VTT RESEARCH NOTES 2465

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Handbook of SOFC system in buildings

Legislation, standards and requirements

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ISBN 978-951-38-7264-9 (soft back ed.)
ISSN 1235-0605 (soft back ed.)

ISBN 978-951-38-7265-6 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 1455-0865 (URL: http://www.vtt.fi/publications/index.jsp)

JULKAISIJA – UTGIVARE – PUBLISHER

VTT, Vuorimiehentie 5, PL 1000, 02044 VTT
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Text preparing Tarja Haapalainen

Edita Prima Oy, Helsinki 2009

Krzysztof Klobut, Teemu Vesanen, Marja-Leena Pykälä, Kari Sipilä, Jari Kiviaho & Rolf Rosenberg. Handbook of SOFC system in buildings. Legislation, standards and requirements. Espoo 2009. VTT Tiedotteita – Research Notes 2465. 78 p.

Keywords fuel cell power systems, SOFC-systems, connection, public networks, power distribution networks, legislation, standards, requirements, buildings, micro-CHP (CHP = Combined Heat and Power generation), district heating

Abstract

The SofcPower 2007–2011 project aims to advance the development of the whole SOFC system towards demonstration in situ and, eventually, commercialisation. This publication is aimed at supporting the installation and exploitation of 50 kW SOFC in an office building in southern Finland. Other demonstration cases are also planned. In this context, the standardization situation has been scanned worldwide. Requirements concerning connection of SOFC system to the public networks have been explored and solutions consulted with authorities and owners of the local natural gas, heating and electricity networks. Experience and compiled documentation are reported here to serve as a guideline for other similar applications.

Installed fuel cell systems must be CE marked and comply with a set of European Union directives. The group of standards related to stationary systems produced by IEC TC 105 committee are the most important regulatory base for application preparation.

A fuel cell power system and associated equipment, components, and controls shall be sited and installed in accordance with the manufacturer's instructions. A written fire prevention and emergency plan shall be provided as required by and in accordance with national standards. The room or area where the fuel cell power system is installed shall have a hydrogen detector.

A new proposal has been developed, which combines a fuel cell system with the otherwise typical district heating connection scheme in Finland. Important precautions must be considered in this case: materials must be carefully selected in the primary and secondary side so that they will be qualified for the whole life cycle. It must be possible to measure energy consumption in both directions (sell/buy mode).

There are important requirements concerning electric energy-generating units. All exposed conductive parts of the electric power system shall be connected to the main earthing terminal or bar. If the neutral conductor exists it shall be connected to the network supply end to the main earthing terminal. The output filters of an interconnection device may not cause resonances with the rest of the electric grid. The interference of the grid operation is not allowed by any other reactive components that may cause changes in the operation parameters of the filters. The systems equipped with an inverter may be connected into the network without a separate synchronising device. The terms of synchronisation shall be followed in case of other generating units. The short-circuit power of the coupling point should be 25 times the rated power of a generating unit.

Preface

This project and publication have been carried out as part of a fuel cell technological programme run by Tekes – the Finnish Funding Agency for Technology and Innovation. The programme creates an environment in which the development of fuel cell technologies and services can succeed. The programme aims to improve opportunities for Finnish industry to create breakthrough products in selected fuel cell product segments. The overriding idea is to develop solutions and value networks ranging from fuels to end applications.

The aim of the project is to advance the development of the whole SOFC system closer towards demonstration and, eventually, commercialisation. This publication is primarily aimed at supporting the installation and subsequent exploitation of 50 kW SOFC in an office building, at first in southern Finland and later also elsewhere. In this context, the standardization situation has been scanned worldwide. In addition, all requirements concerning connection of the SOFC system to the public networks have been explored and solutions consulted with authorities and owners of the local heating and electricity networks.

This publication has been submitted for review to a number of bodies, some of whom are partners in the project. Received comments are gratefully acknowledged.

In addition to the authors, Jenni Jahn (currently with Olof Granlund Ltd), Risto Komulainen (currently with ABB Ltd) and Ari Laitinen (VTT) provided valuable contributions in the early phase of writing the manuscript.

The project has been funded by Tekes, VTT Technical Research Centre of Finland, Wärtsilä Finland, Gasum, Fortum Power and Heat, ABB, The Switch, Sandvik Materials Technology, municipality of Joroinen, Innovation Networks, Ecocat, Vaasan Sähkö, FC Energia, Beneq, Millidyne and Raucell.

The authors express their appreciation to funding organisations, to the reviewers and to all the other individuals who supported their work.

Contents

1. Introduction

A number of drivers support the development of distributed energy generation (DG). These are, for example, the opening of electricity markets, environmental issues (green values), development of small power generation systems, cost of power and heat transmission and increased power quality and reliability demands of end-users. Properly applied distributed generation can have many benefits such as more reliable energy supply, better management of energy use and production, energy savings and increased use of renewable energy. DG can also give broader possibilities for end users to manage energy, such as selling the surplus energy as electricity, heating or cooling energy. On the other hand, the increase in the distribution of energy production can include some risks.

The optimal implementation and use of DG systems and their integration into public energy distribution can be a very challenging task and may require many new products and systems. That means not only the need to develop energy production technologies, but all kinds of products and systems, international and local guidelines, standards and process models for supporting the cost-effective and intelligent interconnection and management of local energy production, storage, use and trading. The energy production units at end-users' facilities and two-way energy flow will mean higher demands on the control and safety systems. The intelligence of the energy management will have an essential role for the optimal implementation and use of the distributed resources. (Klobut et al. 2007.)

Distributed energy production remains an important research topic worldwide because of economical and environmental issues, and higher reliability demands for power network operation. The next step following the theoretical considerations and prototype product development is demonstration. The project considered in this publication is focused on preparation of a SOFC fuel cell demonstration in an office building environment located in Finland. Other demonstration cases are also planned.

1.1 References

Klobut, K., Shemeikka, J., Tuomaala, P., Sipilä, K. & Heikkinen J. 2007. ENTRY – Management of Distributed Energy Systems. In: Ventä, O. (Ed.) Intelligent Products and Systems. Technology theme – Final report. VTT Publications 635. Espoo: VTT. Pp. 107–150. (http://www.vtt.fi/inf/pdf/publications/2007/P635.pdf)

2. Overall requirements

Parts of the text based on Biennial Report on Hydrogen Safety. Chapter VI: Legal requirements, standards and other codes. Version June 2007. HySafe project (FP6 Network of Excellence).

2.1 European directives and CE marking

The European Union introduced a series of measures to ensure the free movement of goods throughout the European Union (EU) and the European Free Trade Area (EFTA). New Approach Directives are examples of these measures. These Directives aim at controlling product design and, above all, at ensuring technical harmonisation of product safety requirements across Europe, so as to guarantee a high level of protection to the public.

The CE marking symbolises that the marked product fulfils all applicable provisions (or requirements) of applicable directive(s) that provide for CE marking (essential requirements, harmonised standards and specific dispositions), and that the product has been subject to the appropriate conformity assessment procedure(s) contained in the directive(s). The scope of the CE marking regime is laid down in the relevant harmonisation directive(s), and can only be applied by the legal entity responsible for the conformity of the product. The CE marking is neither a mark of origin nor a quality mark.

Installed fuel cell systems must be CE marked and comply with a set of EU directives, such as:

- Machinery Directive (98/37/EC, 2006/423/EC)
- Low Voltage Directive (LVD) (2006/95/EC, 73/23/EC)
- Electromagnetic Compatibility Directive (EMC) (2004/108/EC)
- Cogeneration Directive (2004/8/EC)
- Pressure Equipment Directive (PED) (97/23/EC)
- Gas Appliance Directive (GAD) (90/396/EEC, 93/68/EEC).

The PED (Pressure Equipment Directive) has been applicable in Europe since December 1999 and mandatory since end of May 2002. It applies to all stationary vessels with a service pressure of more than 0.5 bar and a PV (pressure water capacity) of more than 50 bar l. In the case of the fuel cell applications, it may be particularly relevant for all pressure vessels (cylinders) and safety accessories (valves, flexible hoses, connectors). This Pressure Equipment Directive allows the same design for the pressure vessels and associated accessories to be used everywhere in the EU.

This Directive only defines the “essential requirements” which are given in its Annex 1. Detailed requirements are given in the harmonized standards (e.g. those prepared by CEN). These EN standards are not mandatory, other procedures or “state of the art” can be used by the manufacturer in order to demonstrate to the notified body that the essential requirements are fulfilled.

The Council Directive 90/396/EEC on appliances burning gaseous fuels (GAD) is based on the New Approach. The scope of the GAD is restricted to appliances burning gaseous fuels used for cooking, heating, hot water production, refrigeration, lighting and washing, i.e. the GAD covers mainly common consumer and commercial products. So-called fittings are also covered. Appliances specifically designed for use in industrial processes carried out on industrial premises are excluded.

The GAD contains the essential requirements that an appliance must meet when it is placed on the Community market. It does not indicate how these requirements must be met, thus leaving flexibility to manufacturers as regards technical solutions to be adopted. In order to facilitate market access, Harmonised Standards – the reference numbers of which have been published in the Official Journal – provide a presumption of conformity with the directive’s essential requirements. Using Harmonised Standards is voluntary. Standardisation work is being coordinated by the CEN (Sector Forum Gas-SFG).

2.2 Standardisation

Though standards and regulations are frequently mentioned together, it should be remembered that they are two fundamentally different things. While regulations are mandatory for everybody within their domain, standards are not. Standards facilitate the trade and use of goods or services. Their main role is to make components or services fit together: pressure cylinders with valves, valves with regulators and further equipment leading the gas to the place of use. This, however, also involves safety issues, and so there is of course an interface with regulations.

The basically clear distinction between regulations and standards stated above is somewhat softened by the fact that directives and other regulations may refer to standards. If this happens, the user is obliged to follow this standard, giving it a power similar to that of a regulation. But regulations usually contain some provision for the case that technical progress produces new products or applications not explicitly covered by the existing standards. These are required to meet the same safety objectives. Just the process to prove that they do is more tedious. While in the case of a conventional product the reference to the standards is enough, extensive test reports may be necessary for new ones. Certification may be done initially on an individual basis only. As soon as the new product proves that there is a market for it, its manufacturers often develop appropriate standards and introduce them into the regulations. This may take time, but it is a general experience with new technologies.

2.2.1 Standardisation panorama

A common marketplace with common regulations needs also common or at least harmonised standards. While ISO is doing this on a world wide scale, there is also CEN for the EU and associated countries. A similar situation prevails with IEC and CENELEC for the field of electrotechnical standards, Table 1.

Table 1. Systematisation frame for global standardisation work.

	General	**Electrical**	**Other**
World	ISO	IEC	…
Interface	Vienna agreement		
EU	CEN	CENELEC	…

The Vienna agreement between ISO and CEN and between IEC and CENELEC, respectively, is to prevent duplicate work and contradictory results. It basically contains two things:

– A topic which is dealt with in ISO or IEC (or CEN or CENELEC, depending who starts first) must not be dealt with by CEN or CENELEC (or ISO or IEC) at the same time.

– Documents produced by one body can (and preferably should) be adopted by the corresponding partner body in a simplified and accelerated procedure.

Standardisation "state of the art" regarding hydrogen applications and fuel cells is depicted in Figure 1. Evidently, international coordination is needed. Therefore, a number of EU projects have been initiated to take a grip on this issue, such as:

– HarmonHy – Harmonisation of Standards and Regulations for a sustainable Hydrogen and Fuel Cell technology.

– HYPER – focusing on EU-wide approval of H2/FC stationary systems.

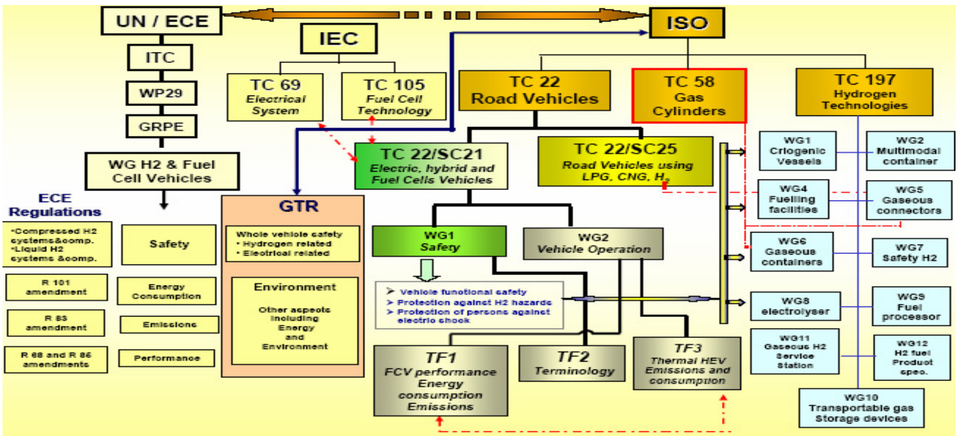

Figure 1. Map of standardisation activities regarding FC and hydrogen (Vergels 2005).

2.2.2 International activities related to FC

The most important committee on standards for hydrogen technology is ISO TC 197 "Hydrogen Technologies". The secretariat is held by the Québec standardisation organisation Bureau de Normalisation du Québec (BNQ) in Canada.

Since there is TC 197 in ISO there is no such committee at CEN. The European experts rather participate in the ISO working groups. A similar situation prevails for fuel cells with IEC TC 105 "Fuel Cell Technology". Given the global character of the technical development, this is certainly appropriate; in which case, CEN and CENELC will not start the drafting of hydrogen or fuel cell relevant standards anymore, and leave this for international activity on ISO and IEC levels.

The main goal of IEC TC 105 is to prepare international standards regarding fuel cell (FC) technologies for all FC applications such as stationary FC power plants, FC for transportation such as FC propulsion systems, and auxiliary power units and portable FC power generation systems. The group of standards related to stationary FC systems are the most important regulatory base for application preparation and therefore are reported in greater detail in other parts of this publication. (See Figure 2.)

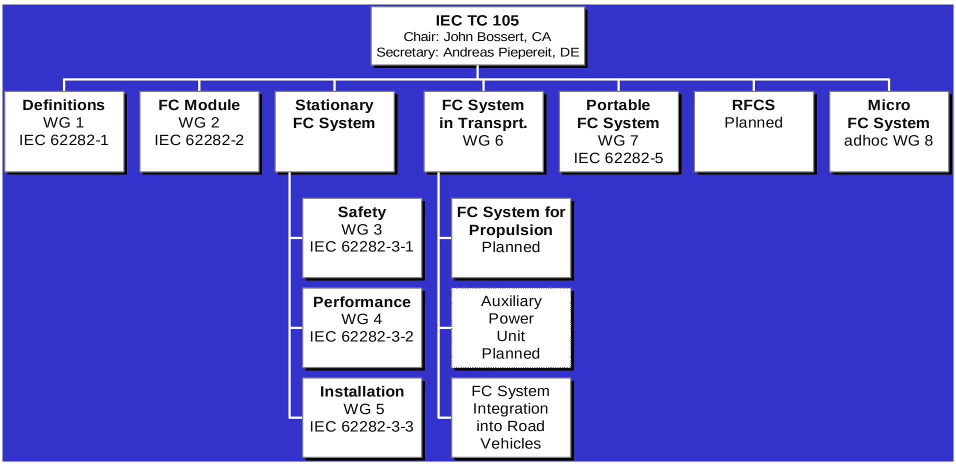

Figure 2. Matrix of activities of IEC/TC 105 committee (Piepereit 2004).

