TECHNOLOGY DEVELOPMENT AND MARKET INTRODUCTION OF PAFC SYSTEMS

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Introduction

New power generating technologies need to be clean, highly efficient (also at partial load), highly reliable and competitively priced. Moreover, they need to be constructed as modules to enable step-by-step capacity increases at an acceptable cost level, and increase planning flexibility as a consequence. They must have low maintenance and low noise levels. Phosphoric acid fuel cell system technology to date has been shown to meet most of these requirements, except for two major issues: the reliability of power plants built and demonstrated to date has been inadequate (hence high maintenance requirements), and cost price levels have not yet been reduced to commercially competitive levels.

Reliability

The reliability of the current generation of fuel cell power plants is one of the most critical issues facing the commercialisation of this technology today. As far as most potential users are concerned, reduced reliability means increased maintenance costs and an increased dependence upon more costly back-up supplies of electrical energy or a need for redundant power supply capacity (extra investment). In fact, in most instances, diminished reliability makes the application of such technology decidedly unattractive, this despite all the advantages attributed to fuel cell systems. Most of the world's fuel cell demonstration programmes have managed to highlight those well-known attributes of fuel cell technology, namely, high efficiency, high part load efficiency, environmental friendliness and modular characteristics. However, many of these programmes have been unable to initiate the round of expected commercialisation of this technology by singularly failing to demonstrate that fuel cell systems can indeed be highly reliable.

Analyses of the reasons for the reduced reliability of many fuel cell power plants in the U.S. and Japan have shown that by far the vast majority of forced shutdowns (>95%) have been caused by the failure of the balance

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of plant components. These stoppages have involved electrical and electronics components (including sensors and cabling), mechanical controls, leakages, reformer malfunctions and rotating equipment shortcomings. In short, those elements that represent established and well-known technologies which are of course in stark contrast with relatively high availability of the 'new' fuel cell stack technology itself.

Modern hydrogen plants, that are in widespread use in the electronics, food, metallurgical and petrochemicals industries as well as in refineries, require constant availability, 24 h per day, over 8400 h per year, without any unexpected shutdowns. Industry uses hydrogen like individuals use tap water or electricity from the grid. Reliability of plant operation is a matter of design philosophy, engineering procedures and quality control. In fuel cell power plants, standard components should be used that have proven operation in existing hydrogen plants. This fact favours larger capacity fuel cell plants, where many more proven components can be used than in small capacity fuel cell plants (<100 kW). In the latter case, dedicated development of many components complicates the matter, though once proven, mass production can more quickly reduce the costs. As an established engineering contractor with extensive experience in all aspects of industrial hydrogen plant technology, where reliable on-stream operation is an economic necessity, KTI is in an excellent position to utilise its knowhow for the benefit of fuel cell system commercialisation.

Economics

In addition to the necessity to demonstrate the reliability of fuel cell power plants, the other major issue currently facing fuel cell commercialisation is that of economics. Broadly speaking, the economics of electric power generating systems can be segregated into fuel costs, operating and maintenance (O&M) costs and capital costs. Current phosphoric acid fuel cell power plant designs can achieve efficiencies in excess of 40%, and it is expected that in the near future (next three years) net system efficiencies will be dependent upon improvements in fuel cell stack, d.c./a.c. inverter and rotating equipment performance. These high efficiencies will ensure that the fuel costs of present and future fuel cell power plants are, and will remain, competitive.

Once the important objective of increased reliability of fuel cell power plant systems is achieved, it is realistic to expect significant reductions in O&M costs. Significant O&M cost reductions will also be achieved through decreasing capital costs requirements, *e.g.* fuel cell stack replacement costs after 40 000 hours of operation. In addition, as technical and operating experience with fuel cell power plants grows, important reductions in O&M costs will be achieved through increased automation of the systems.

The most important improvements in fuel cell system economics will be achieved through reductions in installed capital costs. These cost reductions will only be achieved through increased production volumes of fuel cell systems. The serial production phase of fuel cell system commercialisation will be attained once market acceptance has been achieved. This will only be possible once the potential high reliability of fuel cell systems has been finally demonstrated. At KTI, based upon optimised flowsheet designs, detailed cost estimates for fuel cell power plants have been generated. The capacities of fuel cell power plants studied range from multi-kW through to multi-MW systems. In this way, the economy of scale could be compared with the effect of increasing serial production on the investment costs, and subsequently on the cost of electricity (COE). In order to achieve the reductions in cost necessary to make fuel cell systems competitive with conventional and also with other advanced power generation sources, the fuel cell power plants will have to be serially produced in modules, especially at low capacity.

Serial production has the advantage of reduction of prefabrication labour and overheads, long-term negotiated supply contracts, reduced project contingency, reduced control system costs (*e.g.* through the development of microprocessor control), and the reduction in planning and software requirements. Modular units with a maximum amount of prefabrication will also enable significant reductions in on-site installation costs. In addition, of course, fuel cell manufacturers themselves will also enjoy the benefits of automised serial production of fuel cell stacks. For example, recent studies at KTI have estimated that for a 3 MW_e fuel cell power plant the installed costs can be reduced from \$2800/kW for a first series of 5 units, to below \$1000/kW with serial production.

