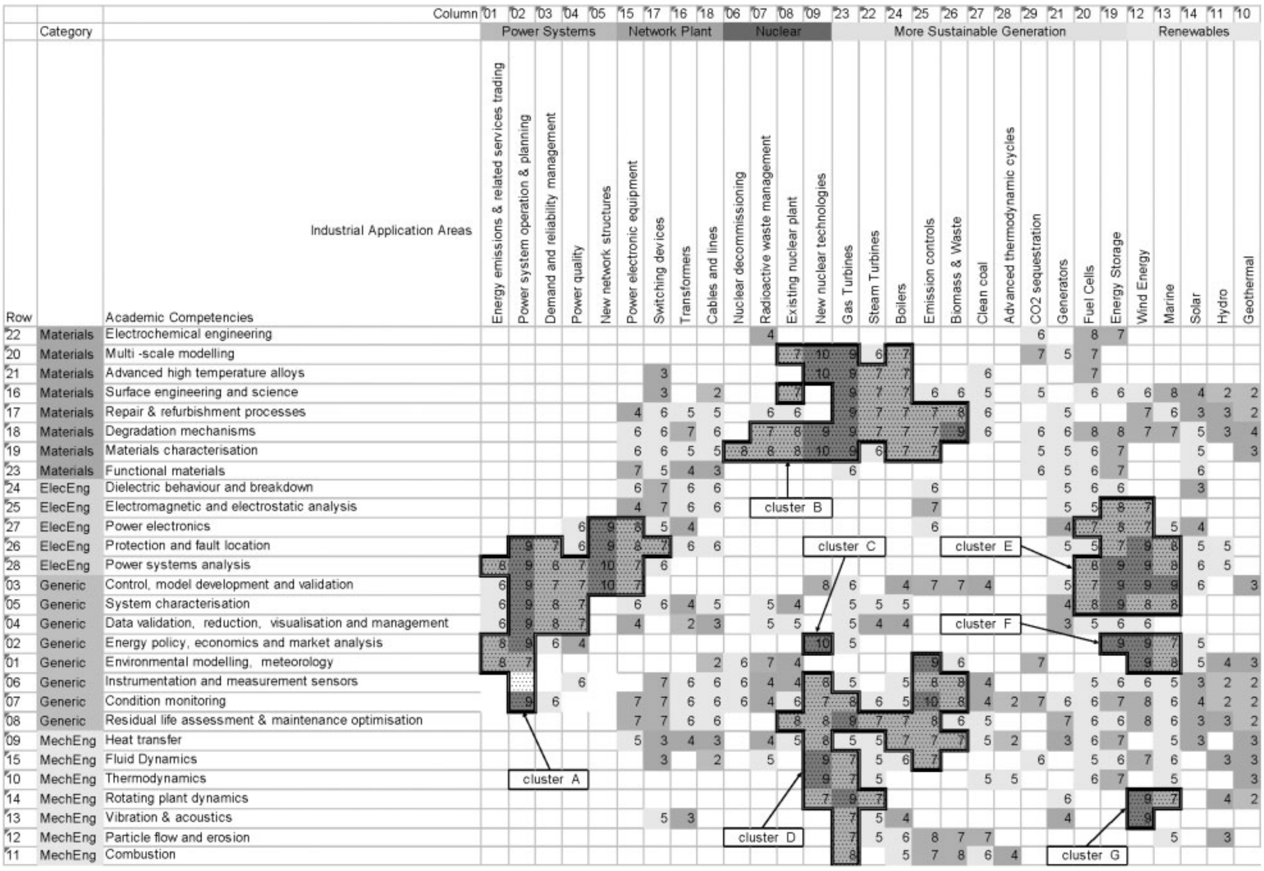
The matrix

Concept

Confronted with the complex set of requirements set out above, it is conventional to classify the issues to give shape to the problem. Industrially relevant research is inevitably an interface between academic capabilities and interests on the one hand and industrial or political pressures and more immediate commercial needs on the other. For this reason it was agreed that a matrix be formed to seek ways in which the established areas of academic expertise could be related to the range of industrial plant and system problems and needs. A working group was established to develop this concept and consultation was held through the ESR Network on the definitions of academic expertise and industrial plant and systems.

The initial matrix formed as a result of this exercise comprised 56 rows defining the range of relevant academic skill areas, and 62 columns representing plant and system categories. The rows defining academic skills ranged from 'molecular dynamics' to 'AI methods in diagnostics and condition monitoring' and 'dielectric breakdown mechanisms'. The columns describing industrial challenges ranged from 'hybrid-cycle fuel cells' to 'concentration of nuclear waste', 'emissions trading' and 'gasification of biomass fuels'. The utility of this matrix was tested by selecting a couple of plant areas and assessing the number of academic skill areas that appeared to be relevant. This exercise showed that the matrix presented a useful level of sparseness, highlighting areas within the matrix where useful synergy exists or may exist.