European harmonised standards provide the detailed technical information enabling manufacturers to meet the essential requirements. A harmonised standard provides a presumption of conformity with the essential requirements covered by the standard. These standards – produced under a mandate from Member States through the Commission – give the technical measures to meet the essential. An example of such standard, very important for FC applications is described below.

prEN 50465 Gas appliances – Fuel cell gas heating appliances – Fuel cell appliance of nominal heat input inferior or equal to 70 kW.

This draft European Standard has been prepared by the CEN/CENELEC Joint Working Group “Fuel Cell Gas Heating Appliances”. Following the BT decision

D123/138 taken by 123 BT it is submitted to CENELEC enquiry. This document is intended to be used as an Application Standard to describe requirements which are specific for the application of a fuel cell in a Fuel Cell Gas Heating Appliance. The basic requirements for fuel cells are described in the standards coming out of the IEC TC 105 committee.

This draft European Standard deals with a very early state of new technology. The requirements of this European Standard are not intended to constrain innovations. When considering materials, designs or constructions not specifically dealt with in this European Standard, the alternatives shall be evaluated as to their ability to yield levels of safety and performance equivalent to those prescribed by this European Standard. This can be done by a risk assessment. Furthermore, not all requirements could be described in detail up to now. This is valid both for the requirements and the test procedures. This will be done in later revisions of this European Standard. This draft European Standard has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association and covers the essential requirements of EC Directive 90/396/EEC (see Annex ZZ).

2.3 References

Biennial Report on Hydrogen Safety. Chapter VI: Legal requirements, standards and other codes. Version June 2007. HySafe project (FP6 Network of Excellence) (http://www.hysafe.net/)

Cogeneration Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market. (http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32004L0008:EN:NOT)

Electromagnetic Compatibility Directive (EMC) 2004/108/EC of the European Parliament and of the Council of 15 December 2004 on the approximation of the laws of the Member States relating to electromagnetic compatibility and repealing Directive 89/336/EEC (http://eur-lex.europa.eu/LexUriServ/site/en/oj/2004/l_390/l_39020041231en00240037.pdf)

Gas Appliance Directive (GAD) Council Directive 90/396/EEC of 29 June 1990 on the approximation of the laws of the Member States relating to appliances burning gaseous fuels. (http://ec.europa.eu/enterprise/gas_appliances/text_directive_en.htm)

Low Voltage Directive (LVD) 2006/95/EC of the European Parliament and of the Council of 12 December 2006 on the harmonisation of the laws of Member States relating to electrical equipment designed for use within certain voltage limits. (http://ec.europa.eu/enterprise/electr_equipment/lv/direct/text.htm)

Machinery Directive 98/37/EC of the European Parliament and of the Council of 22 June 1998 on the approximation of the laws of the Member States relating to machinery. (http://ec.europa.eu/enterprise/mechan_equipment/machinery/welcdir.htm)

Piepereit, A. 2004. The current international status of codes and standards development in fuel cell technology. FCTESTNET International Cooperation Workshop. Leysin, 27 February 2004.

prEN 50465. 2007. Gas appliances – Fuel cell gas heating appliances – Fuel cell appliance of nominal heat input inferior or equal to 70 kW. Final draft, December 2007.

Pressure Equipment Directive (PED) 97/23/EC of the European Parliament and of the Council of 29 May 1997 on the approximation of the laws of the Member States concerning pressure equipment. (http://ec.europa.eu/enterprise/pressure_equipment/ped/directive/index_en.html)

Vergels, F. 2005. HarmonHy: Background and presentation. EU Workshop "Regulations and Standards on H2 and FC Technologies for Vehicles". Brussels, 26 September 2005. (http://www.harmonhy.com/harmonhydocs/HarmonHyWP0-009.ppt)

2.4 Further reading

(CE-marking) Council Directive 93/68/EEC of 22 July 1993 amending Directives 87/404/EEC (simple pressure vessels), 88/378/EEC (safety of toys), 89/106/EEC (construction products), 89/336/EEC (electromagnetic compatibility), 89/392/EEC (machinery), 89/686/EEC (personal protective equipment), 90/384/EEC (non-automatic weighing instruments), 90/385/EEC (active implantable medicinal devices), 90/396/EEC (appliances burning gaseous fuels), 91/263/EEC (telecommunications terminal equipment), 92/42/EEC (new hot-water boilers fired with liquid or gaseous fuels) and 73/23/EEC (electrical equipment designed for use within certain voltage limits). (http://ec.europa.eu/enterprise/gas_appliances/text_directive_en.htm)

HYPER – Installation permitting guidance for hydrogen and fuel cells stationary applications. 2007. A research project funded by the European Commission under the Sixth Framework Programme and contributing to the implementation of the Thematic Priority “Sustainable Energy Systems”. Contract No 039028. (http://www.hyperproject.eu)

HySafe – The EC Network of Excellence for Hydrogen Safety. 2007. Project supported by the European Commission under the 6th Framework Programme and contributing to the implementation of the Key Action “Integrating and strengthening the ERA” within the Energy, Environment and Sustainable Development. Contract n°: SES6-CT-2004-502630. (http://www.hysafe.net)

IEC 62282-3-1. 2006, under construction. Fuel cell technologies – Part 3-1: Stationary fuel cell power systems – Safety. The International Electrotechnical Commission. International Standard.

IEC 62282-3-2. 2006. Fuel cell technologies – Part 3-2: Stationary fuel cell power systems – Performance test methods. The International Electrotechnical Commission. International Standard.

IEC 62282-3-3. 2006, under construction. Fuel cell technologies – Part 3-3: Stationary fuel cell power systems – Installation. The International Electrotechnical Commission. International Standard.

NFPA 853. 2007 Edition. Standard for the Installation of Stationary Fuel Cell Power Plants. Quincy, MA, USA: National Fire Protection Association.

prEN 50438. 2005. Requirements for the connection of micro-generators in parallel with public low-voltage networks.

U.S.DoE. Module 1 – Permitting stationary fuel cell installations. Version 1.0. PNNL-14518 released 1/12/2004.

3. System description

In a fuel cell, the chemical reaction of combustion takes place using an electrochemical reaction, where the reactants are separated by a tight membrane that only allows ions to cross. To complete the electrical balance, electrons have to move through a circuit, which produces a current. Fuel cells use oxygen and hydrocarbons (or pure hydrogen) to produce electricity and heat. In this experiment natural gas will be used as fuel and outdoor air as oxidant. Water is needed in gas reforming.

A fuel cell system consists of several subsystems, which include the fuel processor (i.e. hydrogen reformer), fuel cell stack, auxiliary systems required for operation, and the inverter. The process of producing hydrogen from a fuel source such as natural gas is called reforming, and the process can either be internal reforming or external reforming, depending on the type of fuel cell. The SOFC solution considered here uses internal reforming. The SOFC fuel cells are classified as high temperature fuel cells with an operating temperature of 750–1000 ºC. Their high operating temperature and the high-grade residual heat produced can be utilised for space heating and water heating loads for residential, commercial or institutional applications.

Electricity is generated as direct current and therefore a power conditioning unit must be added to invert the power. A battery can be added to balance the system during peaks.

Most of the generated heat is carried away from the fuel cell with hot exhaust gas, which is led to a heat recovery unit. A possibly considerable share of the heat will also conduct through the casing and warm up the surrounding space. Some existing fuel cell systems control these losses by drawing air through the cabinet. This air is called dilution air.

If more heat is needed than the fuel cell can supply, a conventional burner may be used simultaneously. This is the most conventional solution in applications where district heating is not available. However, the application demonstrated here will use the benefit of district heating and even occasionally support its performance by acting as a source towards the network. The challenge of connecting the fuel cell system with the district heating will be described in the following chapters.

There are a limited number of various district heating connection schemes in Finland pre-elaborated for application in certain types of buildings. None of the existing solutions readily takes into account the possibility of heat generation on site. Figure 3 shows a proposal for the combination of a fuel cell system with the otherwise typical connection scheme applicable for an office building. Heat exchangers of the space heating system and domestic hot water system in Figure 3 are used to exploit the heat from the district heating water and they represent the standardised district heating configuration in Finland.

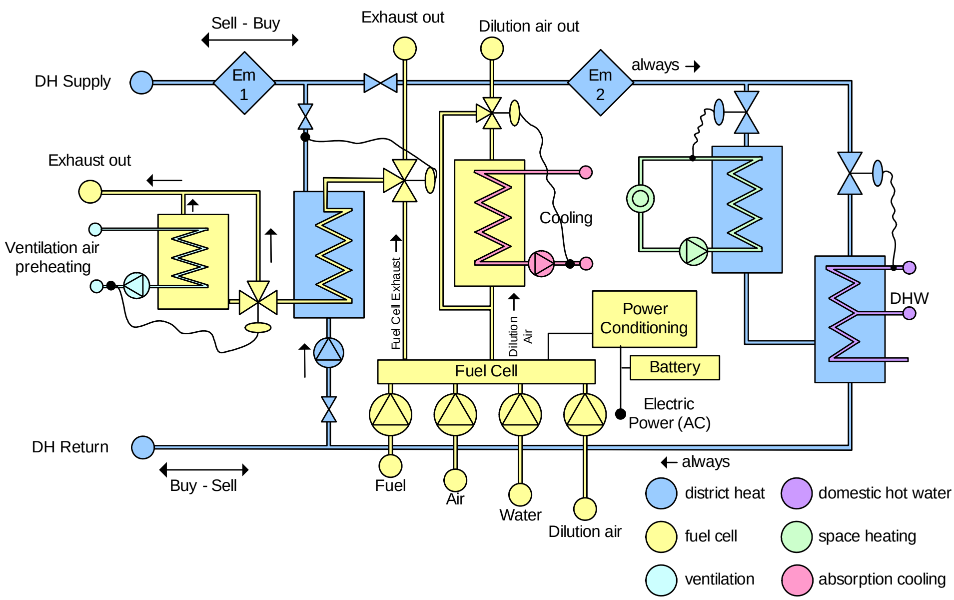

Figure 3. Schematic outline of a building heating system with SOFC.

The embedded simplified fuel cell configuration in Figure 3 is based on a model created in the international IEA ECBCS Annex42 project (Beausoleil-Morrison & Kelly 2007). Hot gas exiting the fuel cell unit is driven through a gas-to-water heat exchanger with a bypassing option. When in use, the unit heats up the primary water in the district heating circuit that transmits the energy for use in the heating and DHW systems. If the building does not demand as much energy as is transferred to district heating water, the excess heat can be sold out towards the network.

When exhaust gas has passed through the first heat exchanger, it can be either rejected outdoors or driven through another heat exchanger, e.g. to preheat incoming mechanical ventilation air, as in Figure 3. Also, energy contained in dilution air may be used in some suitable process, e.g. for absorption cooling of air (Figure 3). The principal idea in designing the connection of the fuel cell with local existing systems is to arrange the connections in a so-called cascade system, in which processes are combined in series in the order of temperature range. An attempt is made to show the idea schematically in Figure 4.

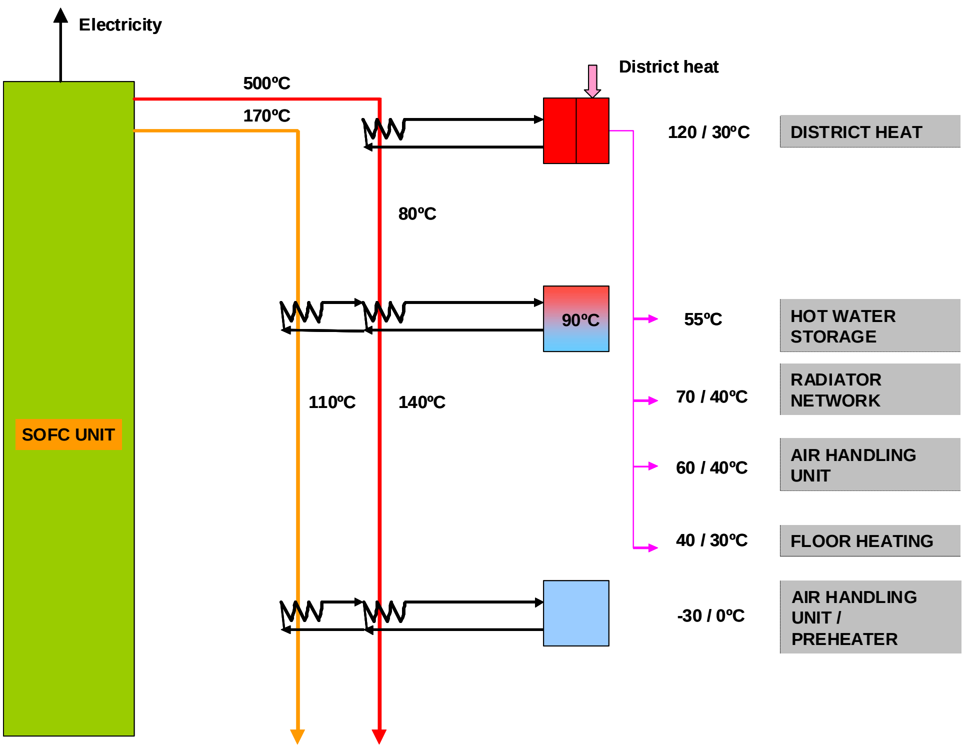

Figure 4. Cascade arrangement of the processes to exploit heat extracted from the SOFC fuel cell.

3.1 References

Beausoleil-Morrison, I. & Kelly, N. 2007. Specifications for Modelling Fuel Cell and Combustion-Based Residential Cogeneration Device within Whole-Building Simulation Programs. Report of Subtask B of FC+COGEN-SIM, The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems, Annex 42 of the International Energy Agency Energy Conservation in Buildings and Community Systems Programme. First published October 2007.

4. Requirements imposed by the building

When installing a fuel cell into a building, the building sets restrictions that affect the design, installation and operation of the fuel cell. This chapter focuses on the relevant regulations and standards related to that. The most important ones are listed in Table 2.

The National Building Code of Finland and the different building instruction registers (RT-, KH- and LVI-kortisto) were studied in this project to find the existing restrictions.

There are not yet any regulations or standards regarding fuel cells or their installation in Finland. For this reason also international standards IEC Fuel Cell Technologies (IEC 62282-3-3) and Fuel Cell Gas Heating Appliances (prEN 50465), which have been previously mentioned in this publication, were examined.

Table 2. Codes and Standards affecting the Fuel Cell Installation.