Sensitivity analyses of all important system parameters have shown areas where relative improvements to reduce the ultimate cost of electricity (COE) are most effective. This means that on the basis of system economics, system designs can be modified to yield any combination of better performance, lower cost, cleaner exhaust gas, etc. This generates feedback that enables design simplification, reformer performance improvements, changes in burner configuration, and can even set targets for fuel cells R&D itself! For example, it has been shown that the current density of phosphoric acid fuel cells has a different optimum value when targeting for a minimum COE for the total system, to when targeting for a minimum fuel cell stack cost per kW_e produced. Most fuel cell manufacturers will schedule their developments according to the latter criterion (equivalent to maximising the number of kW_e per m^2 of cell surface area), whereas a more economic product will result when designing the fuel cell for a global optimum COE instead of the maximum current density.

Technology development

KTI's hydrogen and fuel cell development programmes run essentially concurrently with one another, and include the following activities:

- The development of fully automatic, advanced mini-hydrogen plants
- Burner and reformer development and testing
- Two 25 kW breadboard units in the U.S. and Italy
- A European demonstration program (see Fig. 1) in which a few palette-mounted, completely automated 25 kW_e (a.c.) fuel cell power plants are to be demonstrated, the first of which is currently being started-up in Holland
- A combined electricity (80 kW_e) and pure hydrogen producing unit for Solar-Wasserstoff-Bayern sold on a commercial basis
- Designs and proposals for larger capacity units ranging from multi-hundred kW_e units to several MW_e capacity
- Dynamic simulation of fuel cell power plants with which partial load behaviour, load following characteristics, and dynamic responses to changes in process conditions are being extensively investigated
- High performance rotating equipment studies and selection
- Special efforts to reduce the number of unit operations and equipment items in fuel cell power plants

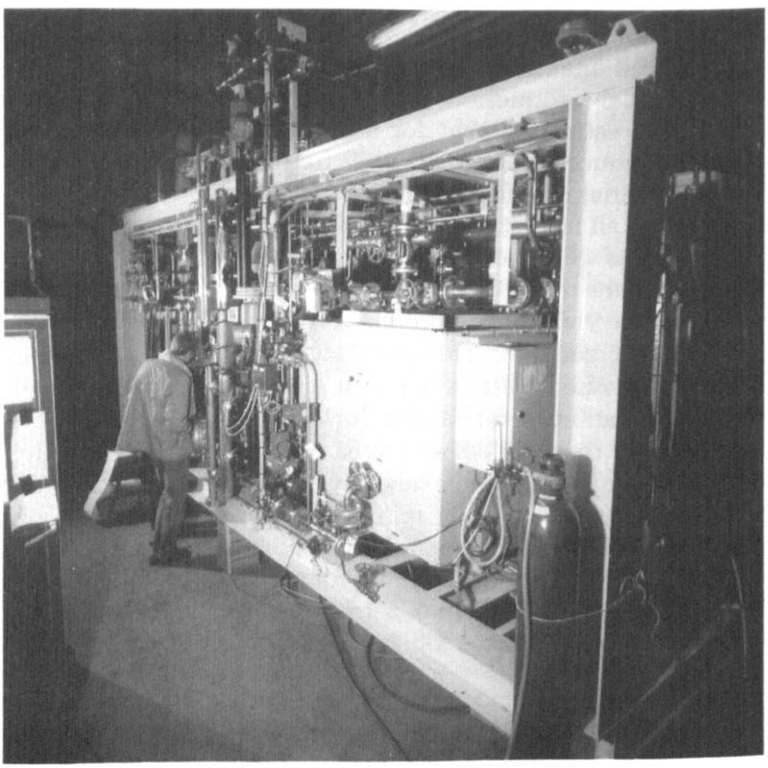

Fig. 1. After installation of the 25 kW demo unit at TU Delft, KTI personnel are making a final inspection of the unit. (The fuel cell stack, supplied by Fuji Electric Corp. in Japan, is located on the right-hand side of the skid and the fuel processor on the left-hand side of the skid.)

- Simplification of plant process control requirements
- Several optimisation techniques, including pressurised combustion, gas separation options (CO_2-removal, air enrichment, hydrogen purification, inerts separation)
- Modular construction
- Cost reduction studies
- Fuel flexibility

Market introduction

As discussed earlier, during the market introduction phase of fuel cell technology it is the reliability and cost issues that come to the forefront. KTI's approach to aiding market introduction of this technology is to ensure a reasonable risk distribution between the potential clients (especially in the initial market niches) and the fuel cell system suppliers. This will be achieved by undertaking the following measures:

- A willingness to undertake negotiated shared responsibility
- The possibility of guarantee provisions
- No major development effort involved in process design, *i.e.* making a maximum use of advanced hydrogen plant technology. This approach implies a minimum development effort with peripheral equipment and a concentration on the fuel cell stack integration, rotating equipment and the electrical requirements of the power plant
- The use of the feedback mechanism from demonstration plants to affect design, performance and cost improvements of the early production units
- Cost reduction studies
- Implementation of cost reduction through the use of existing manufacturing facilities for the production of plant modules
- A continuing assessment of market needs and related technology for developments

In conclusion, KTI is intending to direct its hydrogen and fuel cell development efforts towards addressing the most critical issues facing fuel cell system commercialisation today, namely those of reliability and cost.