However, with a total of nearly 3500 elements, the matrix was too large to visualise and manipulate. It was therefore reduced by judicious merging of rows and columns, involving collapsing up to five headings into one, e.g. the rows for 'fatigue', 'creep and crack modelling', 'corrosion', 'failure mechanisms' and 'stress-strain FE modelling' were reduced to 'degradation mechanisms'. The objective was to reduce the size of the matrix to below 1000 elements and the result was a total of 29 columns and 28 rows. To minimise the attendant risk that the short headings given to these consolidated rows and columns did not adequately and clearly define their scope, it was decided a short description should accompany the heading of each column and row. For reasons of space it is not possible to



1 R&D matrix showing seven clusters for strategic development: A operation and planning of future networks, B materials and waste in thermal power plants, C economics of new nuclear plant, D design and monitoring of thermal power plant, E system integration of non-thermal generation, F meteorological dependency and economics of intermittent generation, G dynamic behaviour of marine and wind generators

include these descriptions here but details are available at http://www.nottingham.ac.uk/esrnetwork/research-strat.htm.

The rows were grouped into four major groups of academic skills: mechanical engineering, materials, electrical engineering and 'generic', while the columns were grouped into five areas: power systems, nuclear, renewables, network plant and more sustainable generation (Fig. 1). The importance of materials and structural research in this matrix is revealed by the fact that 8 of the 28 academic competences are materials oriented, and 7 of the 28 competences are mechanical.

Testing and refinement

The matrix was then tested to identify elements where relevance existed between the academic expertise and industrial application need. For instance, transformers are a key industrial plant area, identified as a column in the matrix. The rows having clear relevance to the technology and operation of transformers include 'instrumentation and measurement sensors', 'heat transfer' and 'dielectric behaviour and breakdown', but there is no obvious connection with academic skills in 'rotating plant dynamics' or 'advanced high temperature alloys'. Another example is CO_2 sequestration, which appears as a column of industrial importance under the 'more sustainable generation' group. This has clear relevance to 'environmental modelling' and 'fluid dynamics' but no obvious connection with 'particle flow and erosion' or 'power electronics' skills in the academic community.

The complete trawl of the matrix to check for such connections revealed that just over 45% of the elements showed relevance between their row and column. The next step was to grade the relevances of the elements so that particularly important areas might be highlighted. This was done in two stages, first addressing the columns then individual elements.

Members of the Network were asked to grade the columns from 1 to 5 (5 being the highest grade) in respect first, of national importance and second, of scope for R&D. For every column the responses for each were averaged and the two averages were added to give a total score, The scores were then ranked and separated into five groups, which were assigned a resulting grade in the range 1–5 (Table 1).

For the individual elements, Network members were asked to grade each of the 378 elements in the matrix identified as having relevance. The grades requested were 0 (outside area of expertise), 1 or 2, the latter representing the highest degree of relevance. The responses for each element were averaged, excluding zero scores, and then ranked by decreasing average into five groups which were then scored from 5 down to 1 in the same manner as shown in Table 1 for the columns.

A total score for each element was then obtained by adding the score for its own score to the score for the column in which it is located, giving a maximum score of 10 and a minimum of 2.

An orographic colouring scheme was adopted to assist in envisaging the disposition of the elements in various scoring bands. It was concluded that many of the highest scoring elements were isolated without any evident connection to other high scoring elements or groups. It is likely that strategic R&D will arise from small clusters of elements where several academic disciplines and/or several industrial application areas are addressed, and so a means of clustering high-scoring groups by re-ordering or the rows and columns was sought. Initial intuitive efforts by the working group revealed that possibilities for improvement should exist, and the input of an expert on clustering was sought.

The algorithm which was used minimises the average grading difference between each element and its four surrounding elements, considering every ordering of the column and row sets and every ordering of the columns and rows within each set, but not exchanging rows or columns between sets, Several cases which appeared close to optimum were considered by the working group with regard to the engineering significance of the clusters which emerged. The principal defining criterion for a cluster in this assessment was that it should contain at least one element scoring 10, it should not include any elements scoring less than 7, and it should be amenable to a simple title. The case which appeared to offer the most rational clusters is shown in Fig. 1.