Title of Code/Standard
Suomen rakennusmääräyskokoelma The National Building Code of Finland, latest revision in 2007 http://www.ymparisto.fi/default.asp?contentid= 198063&lan=fi
TalotekniikkaRYL2002 Osa 1, GI Lämmitysjärjestelmät The Finnish general quality requirements of heating systems. Source: Talotekniikka RYL Handbook with general specifications for Building Services.
TalotekniikkaRYL2002 Osa 1, G5 Kaasujärjestelmät The Finnish general quality requirements of real estate gas systems. Source: Talotekniikka RYL Handbook with general specifications for Building Services.
LVI-ohjekortti, Maakaasulämmitys LVI 62-10287 Natural gas heating – Instruction card. The HEVAC File contains building engineering information. The file contains standards, regulations and product files.
KH-ohjekortti, Maakaasulämmitys KH 23-00362 Natural gas heating – Instruction card. The KH Property Management File is designed for technical, financial and administrative property maintenance. The file contains standards, regulations and product files.
IEC 62282-3-1: Fuel cell technologies – Part 3-1: Stationary fuel cell power systems – Safety **IEC 62282-3-3: Fuel cell technologies – Part 3-3: Stationary fuel cell power systems – Installation** IEC documents cover the safety and installation requirements of stationary fuel cell power systems (FCPS).
IEC 60079-0 Explosive atmospheres – Part 0: Equipment – General requirements **IEC 60079-10 Electrical Apparatus for Explosive Gas atmospheres – Part 10: Classification of hazardous Areas** **IEC/TR 60079-20 Electrical apparatus for explosive gas atmospheres – Part 20: Data for flammable gases and vapours, relating to the use of electrical apparatus**

4.1 General safety requirements and strategy

The requirements for safety are set in standards IEC 62282-3-1 and IEC 62282-3-3, which are quoted in the following chapters. The requirements are slightly different for different-sized fuel cells. Sizing categories are defined in Table 3.

Table 3. Fuel cell system sizing categories.

small	< 10 kWe
medium	> 10 kWe < 500 kWe
large	> 500 kWe
fuel cell system	

The general safety strategy for the installation of the fuel cell systems shall be established according to the following sequence:

- Avoid the possible release of combustible and/or toxic gases and pollutant gases, liquids and solids.
- Eliminate hazards outside the fuel cell system and the related installation, when such energy or gases are released nearly instantaneously.
- Provide appropriate safety markings, concerning the remaining risks of hazards.

Hazards

Using the techniques described above, special care shall be taken to address the following:

- Mechanical hazards – sharp surfaces, tripping hazards, moving masses and instability, strength of materials, and liquids or gases under pressure
- Electrical hazards – contact of persons with live parts, short circuits, high voltage
- Thermal hazards – hot surfaces, release of high temperature liquids or gases, thermal fatigue
- Fire and explosion hazards – flammable gases or liquids, potential for explosive mixtures during normal or abnormal operating conditions, potential for explosive mixtures during failure conditions

- Malfunction hazards – unsafe operation of installation-related equipment due to failures of software, control circuit or protective/safety components
- Hazards generated by erroneous human intervention – deviation from correct operation, errors of manufacturing, installation or maintenance, vandalism
- Material and substance hazards – material deterioration, corrosion, embrittlement, toxic releases, choking hazards (e.g. by superseding, replacing oxygen with inert purge gases)
- Waste disposal hazards – disposal of toxic materials, recycling, disposal of flammable liquids or gases
- Environmental hazards – unsafe operation in extreme hot/cold environments, rain, flooding, wind, earthquake, external fire, smoke or attack by vermin
- Pollution – air, water, soil.

A safety analysis for safety shutdown systems that have otherwise not been evaluated or certified by a third party, e. g. ancillary site equipment and interfaces to the approved FCPS, shall be performed.

4.2 Siting considerations

4.2.1 General siting

The fuel cell power system shall comply with IEC 62282-3-1 Fuel Cell Technologies – Part 3-1: Stationary Fuel Cell Power Systems – Safety.

The manufacturer is responsible for the safety requirements, classification of hazards and protective measures of the fuel cell system. The classification of the environment shall be evaluated in co-operation with the manufacturer’s and the user’s representative.

A fuel cell power system(s) and associated equipment, components, and controls shall be sited and installed in accordance with the manufacturer’s instructions and meet the following requirements:

- It shall be placed and fixed firmly so that it will not be easily moved, toppled, or dislocated.
- It shall be located and secured as necessary so that the system and equipment will not be adversely affected by wind, or seismic events. It

shall be protected so as not to be adversely affected by rain, snow, ice, water and or freezing temperatures, unless the system and installation equipment is designed for those conditions.

- Sites for medium and large power systems shall be protected against access by unauthorized persons commensurate with the location and installation environment. Fire department access shall be provided.
- It shall be located outside of potentially hazardous atmospheres as defined by IEC 60079-10 (Electrical Apparatus for Explosive Gas atmospheres – Part 10: Classification of Hazardous Areas), unless listed and approved for the specific installation.
- It shall be sited so that the power system and equipment do not adversely affect building exits.
- It shall be located so that the power system(s) and components of a fuel cell power system and their respective vent or exhaust terminations are separated from doors, windows, outdoor intakes, and other openings into a building to prevent introduction of exhaust gases into the building.
- The exhaust outlet(s) shall not present a hazard when directed onto walkways or other paths of travel for pedestrians.
- It shall be located in a manner that allows service, maintenance, and emergency access.
- It shall be located away from combustible materials, high-piled stock, and other exposures to fire hazards. Distances and clearance according to manufacturer’s installation instructions.
- It shall be located or protected to prevent physical damage from moving vehicles or equipment.
- Multiple power systems shall be located such that a fire or failure of one of the systems does not present a safety hazard to adjacent power systems.
- Where demonstrated by an engineering analysis that the prescriptive requirements in this section are unnecessary to achieve an equivalent level of safety, approved alternatives shall be permitted by an authority having jurisdiction (AHJ).
- Discharged liquids shall be disposed of according to the AHJ.

4.2.2 Outdoor installations

- Air intakes to a fuel cell power system shall be located so that the plant is not adversely affected by other exhausts, gases, or contaminants. Air intakes to a fuel cell power system shall be kept unobstructed so their flow capacity is not affected by agglomeration of solids, dust, water, ice and snow.
- Air intakes and exhaust to and from a fuel cell power system shall not impact travel on walkways or other paths of travel for pedestrians.
- The exhaust outlet(s) from process areas or areas that contain fuel-bearing components of a fuel cell power system including outlets from relief valves shall be located in such a manner that it will not affect heating, ventilating, and air-conditioning (HVAC) air intakes, windows, doors, and other openings into buildings.
- The area around outlets from fuel processes or compartments that contain fuel-bearing components and relief valves outlets shall be evaluated in accordance with IEC 60079-10.
- Security barriers, fences, landscaping, and other enclosures shall not affect the required airflow into or exhaust out of the fuel cell power system and its components.
- Fuel cell power systems located in open-air structures – that is, with partial roof and/or walls – may be considered outdoor installations when permitted by local or national regulations.

4.2.3 Indoor installations

Medium and large fuel cell power systems

- Indoor medium and large fuel cell power systems and their associated components shall be located in rooms that are protected according to national standards.

Small fuel cell power systems

- Small fuel cell power systems shall not be required to have fire rated separations.

4.2.4 Rooftop installation

According to IEC standard (IEC 62282-3-3):

- Fuel cell power systems and components located on rooftops shall be installed in accordance with outdoor installations.
- The material under and within 30 cm horizontally of a fuel cell power system or component shall be non-combustible or shall be tested or certified to afford an appropriate degree of fire protection to the roof deck. Exemption is made for fuel cell power systems complying with IEC 62282-3-1, section 5.13.b.

4.3 Ventilation and exhaust

4.3.1 General

- All indoor fuel cell power system installations shall be provided with ventilation and exhaust systems as noted below.
- The ventilation systems for indoor installations shall be designed to provide a negative or neutral pressure in the room, with respect to the building where the fuel cell power system is located.

4.3.2 Ventilation

The air that is supplied to the room where the fuel cell power system is located, whether taken from the vicinity of the appliance, an adjacent room or outdoors, may serve as ventilation air, process air or both. This air shall be supplied by either a forced ventilation system or natural ventilation in accordance with the manufacturer’s installation instructions.

If forced ventilation is required for safety during normal operation, a control interlock shall be provided to trigger an alarm and/or shutdown the fuel cell power system upon loss of ventilation, consistent with the safety analysis described in Section 6.

4.3.3 Exhaust system

- The fuel cell power system shall have a dedicated exhaust system that routes the emissions outdoors.
- Small fuel cell power systems may exhaust directly into a utility shed, where they are installed, if the shed:

  a) is unattached from a building or attached without direct access to the building's occupied areas, and

  b) has an interlocked exhaust system that has sufficient flow to assure, under all circumstances, that it will prevent:

     – higher concentrations of air free CO than 300 ppm,
     – 25% of the relevant LFL, and
     – oxygen concentrations below 18%.

4.3.4 Process purging and venting

IEC standard (IEC 62282-3-3) gives requirements for purging and venting.

- Pressure tanks and piping intended to be purged, pressure regulators, relief valves, and other potential sources of combustible gas shall be vented to the outside of the building. For small fuel cell systems the purging is permitted into room atmosphere, if it is ensured that a maximum of 25% of the relevant LFL will not be exceeded and that the atmosphere will not exceed 300 ppm of CO air-free anywhere in the room.
- The vent shall be designed to prevent entry of water or foreign objects.

4.4 Fire protection and detection

A written fire prevention and emergency plan shall be provided as required by and in accordance with national standards.

4.4.1 Site fire protection

If fuel cell power systems are sited at locations that do not have hydrant protection, power systems shall be protected in accordance with a fire risk evaluation.

Fuel cell power systems located inside buildings shall be protected in accordance with combustible gas detection.

4.4.2 Combustible gas detection

According to IEC standard (IEC 62282-3-3), a combustible gas detection system shall be installed in the fuel cell power system enclosure or exhaust system or in the room containing fuel cell power system installations. Location of gas detection systems in the room shall be chosen to provide the earliest possible warning of the presence of combustible gases.

Location of gas detectors shall be in accordance with IEC 60079-29-1, Explosive atmospheres: Gas detectors – Performance requirements of detectors for flammable gases. The requirements for the gas sensors are defined the same standard. For small fuel cell power systems fuelled with odorized gas the combustible gas detection system is not required.

The following criteria for combustible gas detection systems shall be met:

- The combustible gas detection system shall be arranged to trigger an alarm at 25% of the lower explosive level (LEL) or for hydrogen the lower flammable limit (LFL) and be interlocked to shut down the power system fuel supply at 60% LFL.
- The LFL used shall be the lowest flammability limit of the gas or gas mixtures.

A combustible gas detector that meets these requirements shall be provided for all indoor or separately enclosed gas compressors. Exempted are separately enclosed gas compressors, provided room ventilation ensures combustible gas concentrations lower than 25% LEL.

The room or area where the fuel cell power system is installed shall have a hydrogen detector. The gas detection system shall be arranged to trigger an alarm at 25% LFL and be interlocked to shut down the power system fuel supply at 60% LFL.

4.5 Interconnections with site interfaces

All interconnections including piping, electrical wiring, disconnects and ducting between site interfaces and the fuel cell system shall be in accordance with relevant national standards.

4.5.1 Connections to fuel supplies – general

The installation and location of the interface point equipment downstream of the fuel supply system and the associated fuel piping, including the necessary components and their connection to the stationary fuel cell power system, shall be in accordance with this chapter.

All gaseous fuel piping covered by this document shall be marked or identified in accordance with the relevant national standard.

4.5.2 Fuel shut-off and piping

An accessible manual shutoff valve shall be located within 1.8 m upstream of the fuel cell power system, unless the power system is enclosed by a fire-rated room with a fire resistance rating as described in Section 4.2.3. In that case, the shutoff valve shall be located outside the room.

A second shutoff valve may be located within the room for maintenance. If this second valve is not provided, the shutoff, located outside the room, shall be a lockable type.

Piping, valves, regulators, or other equipment shall be located so that they are not subject to physical damage, or otherwise be protected against physical damage.

For indoor installation of a power system being fed by non-odorised fuel gas mixtures, an automatic shutoff valve interlocked with gas detection shall be located outside the building that houses the power system in accordance with Chapter 4.2. The gas detection system shall be arranged to trigger an alarm at 25% LFL and be interlocked to shut down the power system fuel supply at 60% LFL.

4.5.3 Power shutdown

The room or area where the fuel cell power system is installed shall have a hydrogen detector. The pilot installation in Espoo has the following emergency stop procedure in case gas content exceeds 20% LEL or LFL:

- shutdown of the power supply, except of the electrical apparatus for explosive gas atmospheres
- automatic shut off the gas flow to the site and the devices, while the valves shut with no power supply
- gas detectors are electrical apparatus for explosive gas atmospheres and they keep operating
- air conditioning fan is protected against explosive atmospheres, its operation accelerates and ventilates straight outside
- in normal operation the site is unoccupied, the indication of gas detectors is shown outside the site
- in case of emergency shutdown, the pilot lighting protected against explosive atmospheres stays lit during fast exit and possible rescue and extinction
- the control room is separately ventilated, over-pressurised fresh air prevents the leakage gases from flowing from the test site
- the switch cabin is pressurised using a separate compressed-air/nitrogen supply
- the SOFC system under test has an overhead extractor hood

The document for the type of protection for explosions has been drafted for the building in question. The manufacturer has to categorise the internal parts of the SOFC system.

4.5.4 Connections to auxiliary media supply and media disposal

Different fuel cell power systems need some auxiliary media supply and disposal for e.g. normal operation, safety reasons, start-up or shutdown procedures, purging or protection against internal damage; see standard (IEC 62282-3-3). Water, nitrogen, carbon dioxide and hydrogen are typical auxiliary media for fuel cell power systems. As storage of these media is not part of the standard, only the interfaces shall be defined.

Combustible auxiliary gases:

> A redundant safety system consisting of a quick-action shut-off valve controlled by the fuel cell power system's automatic control system, and an accessible second valve with an additional manual operability in the feed line, are required in each system for combustible gases.

Non-combustible or inert auxiliary gases: Connections according to national standards.

Water: tap-water, recycled water. Connections according to national standards.

Waste water disposal. Connections according to national standards.

Discharge pipe (not necessarily for small fuel cell systems): Connections according to national standards.

4.6 On-site piping instructions in the Finnish Handbook of Natural Gas

4.6.1 Pipework

It is recommended to mount the NG piping on the surface whenever possible. The pipes are forbidden:

- inside the cavity walls (sleeved follow-throughs are allowed)
- inside smoke or ventilation air flues
- inside elevator or transportation wells.

NG pipes can be installed in wells reserved for their use. The wells must be such that they can be opened or inspected in other ways. Both ends of the wells must be open to enable appropriate ventilation. Pipe follow-throughs in the wells crossing fire department borders must fulfil fire protection requirements.

Underground piping connections are always welded. Overground piping is usually welded or braced (copper pipes). Welding is also recommended for attaching valves and other components and equipment. Some joints that are made specially for this purpose are also allowed, but welding is highly recommended, especially in basements. If the pipe is hidden inside wall, roof or floor construction, only welding and brazing are allowed.

NG pipes can be brought to the building either underground or overground. The piping must be constructed so that there won’t be significant movement and stress due to frozen ground or building subsidence, etc.

Marking the pipes can be done with tape in residential buildings. Pipes can also be painted with a chosen colour. If the operating pressure exceeds 50 mbar, the pipes must always be marked with yellow. In industrial spaces gas pipes are always marked with yellow colour and a substance tag.

4.6.2 Valves

Usually the gas distributor will buy and install the individual means of isolation (Etelämäki 2007). The valves may be installed either underground or overground.

Indoor pipework must have at least the following means of isolation (shut valves):

- A means of isolation in each incoming pipe to apartment, class room, laboratory room etc. that has two or more gas appliances. The valve should be placed right after the room entry, but it shouldn’t close pipes to other areas.
- A means of isolation before filters, regulators and meters unless they are in same room and right after another means of isolation.
- A means of isolation after regulator or meter unless there is only one gas appliance in same room.
- A means of isolation before each appliance connection.

Ball valves are the recommended valve type. Naturally only those valves should be used which are meant for designed and manufactured for NG.

4.6.3 Vent pipes and connectors

Vent pipes are used in emptying indoor pipelines or in depressurisation during safety measures.

Indoor pipelines sized DN50 or larger must be equipped with vent connector or fixed pipe to be able to empty the pipeline safely outdoors. Connector or pipe is sized DN20 or larger and it must be equipped with at least one means of isolation. If there is no fixed pipe outdoors, the connector must be a blank flange or plug. The vent is placed after the regulator. In addition to the vent connector, the pipeline may also be equipped with a purging connection to make maintenance procedures easier.

Outdoor end of the fixed vent pipe must be placed at least 2.5 m over ground level and not closer than 1.5 m from windows, doors and air vents.

4.7 Heating systems in a building

According to the Finnish building heating, plumbing and ventilation instruction register (TalotekniikkaRYL2002 Part 1/GI), the heating appliance should be installed and located in a separate technical space, heat distribution room or boiler room. In cases where the heating appliance's power exceeds 50 kW, at least one hand extinguisher should be placed in the boiler room close to the exit.

It is important that the boiler room, where the fuel cell is located, fulfils the following restrictions:

- sufficient and adjustable ventilation to keep the temperature below +35 °C
- constant lighting at a minimum of 150–200 lux measured near the indicators and control devices
- floor drain to get piping leakage and overflow water out
- grounded socket-outlet
- power supply for the heat-flow meter (in connection to district heating)
- water supply.

District heating requirements

The pressure loss (with control valve) in the heat distribution center's primary circuit is restricted to a maximum of 60 kPa with the design discharge.

Valves

The valve pressure is at least as high as the maximum allowed operating pressure of piping, however at lowest 60 kPa.

Natural gas piping

The gas pressure control and fluid measurement devices are placed and installed according to G 5520 (natural gas pressure drop and fluid measurement devices), standards SFS 3179 and SFS 5487 and instructions and regulations given by the local distribution company.

4.8 References

Elämäki, M. 2007. Correspondence with Mikko Etelämäki, Product Manager in Gasum Oy, December 2007.

IEC 60079-0 (2007-10) Explosive atmospheres – Part 0: Equipment – General requirements. 191 p.

IEC 60079-10 (2002-06) Electrical Apparatus for Explosive Gas atmospheres – Part 10: Classification of hazardous Areas. 115 p.

IEC 60079-29-1 (2007-08) Explosive atmospheres – Part 29-1: Gas detectors – Performance requirements of detectors for flammable gases. 100 p.

IEC 62282-3-1 (2007-04) Fuel cell technologies – Part 3-1: Stationary fuel cell power systems – Safety. 156 p.

IEC 62282-3-3 (2007+11) Fuel cell technologies – Part 3-3: Stationary fuel cell power systems – Installation. 33 p.

IEC/TR 60079-20 (1996-10) Electrical apparatus for explosive gas atmospheres – Part 20: Data for flammable gases and vapours, relating to the use of electrical apparatus. 47 p.

prEN 50465. 2007. Gas appliances – Fuel cell gas heating appliances – Fuel cell appliance of nominal heat input inferior or equal to 70 kW. Final draft, December 2007.

TalotekniikkaRYL2002 Part 1/GI. Lämmitysjärjestelmät (Heating systems).

4.9 Further reading

Atex 137 workplace directive 1999/92/EY, http://ec.europa.eu/enterprise/atex/dir92-en.pdf or in Finnish http://ec.europa.eu/enterprise/atex/dir92-fi.pdf

Maakaasukäsikirja (Finnish Handbook of Natural Gas). 2004. Maakaasuyhdistys ry. http://www.maakaasu.fi

Maakaasukäsikirja is based on following list of Finnish guides and standards:

- Maakaasun määrämittaus, Maakaasuyhdistys r.y., 1989.
- **M1** Maakaasun ja nestekaasun koostumus ja ominaisuudet, Gasum Oy, 1993.
- **M5** Kaasun käyttökohteiden putkistot sekä käyttölaitteiden sijoittaminen ja varustelu, Gasum Oy, 1998.
- **M6** Maakaasun ja nestekaasun palaminen, Gasum Oy, 1997.
- **M18** Maakaasun jakelu- ja käyttöputkiston mitoitus, GasumOy, 1997.
- **SFS-EN 1594** Kaasuputkistot. Maksimikäyttöpaine yli 16 bar. Toiminnalliset vaatimukset, 2000.
- **SFS-EN 1775** Kaasuputkistot rakennuksiin. Maksimikäyttöpaine alle 5 bar. Toiminnalliset suositukset, 1998.
- **SFS-EN 1776** Maakaasun mittausasemat. Toiminnalliset vaatimukset, 2001.
- **SFS-EN 1918-1** Maanalaiset kaasuvarastot. Osa 1: Toiminnalliset suositukset kaasun varastoinnille akviferi-kerrostumissa, 1998.
- **SFS-EN 1918-2** Maanalaiset kaasuvarastot. Osa 2: Toiminnalliset suositukset kaasun varastoinnille öljy- ja kaasukentissä, 1998.
- **SFS-EN 1918-3** Maanalaiset kaasuvarastot. Osa 3: Toiminnalliset suositukset kaasun varastoinnille suolakerrostumiin liuotetuissa onkaloissa, 1998.
- **SFS-EN 1918-4** Maanalaiset kaasuvarastot. Osa 4: Toiminnalliset suositukset kaasun varastoinnille kallioluolissa, 1998.
- **SFS-EN 1918-5** Maanalaiset kaasuvarastot. Osa 5: Toiminnalliset suositukset kaasuvarastojen maanpäällisille laitteistoille, 1998.
- **SFS-EN 12007-1** Kaasuputkistot. Maksimikäyttöpaine enintään 16 bar. Osa 1: Yleiset toiminnalliset suositukset, 2000.
- **SFS-EN 12007-2** Kaasuputkistot. Maksimikäyttöpaine enintään 16 bar. Osa 2: Toiminnalliset suositukset polyeteenille (maksimikäyttöpaine enintään 10 bar), 2000.
- **SFS-EN 12007-3** Kaasuputkistot. Maksimikäyttöpaine enintään 16 bar. Osa 3: Toiminnalliset suositukset teräkselle, 2000.
- **SFS-EN 12007-4** Kaasuputkistot. Maksimikäyttöpaine enintään 16 bar. Osa 4: Toiminnalliset suositukset putkiston uusimiselle, 2000.
- **SFS-EN 12186** Kaasuputkistot. Siirto- ja jakeluputkistojen paineenvähennys-asemat. Toiminnalliset vaatimukset, 2001.
- **SFS-EN 12279** Kaasuputkistot. Paineenvähennyslaitteistot taloliittymissä. Toiminnalliset vaatimukset, 2000.
- **SFS-EN 12327** Kaasuputkistot. Painekoe, käyttöönotto ja käytöstä poistaminen. Toiminnalliset vaatimukset, 2000.

- **SFS-EN 12583** Kaasuputkistot. Kompressoriasemat. Toiminnalliset vaatimukset, 2000.
- **SFS-EN 12732** Kaasuputkistot. Teräsputkiston hitsaus. Toiminnalliset vaatimukset, 2000.
- **SFS 2730** Maakaasuputkisto. Suunnitteluperusteet, 1991.
- **SFS 2731** Maakaasuputkisto. Teräsputket. Rakenneaineen valinta ja seinämän paksuuden mitoitus, 1990.
- **SFS 2895** Maakaasuputkisto. Paineenvähennysasema, 1989.
- **SFS 2896** Maakaasuputkisto. Rakentaminen, 1988.
- **SFS 2897** Maakaasuputkisto. Painekoe, 1987.
- **SFS 3177** Maakaasuputkisto. Merkinnät, 1977.
- **SFS 3179** Kaasuputkistot. Käyttöpaine enintään 4 bar. Kaasuputkistojen ja käyttölaitteiden sijoitus, asennus, varustelu, paine- ja tiiviys kokeet sekä käyttöönotto, 1991.
- **SFS 5487** Maakaasuputkisto. Jakelu- ja käyttöputkiston paineenvähennys-laitteisto, 1989.
- **SFS 5717** Maakaasun siirtoputkiston sijoittaminen suurjännitejohtojen ja kytkin-laitosten läheisyyteen, 1992.

5. Requirements imposed by the natural gas network

In this fuel cell case, the used fuel is natural gas. Therefore only natural gas connection is studied. Later also other fuel sources as hydrogen and biogas fuel systems, and the restrictions they set to the fuel cell system, should be investigated.

General guidelines and instructions concerning installation and use of natural gas are given in KH-23-00362, LVI-62-10287 and “Talotekniikka RYL 2002 Osa 1” (LVI 01-10355). Below are listed requirements imposed by the natural gas network.

5.1 Construction permits

If the maximum allowed piping operating pressure is 20 kPa (0.2 bar) and the target gas consumption is not higher than 50 Nm^3/h, which is equal to an effect of 500 kW, the natural gas piping and gear connected to it do not need a construction permit. If both of the limits are exceeded, according to the natural gas statue 1058/1993, a construction permit has to be applied for from TUKES (Turvatekniikan keskus) for the piping system.

5.2 Natural gas supply

The natural gas distribution piping is made almost exclusively of plastic. Operating pressure is usually at highest 400 kPa (4 bar), but still never exceeding 800 kPa (8 bar).

5.2.1 Pressure drop equipment

Before the volume measurement and delivery into the customer's natural gas piping, the gas pressure is dropped to match the usage equipment. The pressure is dropped with control valves directly to the level required by the gear or close to it.

The pressure level of the gas leaving the pressure drop equipment (= control pressure) is chosen case-specifically. If the gears are in an apartment, accommodation facility, day care apartment or assembly room, the gas piping leading to these can have a maximum operating pressure of 20 kPa (200 mbar).

5.3 The basics of natural gas piping dimensioning

The flow dimensioning of the pipeline is based on the supplied gas amount, pressure level, the available pressure loss and piping length. Usually the piping size is chosen based on experience. Then, from the desired gas flow, the developed pressure loss can be controlled. Usually it is justified to equip each gear, burner or burner group with its own pressure control units. (KH 23-00362.)

5.4 The natural gas place of delivery specific pressure control and volume measurement

5.4.1 Placement of the pressure control equipment

The pressure control equipment is placed according to standard SFS 5487. The placement depends on the incoming gas pressure to the control device as follows:

- Inlet pressure at most 0.2 bar.

The pressure control equipment can be placed freely indoors or outdoors.

- Inlet pressure at most 4 bar.

The pressure control equipment can be placed freely indoors or outdoors. If the placement space has a direct connection to accommodation, apartments, a day care or meeting spaces, the pressure control equipment has to be placed in a compact shelter closet which has a direct ventilation connection to the outdoors.

- Inlet pressure higher than 4 bar, however at most 8 bar.

The pressure control equipment can not be placed in a building which has accommodation, apartments, a day care or meeting spaces.

5.4.2 General requirements of the gear placement

Gears can only be placed in such spaces whose size and ventilation are sufficient. The gear should be placed so that objects and surfaces located in close connection don't heat up in a way that risks safety. A boiler with an effect of maximum 20 kW may be placed in spaces that are in connection with apartments, such as a utility room, entrance tambour, entrance hall, storage or hobby room. The boiler should be of a type which is approved for apartment installation. (LVI 62-10287.)

5.5 Hazards of fuels other than hydrogen

Parts of the text based on Installation Permitting Guidance for Hydrogen and Fuel Cells Stationary Applications, 2nd draft version (HYPER project 2008).

In European Union REACH (Registration, Evaluation and Authorisation of Chemicals) legislation must be obeyed. The REACH regulations concerning the chemicals safety are under development and guidance documentation is being prepared. Development of chemical safety reports often requires modelling of exposure scenarios and takes time. The latest versions of the documents must always be used. (Uuksulainen et al. 2008.)

SOFC fuel cells utilise suitable hydrocarbons directly from the fuel. The processing and/or use of these hydrocarbon fuels will produce carbon dioxide. Appropriate measures, such as containment and ventilation, should be taken to ensure that any carbon dioxide effluent stream is effectively discharged and does not produce an asphyxiation risk. (HSG 2004.)

Natural gas (methane) is lighter than air and will tend to diffuse upwards, but at a much slower rate than hydrogen. The explosion limits for natural gas (5–15% v/v) are also much narrower than hydrogen. The characteristics of both fuels should be considered for any dual fuel systems. (Biennial Report 2006.)

Liquefied petroleum gas (LPG) is considerably heavier than air, especially when cold, for example when taken directly from a liquid storage vessel. In the event of a leak, LPG vapour will usually percolate downwards and may accumulate on the floor or in low-lying sumps, rapidly producing a flammable atmosphere. Mixtures containing 2–10% v/v LPG in air will readily ignite and explode. The significant differences in the buoyancy and dispersion characteristics of the two fuels should be carefully considered in systems where LPG and hydrogen may both be present. The pipework and equipment used to store and supply LPG fuel should also be suitable and be designed to an appropriate standard. (HSE Books 1998.)

Methanol can be used directly by some types of fuel cell. This fuel had some hazards that demand particular attention. In addition to being a highly flammable liquid, methanol is also toxic by inhalation, ingestion and notably, by skin absorption. (Lewis & Irving 2000.)

Appropriate precautions such as containment and ventilation should be taken to prevent spillages and the accumulation of hazardous methanol/air mixtures whenever it is used.

5.6 References

Biennial Report. 2006. Biennial Report on Hydrogen Safety – Chapter 1: Hydrogen fundamentals: Version 1.0. October 2006. HySafe project (FP6 Network of Excellence) (http://www.hysafe.net/).

HSE Books. 1998. Safety in the installation and use of gas systems and appliances. Gas Safety (Installation and Use) Regulations 1998. Approved Code of Practice and Guidance. L56 (Second Edition). ISBN 071761635 5.

HSG 243. 2004. Fuel Cells: Understand the hazards, control the risks. HSE Books. ISBN 0717627667.