Use and further development of matrix

Reassuringly, many of the seven clusters which appear from this analysis have already been the subject of focused attention, in whole or in part, through existing ESR Network strategy papers (particularly INSTEPP and TOPSYNC) and through EPSRC SUPERGEN themes (especially plant life extension, future network technologies, biomass and wind energy).

The total elements scores within these seven clusters might be used to prioritise their selection and adoption as subjects for future strategy papers within the Network, and the distribution of higher scoring elements within these clusters might be used to explore whether the clusters can be subdivided to give target areas a more restricted scope with sharper focus. The matrix has already been used to decide upon the next strategy paper (SYNTER). Strategy papers for the other six clusters highlighted in the matrix will be tackled in turn, but it is clear that further work is needed to refine the matrix and in particular to engage a wider community in the ranking and clustering process, A further working group has now been established within the Network to tackle these refinements.

Concluding remarks

The growing importance attached to electricity supply in UK at last reflects the crucial and strategic nature of this sector in the nation's economy. In the past few years the initiatives announced by Government have grown, and include the EPSRC SUPERGEN programme, the UK Energy Research Centre, the Carbon Trust, the Energy Research Partnership and most recently the Energy Technology Institute. Each has a contribution to make but there is a danger that priorities become confused rather than clearer. The matrix represents the considered view of research needs obtained from representatives of the leading generators, system operators and manufacturers and many of the UK's most authoritative academics. It is hoped that can make an impact on this process.

Importantly from the perspective of the materials community, two of the

Table 1 Grading of matrix columns

Col	Industrial application	Average responses: National importance	Average responses: R&D scope	Total	Resulting grade
9	New nuclear technologies	4·17	3·93	8·10	5
25	Emission controls	4·00	3·87	7·87	5
19	Energy storage	3·84	4·00	7·84	5
5	New network structures	4·00	3·82	7·82	5
26	Biomass and waste	3·78	3·88	7·66	5
12	Wind energy	4·11	3·47	7·58	4
29	CO_2 sequestration	3·65	3·88	7·53	4
20	Fuel cells	3·63	3·88	7·51	4
13	Marine	3·68	3·82	7·50	4
23	Gas turbines	3·72	3·53	7·25	4
2	Power system operation and planning	3·72	3·31	7·03	4
15	Power electronic equipment	3·50	3·47	6·97	3
27	Clean coal	3·53	3·44	6·97	3
8	Existing nuclear plant	4·00	2·94	6·94	3
6	Nuclear decommissioning	3·89	3·00	6·89	3
7	Radioactive waste management	3·79	3·07	6·86	3
3	Demand and reliability management	3·74	3·06	6·80	3
1	Energy emissions & related services trading	3·79	2·69	6·48	3
4	Power quality	3·32	3·06	6·38	2
14	Solar	2·89	3·33	6·22	2
17	Switching devices	3·24	2·81	6·05	2
21	Generators	3·22	2·71	5·93	2
24	Boilers	3·06	2·71	5·77	2
22	Steam turbines	3·17	2·59	5·76	2
28	Advanced thermodynamic cycles	2·82	2·88	5·70	1
18	Cables and lines	3·00	2·69	5·69	1
16	Transformers	3·06	2·38	5·44	1
11	Hydro	2·68	1·81	4·49	1
10	Geothermal	2·17	2·07	4·24	1

seven research and development clusters identified are directly related to materials issues: 'Materials and waste in thermal power plants' and 'Design and monitoring of thermal power plant' (clusters B and D respectively in Fig. 1). Both are substantial clusters and it is likely that they will be addressed soon by the Network for the development of strategy papers. But it is also recognised that these two areas are very complex in their own right, and further development of the matrix may find ways of refining these clusters and identifying special 'pinch points'.

Acknowledgements

The support of all ESR Network members in developing the concept and detail of the matrix is gratefully acknowledged. Dr D. Hobson, formerly of E-ON UK, made the initial proposal and the working groups which have developed the matrix so far comprised: Dr A. Aroussi, University of Nottingham, G. R. Clark, formerly of ALSTOM, Professor P. A. Crossley, University of Manchester, Dr R. W. Dunn, University of Bath, Professor H. E. Evans, University of Birmingham, Professor R. G. Faulkner, Loughborough University, Professor P. E. J. Flewitt, BNFL, Magnox Electric Ltd, Dr Y. Hardalupas, Imperial College London, D. W. Klaus, formerly of VATECH Reyrolle, Dr P. L. Lewin, University of Southampton, Dr L. Mogridge, formerly of RWE Npower, and Professor J. R. Nicholls, Cranfield University. Thanks are especially due to Dr Mogridge for the spreadsheet work necessary in the initial creation and development of the matrix, and to Dr Dunn for the work on clustering.