HYPER project. 2008. Installation permitting guidance for hydrogen and fuel cells stationary applications. 2nd draft, April 2008. A research project funded by the European Commission under the Sixth Framework Programme and contributing to the implementation of the Thematic Priority “Sustainable Energy Systems”. Contract No 039028. (http://www.hyperproject.eu)

KH-23-00362. KH-ohjekortti, Maakaasulämmitys.

Lewis, R. J. & Irving, N. 2000. Sax’s dangerous properties of industrial materials. 10th Edition. John Wiley and Sons. ISBN 0471354074.

LVI-01-10355. Talotekniikka RYL 2002 Osa 1.

LVI-62-10287. LVI-ohjekortti, Maakaasulämmitys.

Uuksulainen, S., Riala, R., Santonen, T. et al. 2008. Developing REACH Exposure Scenarios for Methanol (Alustavien REACH-altistumisskenaarioiden kehittäminen metanolille). TSR (105338) Final Report. Helsinki: Finnish Institute of Occupational Health.

6. Requirements imposed by the district heating network

When connecting the SOFC-based micro-CHP unit for the building's internal and external networks, a number of important precautions must be considered.

6.1 Materials

Materials must be selected in primary and secondary side that they will be qualified the whole life cycle. Coal steel is forbidden on heat exchange surfaces as well as in hot tap water heat exchangers in the secondary side.

6.2 Pressure level

Design pressure is 1.6 MPa (EI, K1/2003) in the DH primary side and 1.0 MPa for the hot tap water pipeline and 0.6 MPa for the heating pipeline in secondary side.

Minimum pressure difference Δp after an energy meter is 60 kPa and at least half of it must be used in a control valve. The other cells for pressure loss are shown in Table 4.

Table 4. Pressure loss in DH primary and secondary side.

	Primary side	**Secondary side**
tap water heat exchanger	20 kPa	50 kPa
other heat exchangers	20 kPa	20 kPa
pipes and equipments control valve not included	5 kPa	5 kPa

Recommendation of water flow in the secondary side as a function of pipe diameter (DN) is shown in Table 5.

Table 5. Water flow in secondary side pipe and equipment if pressure loss is less than 5 kPa.

Diameter in secondary side (pipe, dirt or air strainer, line regulating and cut-off valve) DN	**Permissible water flow (dm^3/s)**	
	screwed equipment	welded/flanged equipment
20	0.2	
25	0.3	
32	0.5	0.7
40	0.9	1.1
50	1.5	1.7
65		3.1
80		4.9
100		8.5

Water velocity is normally 2 m/s maximum in delivering steel pipelines and in small service pipelines 3 m/s maximum. In copper pipes water velocity is 1 m/s maximum.

6.3 Temperature level

Supply temperature is 120 °C in the primary side (into the house), 58 °C for hot tap water pipeline and 70 °C for heating pipeline in the secondary side (EI, K1/2003). In case of floor heating systems temperature is 45 °C maximum (overheating protection is 55 °C). The return temperature should be 45 °C maximum from room heating and 25 °C maximum from hot tap water circle.

Temperature drop ΔT should be 25 °C minimum in radiator or air heated houses and 5–10 °C in floor heating system.

6.4 Connection of the consumer to DH system

The consumer substation defined in recommendation K1/2003 consists of two or three heat exchangers and it is called an indirect connection. Quality of pressure and water is easier to keep under control compared to the direct connection without heat exchangers. In the secondary side (consumer side) the pressure can be lower than in the primary side (DH network). All the heat exchangers are temperature-controlled by a control valve. A principle of the Finnish substation is shown in Figure 5, where DHW is the domestic hot tap water heat exchanger and the heating heat exchanger is designated for radiator and air conditioning heating.

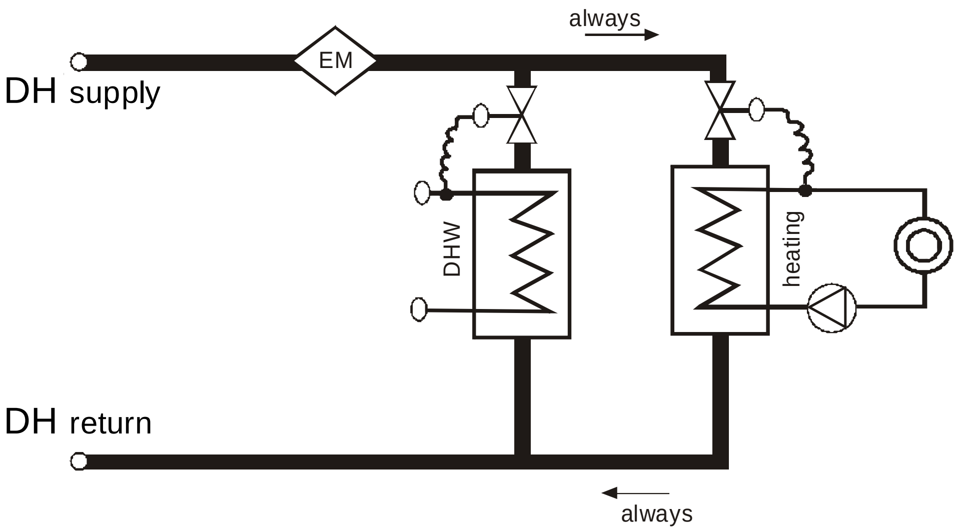

Figure 5. Substation connection of the consumer to the DH system.

6.5 Energy metering

Energy meters must be certificated of compliance with a standard in Finland (EI, K13/2008).

Energy meters must be design for 120 °C of water temperature and design pressure is 1.6 MPa.

The meter must be workable in indoor temperatures of 5–55 °C (class A of exposure conditions). The room temperature in the metering room must be between 10–35 °C, which has to be insured with ventilation and isolating of the warm pipes.

Water quality in DH pipelines must be set based on the recommendation of the DH circulation water by the Energy Industry Association (EI, KK3/2007). In the building side, care must be taken of the calcareous fur because of the high temperatures in the FC exhaust gas (softening of water with a desalination filter!).

6.6 Requirements in case of heat-trade

In the case of a micro CHP plant, generation of heat or electricity may exceed the consumption in the building. The extra capacity can be sold to the district heating network or the electricity grid. The substation must be equipped to drive it both directions (sell or buy).

6.6.1 Connection of the consumer/supplier to DH system

The consumer/supplier can be connected in a number of ways to the DH system, as presented and discussed in the HETRA project (Sipilä et al. 2005).

In the case of fuel cells, the CHP plant can be connected indirectly to the DH network with a heat exchanger, Figure 6.

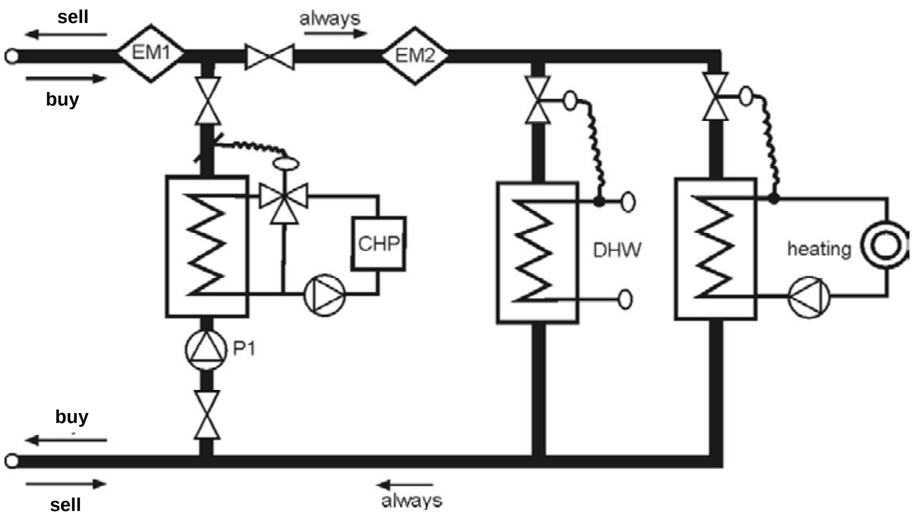

Figure 6. Indirect connection of the CHP plant to the DH network with a heat exchanger (arrows indicate flow directions in different heat trading situations).

This connection is suitable to combine a CHP unit with the DH network. It is safe concerning leaks (water and gas), easy to control and suitable both for new installations and renovations. (See Table 6.)

Table 6. Pros and cons of the case where the CHP plant is connected indirectly to the DH network and heat is sold upstream of the DH network.

Pros	***Cons***
Modularity of the substation configuration is possible with the standard unit	More complicated and more expensive than direct connection
Safe solution regarding water and gas leaks	Extra heat exchanger and secondary network are needed
Good controlability	Extra pump is needed to sell heat upstream
Construction pressure of CHP is not dependent on the pressure in the DH network	

The water temperature injected into the network must not differ by more than 10 °C from the driven temperature in the DH network.

In a sale situation the booster pump must be used to compensate for pressure loss in customer equipment and pressure difference between the supply and the return DH pipeline. The pump requirements are designed like the pumps in the DH networks, corresponding to the maximum water mass flow in the sale mode.

It must be possible to measure energy in both directions (sale/buy mode) and a meter's requirements are like in the normal customer case.

6.7 References

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7. Requirements imposed by the district heating substation

7.1 Substation safety

Most of the substation safety regulations are addressed to the SOFC system manufacturers to guarantee the safety of the devices. What happens inside the SOFC module is outlined from this survey. Regulations to connect the module to building systems are described in Chapter 4.

7.2 Substation controlability

7.2.1 Fuel cell system dynamics

This chapter is based on work done in IEA Annex42 (Beausoleil-Morrison & Kelly 2007).

SOFCs tend to have slow transient response characteristics due to their high operating temperatures, large thermal inertia, and the thermal stresses that can be induced by sudden temperature changes within the stack. Given this reality, it is important to consider the transient behaviour of the fuel cell to be able to control the system efficiently.

The transient behaviour of the stack is highly complex and essential to overall system performance. Methods used to manage this transient behaviour are likely to be considered proprietary by manufacturers.

A second aspect of dynamics is to consider the start-up period during which the stack is heated to its operating temperature and then its voltage is gradually reduced to its operating point. The stack is usually warmed either through the combustion of fuel or through electric resistance heating (some products may use both modes of heating during different points in time over the period). The fuel cell may produce some electricity during the voltage-reduction phase.

The control of the warming and the voltage-reduction phases of the start-up period can be quite complex and vary from manufacturer to manufacturer. The fuel and electrical supply and electrical production will be tightly controlled to protect the integrity of the stack, and can vary considerably throughout the phase.

Furthermore, given the complex nature of starting and stopping a SOFC and the potential impact this can have upon durability, SOFC cogeneration devices should undoubtedly be controlled to minimise stop-start cycles.

A third aspect of consideration is the cool-down period. During this time, the FCPM produces no electrical output and it cannot be completely turned off or switched back into operation until the cool-down time has elapsed. Fuel and/or electricity can be consumed during the cool-down period to monitor and control the cooling process, in order to avoid excessive thermal stresses.

Briefly, controlling the fuel cell system efficiently requires high levels information about the device. The instructions for safe and efficient drive should be required from the system supplier or manufacturer.

7.2.2 Possible strategies

Ellis (2002) presents four basic strategies that are likely to be implemented with a fuel cell cogeneration system in one facility: *load tracking* or *base load strategies* which can be based on either thermal or electrical power demand. Ellis also mentions two other cogeneration strategies: *peak shaving* and *economic dispatch*. He argues that they would call for fuel cell operation during only limited periods, and due to the relatively high first cost of fuel cell systems, such strategies would not be likely to be attractive. (Ellis 2002.) Proper studies addressing the issue are not available but if the cogeneration system is connected to a group of different types of buildings instead of a single building, peak shaving and economic dispatch might also allow enough operation time for a fuel cell to be feasible.

- *Load tracking strategy* calls for the fuel cell to have a capacity that exceeds either the minimum electrical or thermal requirement for the facility. The fuel cell output power changes in response to the needs of the facility.

  With *electrical load tracking strategy,* the thermal output of the fuel cell system is used whenever possible; otherwise it is simply rejected into the atmosphere. A separate heat source is required to provide thermal energy when the waste heat from the fuel cell is not adequate.

With a *thermal load tracking strategy*, electrical power that is generated during the course of supplying the thermal load is used by the facility to replace purchased electric power. The excess power can often be sold to the utility.

- With a *base load strategy*, the fuel cell system is designed to supply the minimum amount of power required by the facility. Therefore, the fuel cell system can operate at peak power output continuously. Electrical power is purchased from or sold to the grid to balance the electrical demand for the facility with the power supplied by the fuel cell system. A shortage of thermal energy is compensated for by a separate thermal source such as a boiler.
- With a *peak shaving strategy*, the fuel cell system provides power only during on-site or utility peaks.
- With an economic dispatch, the fuel cell system operates only if it is more economical than other options.

7.2.3 Selecting control strategy

Typical energy consumption of a four-person household is shown in Figure 7. It shows how the consumption breaks up. Changes in electricity demand are very fast when compared to changes in heating power.

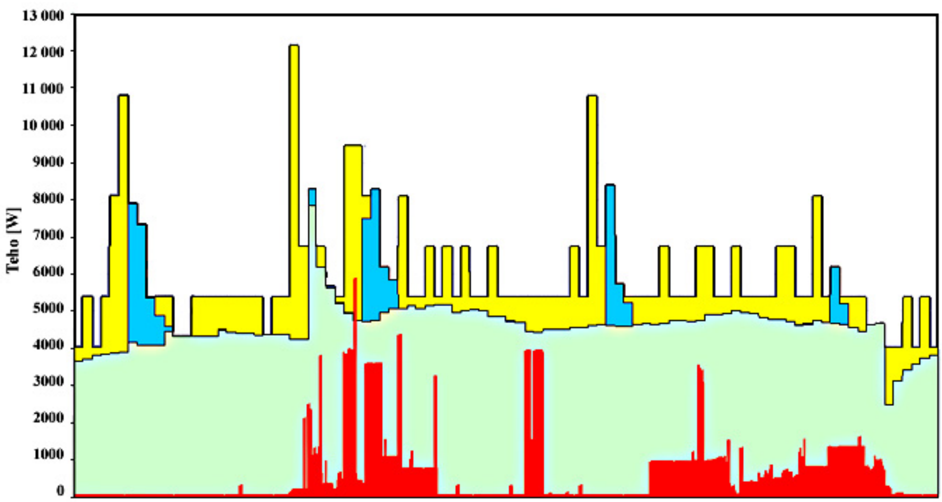

Figure 7. Load curves for gas heating and electricity of a four-person household in Germany (Birnbaum & Weinmann 2003). Red = electricity demand, green = boiler power for room heating, blue = additional boiler power for hot water, yellow = losses of power and off-gas.

The monthly consumption in a new Finnish household is shown in Figure 8. Total energy consumption is about 13 MWhs for heating and 5 MWhs for electricity. For a 100 gross-m^2 house, this means an energy performance value of 180 kWh/gross-m^2/year. According to the Finnish energy certification decree (Ministry of the Environment 2007b) this is rated as grade C house (scale from A to G), which is – along with the grade D – the most common grade for existing buildings. The electricity consumption also matches the typical value presented in the Finnish building code part D5 (Ministry of the Environment 2007a).

The ratio of heat to electricity varies during the year. Heating and electricity demands are almost equal in the summer, but in the winter, heating demand can be even four times higher. Similar trends can be observed in demonstration building, Figure 9, where in summer months electricity consumption even exceeds heating consumption.

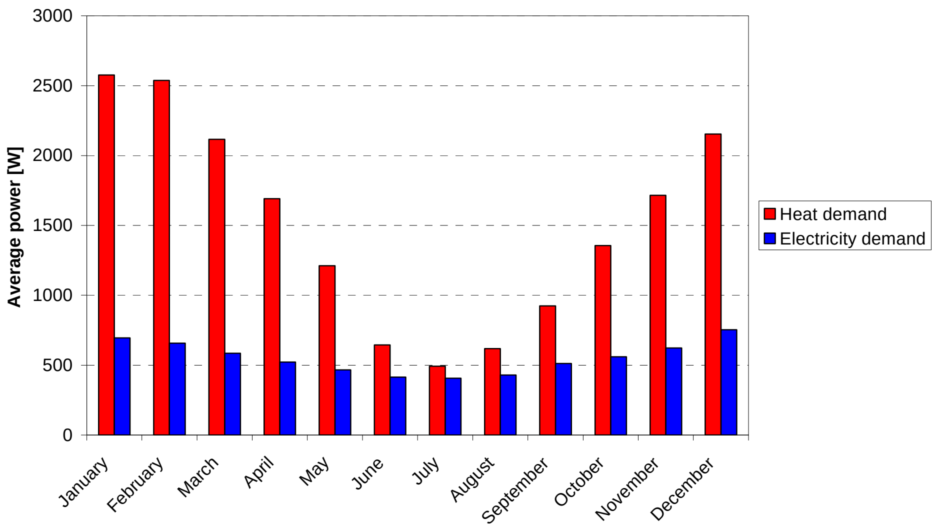

Figure 8. Monthly consumption of heat and electricity (Jahn & Shemeikka 2004).

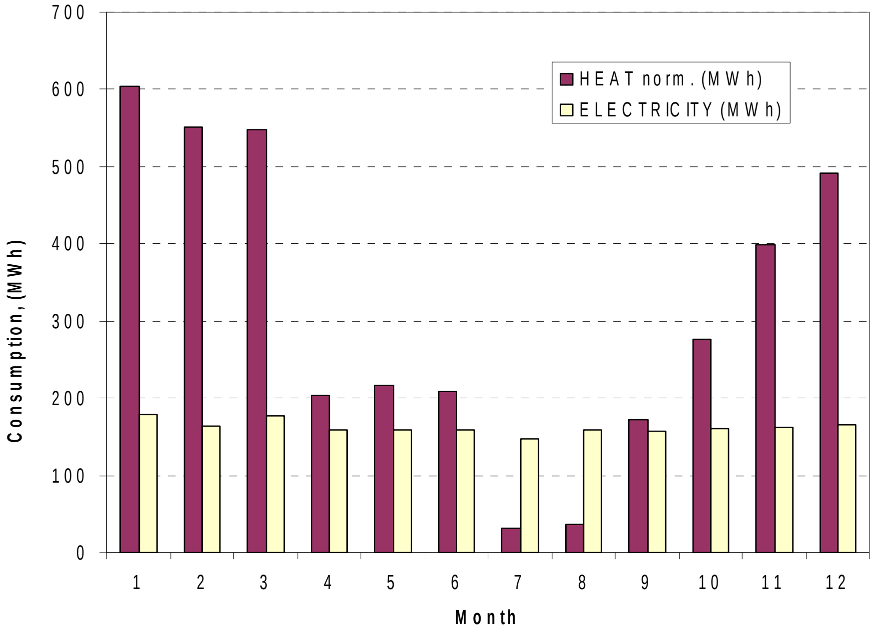

Figure 9. Monthly energy consumption in 2006 in the laboratory/office facility where 50 kW SOFC will be demonstrated.

The power output of the fuel cell system cannot be changed very rapidly. Theoretically, electrochemical reactions should be very fast (timescale in milliseconds), but in real life thermal inertias of stack materials and heat transfer properties limit the changes in reaction speed. Even if the cell is hot already, the thermal lag of the stack is estimated to be in the hundreds of seconds. In addition, the fuel delivery system with a (pre-)reformer sets new restrictions for power changes. (Braun 2002.)

Since the system can't respond to changes very fast, the more even **thermal load tracking strategy** looks attractive. However, it has some disadvantages. During the heating season the system produces too much electricity, which has to be sold to the grid. The profitability depends on the electricity selling price. Another disadvantage is that the system has to be designed to meet much more power than with electricity load tracking strategy. This results in higher investment costs. If the thermal load tracking strategy is chosen, the potential of reducing the difference between heating and electricity demands with energy saving measures should be studied.

Base load strategies are easy to implement, but greater share of total energy demand has to be bought or generated with other devices. The feasibility of base load strategies also depends on energy prices.

The pure **electricity load tracking strategy** runs most of the day with very low power when compared to peak power demand. This may result in difficulties in keeping the temperature high enough. Additional stack heating may be needed, which reduces the efficiency. Typically the problem is solved by setting a minimum power, which does not decrease even if the demand drops lower. Another option is to run the system down. The choice between the alternatives is made depending on the electricity selling and storage possibilities and the regularity of the undershoots. (Ferguson & Ugursal 2004.)

Rapid changes in power demand are another problem in electricity load tracking strategy. Not all of the peaks can be handled by controlling the fuel cell, and the electricity storage system is required to be able to ensure the quality of electricity. The utility grid is one option for the “storage”, but some others also exist.

7.3 Heating and electricity storage

7.3.1 Heat storage

Electricity load tracking strategy leads to varying heat production. Peaks in heat production that last minutes, or a couple of hours, can be easily balanced with the heat capacity of the building or the heating system. Typical components are water tanks, floor heating and massive building structures. Phase changing materials (PCM) have also been used. (Marko & Braun 1994.)

Larger scale heat storage systems use large water stores or the ground. These types of solutions have also been tested in seasonal storage. Seasonal storage can be charged with heat energy in the summer and discharged when heating is needed. A typical example is a water-filled cave. (Marko & Braun 1994, VTT Prosessit 2004.)

The balancing of seasonal heat differences with storage is usually complex and expensive. Another aspect is to forget the production side and look for the consumer side. Differences can be balanced by connecting several buildings of different types to same heat production system. The target is to find a combination of buildings which matches the heat and electricity consumption profiles of the fuel cell system. (Jahn 2005.)

7.3.2 Electricity storage

A fuel cell system time constant is typically 30 seconds or more and the electrical system in a building should be able to respond to consumption changes on millisecond timescales. To manage this contradiction, an electrical storage or a grid connection is needed. Usually the grid connection is recommended if it is available. In stand-alone systems, batteries or other energy storage devices are naturally required to meet dynamic and peak loads. (Braun 2002.)

In a grid-connected configuration, the cost-effective use of batteries (or other energy storage methods) is uncertain and can depend on the utility net metering plan, grid-connection charges, and the dynamic capability of the fuel cell. (Braun 2002.)

If electricity storage is used, at least following alternatives are available (Jäntti 2003, Wikipedia 2007):

- batteries
- pumped-storage hydroelectricity
- Compressed Air Energy Storage (CAES)
- Flywheel Energy Storage (FES)
- (super)capacitors
- Superconducting Magnetic Energy Storage (SMES)
- regenerating fuel cells (Smith 2000, Verma & Basu 2004).

Another interesting alternative to electricity storage is energy demand management, also known as demand side management (DSM). For decades, utilities have sold off-peak power to large consumers at lower rates, to encourage these users to shift their loads to off-peak hours. In Finland, most of the buildings with electrical heating have time-of-day-tariff contracts with their electricity company.

In the future, electrical devices could automatically ask the management system if it is a good moment to start running. A freezer is a good example. It could use the cheap (or excess) energy period to cool down a few degrees below the setpoint and stand by during the expensive energy period. It could also make a reservation of energy to the management system in advance, to allow the system to prepare to for upcoming demand. (Valkonen et al. 2004.)

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8. Electrical requirement for interconnection of distributed energy generation units into the low-voltage grid

8.1 General

These requirements are mainly generated by a Finnish working group in the research project FINSOFC (VTT-FINSOFC Workgroup paper 2005). Some clarifications from additional researches (ElDIG) and the modern requirements of a network operator (Helsinki Energy) have been noted (Helsinki Energy 2009, ElDIG, draft 2007). There are several activities going on in this field. “Smart Grid” by the European Union, TF C6.04.01 by CIGRE and many national efforts may be mentioned as examples. Changes in the requirements may therefore follow in the future. Generally the requirements are international. The specific cases valid only in Finland or any other country will be clearly marked.

The following international standards specify the connection between the fuel cell and the electric network:

- EN 50438: 2007
- IEEE Std 1547™-2003.

EN 50438

European standard EN 50438 is intended for installation of equipment rated up to and including 16 A per phase and 230/400 V. In Finland, the scope is extended to a rated power of 30 kVA for three-phase equipment. Additionally, Cyprus and Ireland allow the extension of the scope > 16 A. The standard specifies the requirements mainly in the domestic market, i.e. Cenelec members. The standard introduces an Inform and Fit procedure, which is allowed in most

Cenelec members. Countries not allowing that procedure are Austria, Switzerland, Czech Republic, Germany, Spain, Finland, France, Italy, Norway, Poland and Sweden. The following titles are specified in standard EN 50438:

- connection requirement: electrical installation and interface protection
- power quality
- operation and safety
- commissioning.

The normative Annex A gives National deviations for interface protection settings for 18 countries in total. The informative Annex C of EN 50438 gives the guidelines for the type testing of the interface protection (EN 50438).

IEEE 1547

IEEE 1547 is an international standard for interconnecting the distributed resources. It is valid for the aggregate capacity of 10 MVA or less, interconnected at typical primary or secondary distribution voltages. The frequency of 60 Hz is supposed. The standard specifies the following specifications and requirements:

- general requirements, e.g. for voltage regulation and interconnection
- response to abnormal conditions like area electric power system faults
- power quality
- islanding.

The standard provides the requirements for testing the interconnection system (IEEE 1547).

8.1.1 Applicability

These requirements concern electric energy-generating units, which are intended to be connected into the low voltage network by the inverter device. In addition to the previously mentioned international/European standards, there are several national standards in use.

In the standards, the devices are divided into two or more categories depending on the rated current of a system. The requirements in this Chapter are given in such a form and accuracy that identification and control, for example by measuring, is possible.

8.1.2 Earthing

All exposed conductive parts of an electric power system shall be connected to the main earthing terminal or bar. If the neutral conductor exists it shall be connected in the network supply end to the main earthing terminal. The relevant national standards shall be followed. The Finnish National Standard SFS 6000 (SFS Handbook 600 2007) introduces several earthing systems. One of them is the so-called TN-S system, see Figure 10: one point is connected straight to the earth and the exposed conductive parts are connected to an earthed point of a distribution system using protective conductors. Separate neutral and protective conductors are used in the whole system. Earthing the neutral of a generating unit is not always possible. The generator is protected according to the touch voltage terms. The plant earth is connected to the system earth, when the generator operates in parallel with the network. In isolated operation, the functionality of earthing has to be taken care of by, for example, connecting the inverter with a transformer whose secondary can be earthed with a fictive zero.

EN 50438 generally requires for a micro-generator operating in parallel with the distribution network that there shall be no direct connection between the generator winding and the earth terminal of the distribution network operator. The reason for this is to avoid damage to the generator during faults of the distribution network. Anyway, for those micro-generators, e.g. fuel cells which are connected via an inverter, it is permissible to connect one pole of the DC side of the inverter to the distribution network if the insulation between the AC and the DC sides meets the requirements of the standard (EN 50438).

According to IEEE 1547 the grounding scheme shall not cause overvoltages that exceed the rating of the equipment connected to the area electric power system (IEEE 1547 2003).

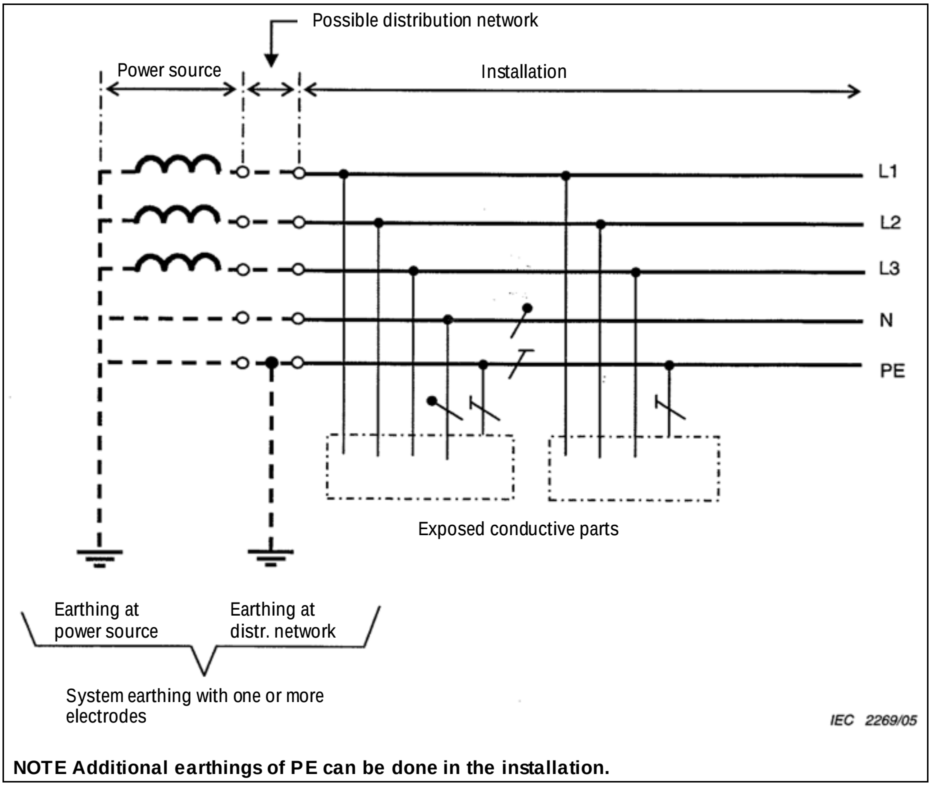

Figure 10. TN-S distribution system, with separate neutral and protective conductors in the whole system (SFS Handbook 600 2007).

8.1.3 Connection and disconnection

The operational connections can be done by the semiconductor switch of the inverter. The inverter may be connected to the network also when the fuel cell is not generating active power. The inverter is in that case used for the reactive power production. The power factor limits given for normal operation are not applied if reactive power is needed.

After an interruption in the supply network has occurred, the fuel cell system shall be disconnected from the network. The connection may be recovered after the voltage and frequency of the utility network has been within the allowed limits for at least 10 min (Helsinki Energy 2009). The circuit breaker has to be placed in a producer's switchgear. The circuit breaker can be replaced by a disconnector having a breaking capacity or a combination of a circuit breaker and a disconnector. Depending on the system size the standards EN 50438 and IEEE 1547 give shorter delays for reconnection than the above mentioned:

- 3 min for mechanical AC generation (EN 50438 2007)
- 20 s for inverter-based systems (EN 50438 2007)
- 5 min for distributed resources up to 10 MW (IEEE 1547 2003).

For safety reasons, the switch has to be lockable into the open position in order to prevent the supply into the utility network, for instance during repair work in the network.

8.2 Interconnection technical terms and power quality

8.2.1 Current harmonics and total harmonic distortion

The requirements for the current and voltage harmonics as well as for the total harmonic distortion (THD) are given in the EN standard (SFS-EN 50160 2000). The THD value may not exceed 10%. For special reasons, different requirements may be stated. The maximum allowed values for individual harmonic current components of a power unit are presented in Table 7. If the product standard exists, it will be followed. The reference current is the rated current of the network connection point i.e. either the rated current of main fuse or the current calculated from the maximum power of the contract. There are no specific limits for interharmonic (including subharmonic) current components. Standard EN 50438 for current values ≤ 16 A refers to IEC publication 61000-3-2, Class A.

Table 7. Maximum acceptable values for different harmonics at the network connection point (SFS-EN 50160 2000).

<table>
<tr><th>Reference current</th><th colspan="2">Recommended limit values</th></tr>
<tr><td>≤ 25 A</td><td colspan="2">Equipment filling relevant standards may be used</td></tr>
<tr><td>25 A … 200 A</td><td colspan="2">Max total current distortion may not exceed 10% of a rated current.</td></tr>
<tr><td rowspan="7">> 200 A</td><td colspan="2">Max total current distortion may not exceed 8% of a rated current. Minimum of 20 A is accepted. Moreover, for individual over-harmonics, the following limits exist:</td></tr>
<tr><td>Order of harmonics, n</td><td>Acceptable value from the reference current</td></tr>
<tr><td>< 11</td><td>7.0%</td></tr>
<tr><td>11–16</td><td>3.5%</td></tr>
<tr><td>17–22</td><td>2.5%</td></tr>
<tr><td>23–34</td><td>1.0%</td></tr>
<tr><td>> 34</td><td>0.5%</td></tr>
</table>

Remark: If the device is used for active shunt, the values may be different from the presented values.

8.2.2 DC current component

For inverter-based systems, only symmetrical control is permitted. Systems which inject DC current by design (e.g. half wave operation) are not permitted. NOTE this requirement prohibits all systems which inject DC into the network by construction and will therefore lead to a minimal impact on the network. This technical requirement can be fulfilled with reasonable effort for a broad range of technologies (EN 50438 2007). The Distributed Resource (DR) and its interconnection system shall not inject DC current greater than 0.5% of the full rated output current at the point of DR connection (IEEE 1547 2003).

8.2.3 Voltage variation and flickering

Voltage variation and flickering must comply with the limits stated in Table 8. The required values slightly differ for the different groups of rated values. The necessary type tests for different equipment are in the relevant standards.

- IEC 61000-3-3 (equipment with $I_n \leq 16$ A), (IEC 61000-3-3 2008)

- IEC/TS 61000-3-5 (equipment with $I_n > 16$ A), (IEC/TS 61000-3-5 1994)
- IEC 61000-3-11 (equipment with 16A < $I_n \leq 75$ A), (IEC 61000-3-11 2000).

The demonstration of flickering and the voltage change shall be considered as a type test.

Table 8. Limits for the voltage variation and flickering for equipment with In ≤ 16 A (IEC 61000-3-3 2008).

Parameters	
P_{st}	≤ 1
P_{lt}	≤ 0.65
d(t) shall not exceed for more than 500 ms	3.3%
d_c	3.3%
d_{max} a) without additional conditions b) manually switched equipment or automatically more than twice per day c) equipment attended whilst in use or switched on automatically	 ≤ 4% ≤ 6% ≤ 7%

Where P_{st} is a short-term irritation index
P_{lt} is a long-term irritation index
d(t): U(t)/Un is a relative voltage change
d_c is a change in stationary voltage (see Figure 11)
d_{cmax} is a maximum allowable temporary voltage change (see Figure 11).

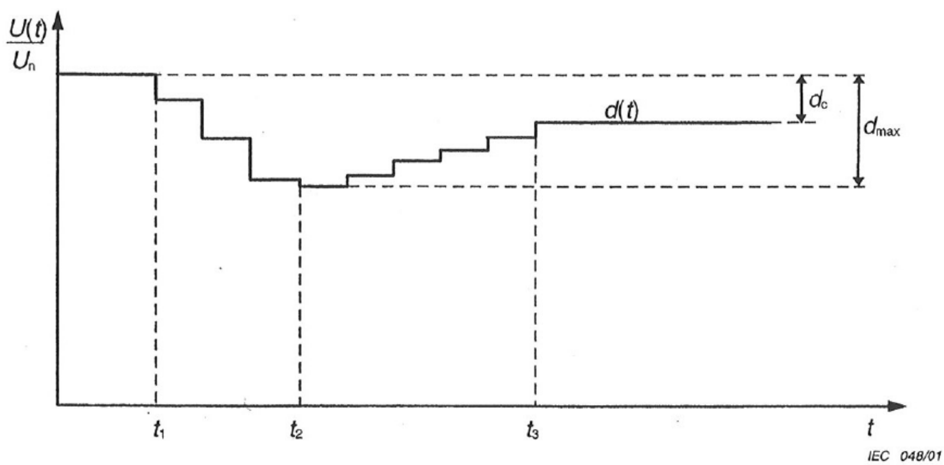

Figure 11. Relative voltage change characteristics (IEC 61000-3-3 2008).

8.2.4 Voltage harmonics and THD

Voltage harmonics of a fuel cell system may not differ noticeably from the case when the generator unit is not in use. Power quality may not change; see EN50160 power quality definitions (SFS-EN 50160 2000).

8.2.5 Power factor

The equipment shall operate so that power factor at the connection point is $\cos(\varphi) = 0.95 \ldots 1$ (inductive or capacitive), but reactive power may not exceed 10% of total power at power factor 1. When specially agreed, the limits may be exceeded. The limits are clarified in Figure 12.

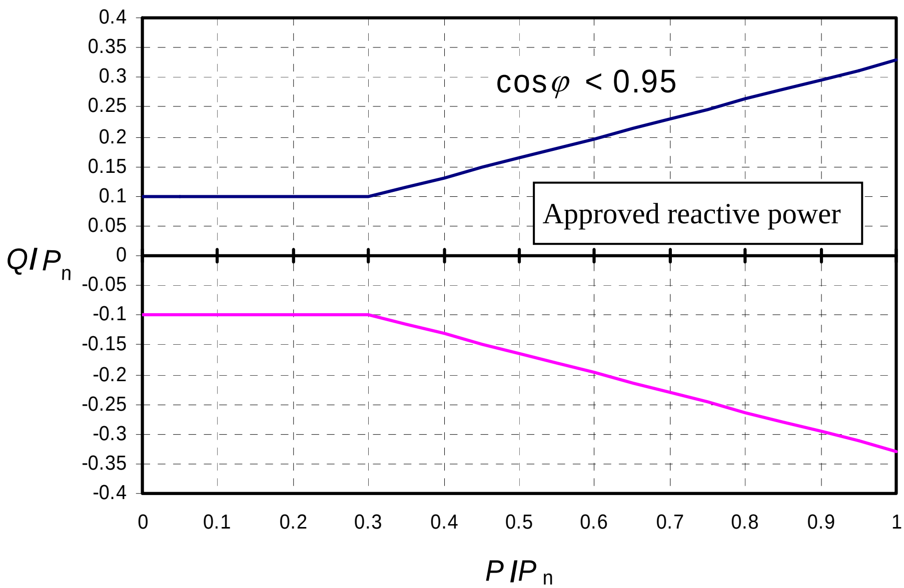

Figure 12. Limits for relative accepted reactive power.

8.2.6 Interconnection device and control signals

Interconnection devices may not block the flow of the used control signals in a network. Moreover, the resonance case must be avoided in all cases with the control signals. Used frequency range for the network control is ~100 Hz…~1350 Hz. The following limits are valid for this range:

- Voltage interference caused by interconnection device may not exceed 0.1% U_n at the signal frequency.
- At the frequencies of ±100 Hz from the signal, the interference must remain lower than 0.3% U_n.

Remark: limits for higher frequencies (distribution line carrier, DLC: ~3 kHz…~5 kHz) are under consideration.

8.2.7 Filters and resonance in output

The output filters of an interconnection device may not cause resonances with the rest of the grid. The interference of the grid operation is not allowed by any other reactive components that may cause changes in the operation parameters of the filters. Requirements in above Chapter 8.2.6 must also be fulfilled.

8.2.8 Asymmetrical connections

Only three-phase connections are allowed for equipment having nominal current above 25 A. When connecting to the grid, the voltage-asymmetrical quality criteria may not be changed at the coupling point.

Interconnection must withstand some asymmetry of a grid. Asymmetric voltage limits for a low voltage network are stated in standard (SFS-EN 50160 2000). 95% of the ten minutes average effective power of a negative sequence voltage component may not exceed 2% of the positive sequence voltage component value.

8.3 Protection and operation in the case of a fault

8.3.1 Relay protection

Table 9 gives the operational parameters for the protection device between the power unit and the common distribution network. Settings are for a low voltage network and representative, case-related decisions have to be made specially for operation times. An inverter can be used for protection purposes (< 25 A) if it is approved for protection purposes complying with DIN VDE0126 (for photo voltaic devices).

In cases where the power system is intended to be used in islanding operation, the settings presented in Tables 9 and 10 for the protection devices in the connection point between island and the supply network, see Figure 13 case A. The protection for the individual power unit has to be separated from this one. The relay settings given in Tables 9 and 10 are equal after the latest update of instructions (Helsinki Energy 2009). Additionally, standard EN 50438 gives the national deviations for 18 other countries, too. Figure 13, case B shows a power unit with no islanding possibility.

In both cases the protection devices have to be approved for their purpose. Moreover, each power unit has to have its own protection systems (case-related LoM, ‘loss of mains’ and frequency protection etc.). If break ride through feature is required, the values in Tables 9 and 10 are not valid in this respect.

Table 9. The required protection relays and settings for a small scale power plant in which In > 25 A (Helsinki Energy 2009).

Relay	Settings	Operation time
Overvoltage	*U* + 10%	1.5 s
	U + 15%	0.15 s
Undervoltage	*U* - 15%	5 s
	U - 50%	0.15 s
Overfrequency	51 Hz	0.2 s
Underfrequency	48 Hz	0.5 s
YSE, LoM	*)	0.15 s
*) tripping limits shall be agreed with the distribution network holder depending on the type of LoM.		

Table 10. Interface protection settings for micro-generation rated ≤ 16 A and 230/400 V or in Finland ≤ 30kVA (EN 50438 2007).

Parameter	Trip setting	Maximum clearance time (s)
Overvoltage (stage 1)	U_n + 10%	1.5
Overvoltage (stage 2)	U_n + 15%	0.15
Undervoltage (stage 1)	U_n – 15%	5
Undervoltage (stage 2)	U_n – 50%	0.15
Overfrequency	51.0 Hz	0.2
Underfrequency	48.0 Hz	0.5
LoM[a)]		0.15

[a] LoM protection shall use recognised techniques suitable for the distribution network protection.

REMARK Isolation of the microgenerator shall be achieved by the separation of mechanical contacts. This mechanical device shall be a lockable isolation switch.

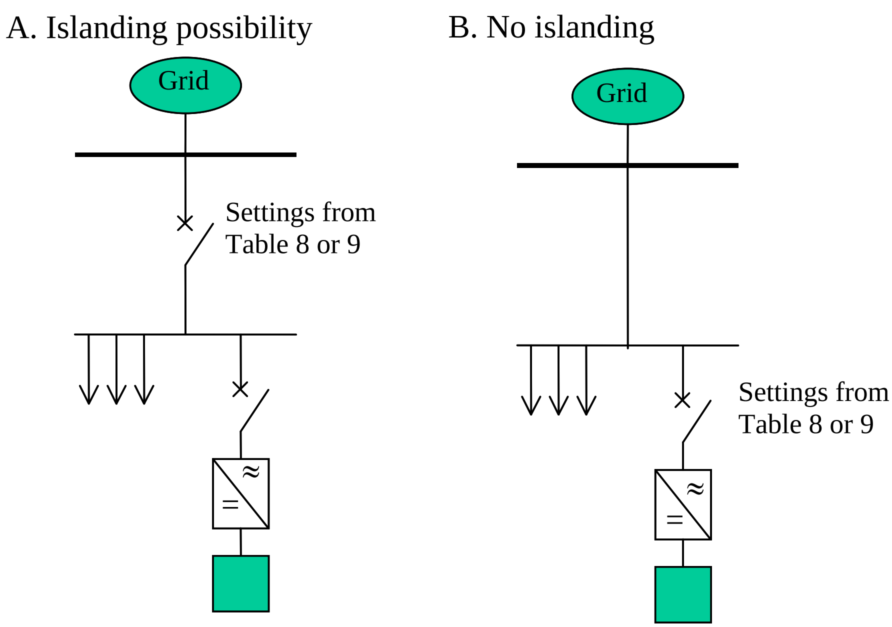

Figure 13. Settings of protection devices (Tables 8 and 9) in different operational cases.

Table 11. Limits given in IEEE 1547 standard for 60 Hz systems.

Parameter	Voltage range (% of rated value)	Clearing time (s)[1)]
Undervoltage	$U_n < 50\%$	0.16
Undervoltage	$50\% \leq U_n < 88\%$	2.00
Overvoltage	$110\% < U_n < 120\%$	1.00
Overvoltage	$U_n \geq 120\%$	0.16
DR size	**Frequency range (Hz)**	**Clearing time (s)[1)]**
≤ 30 kW	60.5 Hz	0.16
	59.3 Hz	0.16
> 30 kW	60.5 Hz	0.16
	< {59.8–57.0} (adjustable set point)	Adjustable 0.16 to 300
	< 57.0	0.,16

[1)] Maximun clearing times for DR ≤ 30 kW and default clearing times for DR > 30 kW.

Table 11 shows the protection limits of IEEE 1547, considering that the generating unit of DR is a 60 Hz source.

The deviation of the limits in Tables 8 to 10 as well as the values valid in 18 European countries (EN 50438) show that each country has to be checked separately.

8.3.2 Synchronisation

The preconditions for synchronisation are the following:

a) The phase order on both sides of the circuit breaker are within allowable limits.
b) The voltage level on both sides of the circuit breaker are within allowable limits.
c) The frequency on both sides of the circuit breaker are within allowable limits.
d) The phase displacement between the grid and the generating unit is close enough.

According to standards the allowable maximum temporary voltage change due to the interconnection of a DG unit is 5%. In Finland the recommended base for design is 4%, and so the synchronisation of connecting device causes maximum

4% oscillation (value d_{cmax} in Chapter 8.2.2). Requirements stated in Chapter 8.2.3 for flickering must also be fulfilled. The automatic synchronising devices must be used.

Terms of synchronisation

1. *Inverter*

   The device equipped with inverter may be connected into the network without a separate synchroniser device, if the power electronic part of a network has automatic synchronising unit and no hazardous transient current occur during the connection operation. In other cases the values defined for synchronous generator are applicable.

2. *Synchronous generator:*
   a. Voltage difference $\Delta U < \pm 10\,\%\,U_n$ (Helsinki Energy $\Delta U < \pm 8\,\%\,U_n$)
   b. Frequency: $\Delta f < \pm 0{,}5\,\mathrm{Hz}$
   c. Phase: $\Delta \varphi < \pm 10\,°$

Remark: Synchronisation terms are partly based on VDEW instructions (VDEW 2001) "Eigenerzeugungsanlagen am Niederspannungsnetz. Richtlinie für Anschluss und Parallelbetrieb von Eigenerzeugungsanlagen am Niederspannungsnetz", Inverter case is not according to VDEW.

8.3.3 Additional issues

A semiconductor device may not be used as a disconnector. Moreover, the disconnector must have a visible or reliably shown and marked open position indicator, see SFS 6000: 537.2.1.2 and 537.2.1.3 (SFS Handbook 600 2007).

Isolation transformer is not necessary between the interconnection device and grid, if the terms stated in Chapter 8.2.2 "DC current component" are fulfilled. The supply of the generator unit has to be terminated if those terms are overrun. For termination, the internal protection functions of the interconnection device may also be used instead of external protection devices.

Ratio of the short circuit power at coupling point to that of the generating unit:

$$S_{\text{grid}} \geq \left(\frac{1}{d_{\text{cmax}}} S_{\text{gen}} \frac{I_{\text{start\_gen}}}{I_{\text{n\_gen}}} \right) 100\%$$

where S_{grid} is a short-circuit power at the coupling point.
S_{gen} is a rated short-circuit power of a generating unit
I_{start_gen} is an inrush current of a generating unit start up
I_{n_gen} is the rated current of a generating unit
d_{cmax} is the maximum allowed voltage change.

If the maximum allowed voltage change is 4% (Chapter 8.3.2) and inrush current is the same as nominal current, the short-circuit power of the coupling point should be

$$S_{\text{grid}} \geq \left(\frac{1}{4\%} S_{\text{gen}} \right) 100\% = 25 \cdot S_{\text{gen}}$$

in other words, 25 times the rated power of a generating unit.

8.4 Test specifications for interface protection and performance

Standard (IEEE 1547) gives the design test specifications for the following:

- Response to abnormal voltage and frequency
- Synchronisation
- Interconnect integrity test
- Unintentional islanding
- Limitation of dc injection
- Harmonics.

The following test requirements for interface protection of devices ≤ 16 A are given in the standard (EN 50438 2007):

- The tests will verify that the operation of the micro-generator interface protection shall result in the cessation of energising the distribution network when the network parameters are exceeded or Loss of Mains (LoM) occurs.

- The manufacturer must declare the ambient operating temperature range of the micro-generator.
- Over/under voltage protection shall occur within the specified clearance time.
- Over/under frequency – operation of the under/over frequency protection will be demonstrated for an increase or decrease of frequency within ± 0.5% of the trip settings.
- Loss of Mains (LoM) protection shall ensure that the micro-generator ceases energize the distribution network until all distribution network operator (DNO) protection operations have cleared and normal network supplies have been restored.
- Examples of micro-generator protection systems suitable for LoM detection and protection include but are not limited to existing accepted techniques such as Rate of Change of Frequency (ROCOF) and Vector Shift.
- LoM test arrangement is shown in Figure 14.
- Re-connection is allowed only after the voltage and frequency at the supply terminals have remained within the permissible tolerances of the nominal voltage and frequency.
- Verification of disconnection in the event of failure of solid-state switching device.
- Verification of leakage current of solid-state switching devices on off state, maximum value is 0.1 mA in the off state.
- The micro-generator power factor (pf) should be in the range 0.95 lagging and 0.95 leading inclusive, for three test voltages 230 V and 230 V ± 8%.
- For electronic inverters manufacturers shall declare the short circuit contribution.
- Manufacturers have to declare their test procedure of the harmonic current emission, limits of class A of EN 61000-3-2.
- Manufacturers have to declare their test procedure of voltage fluctuations and flicker, limits of EN 61000-3-3.

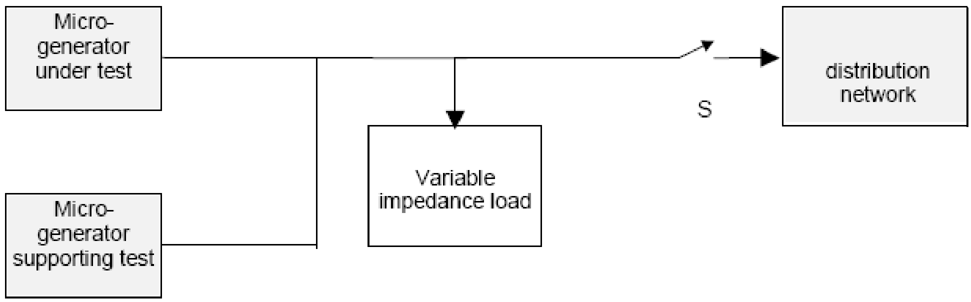

Figure 14. LoM test arrangement (EN 50438), s = switch.

Standard IEC 62282-3-2 specifies the performance test methods for stationary fuel cell power systems. The following electrical tests are included:

- Electrical power output
- Total harmonic distortion
- Electrical efficiency
- Response of power output.

8.5 References

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Appendix 1: (Generaattorilaitteiston aiheuttamat sallitut yliaaltovirrat suhteessa tuottajalle varattuun siirtokapasiteettiin) (harmonics)

Appendix 2: (Tahdistusehdot ja suojareleiden asetteluohje) (relay settings)

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9. Summary

This publication is aimed at supporting the installation and exploitation of 50 kW SOFC, a product of Wärtsilä Ltd, in an office building in southern Finland. Other demonstration cases are also planned. In this context, the standardisation situation has been analysed worldwide. Since local regulations always have priority, all requirements concerning connection of SOFC system to the public networks have been explored and solutions consulted with authorities and the owners of the local natural gas, heating and electricity networks. Experience and compiled documentation are reported here to serve as a guideline for other similar applications.

Installed fuel cell systems must be CE marked and comply with a set of European Union directives, such as:

- Machinery directive (98/37/EC, 2006/423/EC)
- Low voltage directive (LVD) (73/23/EC, 2006/95/EC)
- Electromagnetic compatibility directive (EMC) (2004/108/EC)
- Cogeneration directive (2004/8/EC)
- Pressure Equipment Directive (PED) (97/23/EC)
- Gas appliance directive (GAD) (90/396/EEC, 93/68/EEC).

The draft prEN 50465 European Standard, prepared by the CEN/CENELEC Joint Working Group "Fuel Cell Gas Heating Appliances", is intended to be used as an application standard describing requirements which are specific for the Fuel Cell Gas Heating Appliance. The basic requirements for fuel cells are described in the standards coming out of the IEC TC 105 committee. The group of standards related to stationary systems (IEC 62282-3 parts 1–3) is the most important regulatory base for application preparation and therefore is reported in greater detail in this publication.

The general safety strategy for the installation of the fuel cell systems shall be established according to the following sequence:

- Avoid the possible release of combustible and/or toxic gases and pollutant gases, liquids and solids.
- Eliminate hazards outside the Fuel Cell System and the related installation, when such energy or gases are released nearly instantaneously.
- Provide appropriate safety markings, concerning the remaining risks of hazards.

A fuel cell power system(s) and associated equipment, components, and controls shall be sited and installed in accordance with the manufacturer's instructions. It shall be located so that the power system(s) and components of a fuel cell power system and their respective vent or exhaust terminations are separated from doors, windows, outdoor intakes, and other openings into a building to prevent introduction of exhaust gases into the building. The ventilation systems for indoor installations shall be designed to provide a negative or neutral pressure in the room, with respect to the building where the fuel cell power system is located.

A written fire prevention and emergency plan shall be provided as required by and in accordance with national standards. The room or area where the fuel cell power system is installed shall have a hydrogen detector. The gas detection system shall be arranged to trigger an alarm at 25% LFL and be interlocked to shut down the power system fuel supply at 60% LFL.

An accessible manual fuel shutoff valve shall be located within 1.8 m upstream of the fuel cell power system, unless the power system is enclosed by a fire resistance rated room, in which case the shutoff valve shall be located outside the room. The gas pressure control and fluid measurement devices are placed and installed according to G 5520 (natural gas pressure drop and fluid measurement devices), standards SFS 3179 and SFS 5487 as well as instructions and regulations given by the local distribution company. If the natural gas piping maximum operating pressure is 20 kPa (0.2 bar) and the target gas consumption does not exceed 50 Nm^3/h, which equals an effect of 500 kW, the natural gas piping and connected gear do not require a construction permit. If both limits are exceeded, a construction permit for the piping system must be obtained from TUKES (Turvatekniikan keskus, Safety Technology Authority) according to the natural gas statue 1058/1993.

There are a limited number of various district heating connection schemes in Finland pre-approved for use in certain types of buildings. None of the existing solutions takes readily into account the possibility of heat generation on site. Therefore a new proposal has been developed, which combines a fuel cell system with the otherwise typical connection scheme applicable to an office building in Finland. A number of important precautions must be considered in the connection. Materials must be carefully selected in the primary and secondary side so that they will be qualified for the whole life cycle. Coal steel is forbidden on heat exchange surfaces and in hot tap water heat exchangers in the secondary side. Design pressure is 1.6 MPa in the district heating primary side and 1.0 MPa for the hot tap water pipeline and 0.6 MPa for the heating pipeline in the secondary side. The minimum pressure difference Δp after energy meter is 60 kPa, and at least half of it must be used in control valve. It must be possible to measure energy consumption in both directions (sell/buy mode), otherwise requirements on the metering device are the same as in a regular customer case.

The transient behaviour of the fuel cell stack is highly complex and essential to overall system performance. Methods used to manage this transient behaviour are likely to be considered proprietary by manufacturers. Therefore, controlling fuel cell system efficiently requires high levels information about the device. The instructions for safe and efficient drives should be required from the system supplier or manufacturer.

There are important requirements concerning electric energy-generating units that are going to be connected into the low voltage network by the inverter device. All exposed conductive parts of electric power systems shall be connected to the main earthing terminal or bar. If the neutral conductor exists it shall be connected to the main earthing terminal at the network supply end.

The operational connections can be made by the semiconductor switch of the inverter. The inverter may be connected to the network also when the fuel cell is not generating active power. The inverter is, in that case, used for the reactive power production. The power factor limits given for normal operation are not applied if reactive power is needed. The requirements for the current and voltage harmonics as well as for the total harmonic distortion (THD) are given in the EN standard (SFS-EN 50160). The THD value may not exceed 10%.

For inverter-based systems, only symmetrical control is permitted. Systems which inject DC current by design are not permitted (EN 50438) for maximum 16 A devices. The DR and its interconnection system shall not inject dc current greater than 0.5% of the full rated output current at the point of DR connection (IEEE 1547), which is valid for the aggregate capacity up to 10 MVA. Voltage variation and flickering must comply with the limits stated in the standard (IEC 61000-3-3). The voltage harmonics of a fuel cell system may not differ noticeably from the case when the generator unit is not in use; power quality may not change, see SFS-EN50160.

The output filters of an interconnection device may not cause resonances with the rest of the electric grid. The interference of the grid operation is not allowed by any other reactive components that may cause changes in the operation parameters of the filters. According to standards, the allowable maximum temporary voltage change due to the interconnection is 5%. In Finland the recommended base for design is 4%, and so the synchronisation of connecting device causes maximum 4% oscillation. The automatic synchronising devices must be used.

The limits for interface protection are given for voltage and frequency and in some cases for loss of mains -protection. The limits deviate in different countries. The systems equipped with an inverter may be connected into the network without a separate synchronising device. The terms of synchronisation shall be followed in case of other generating units. The short-circuit power of the coupling point should be 25 times the rated power of a generating unit.

Series title, number and report code of publication

VTT Research Notes
VTT-TIED-2465

Author(s)
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Title

Handbook of SOFC system in buildings
Legislation, standards and requirements

Abstract

This publication is aimed at supporting the installation and exploitation of 50 kW SOFC in an office building. In this context, the standardisation situation has been scanned worldwide. Requirements concerning connection of the SOFC system to the public networks have been explored and solutions consulted with authorities and owners of the local natural gas, heating and electricity networks. Installed fuel cell systems must be CE marked and comply with a set of European Union directives. The group of standards related to stationary systems produced by the IEC TC 105 committee is the most important regulatory base for application preparation.

A fuel cell power system and associated equipment, components, and controls shall be sited and installed in accordance with the manufacturer's instructions. A written fire prevention and emergency plan shall be provided as required by and in accordance with national standards. The room or area where the fuel cell power system is installed shall have a hydrogen detector.

A new proposal has been developed, which combines a fuel cell system with the otherwise typical district heating connection scheme in Finland. Materials in connection with this must be carefully selected in the primary and secondary side to qualify for the whole life cycle. It must be possible to measure energy consumption in both directions (buy/sell mode).

There are important requirements concerning electric energy-generating units. All exposed conductive parts of the electric power system shall be connected to the main earthing terminal or bar. If the neutral conductor exists it shall be connected at the network supply end to the main earthing terminal. The output filters of an interconnection device may not cause resonances with the rest of the electric grid. The interference with the grid operation is not allowed by any other reactive components that may cause changes in the operating parameters of the filters. The systems equipped with an inverter may be connected into the network without a separate synchronising device. The short-circuit power of the coupling point should be 25 times the rated power of a generating unit.

ISBN
978-951-38-7264-9 (soft back ed.)
978-951-38-7265-6 (URL: http://www.vtt.fi/publications/index.jsp)

Series title and ISSN	Project number
VTT Tiedotteita – Research Notes 1235-0605 (soft back ed.) 1455-0865 (URL: http://www.vtt.fi/publications/index.jsp)	26068

Date	Language	Pages
February 2009	English	78 p.

Name of project
SofcPower 2007–2011

Commissioned by
Tekes, VTT, Wärtsilä Finland, Gasum, Fortum Power and Heat, ABB, The Switch, Sandvik Materials Technology, municipality of Joroinen, Innovation Networks, Ecocat, Vaasan Sähkö, FC Energia, Beneq, Millidyne, Raucell

Keywords	Publisher
fuel cell power systems, SOFC-systems, connection, public networks, power distribution networks, legislation, standards, requirements, buildings, micro-CHP (CHP = Combined Heat and Power generation), district heating	VTT Technical Research Centre of Finland P.O. Box 1000, FI-02044 VTT, Finland Phone internat. +358 20 722 4520 Fax +358 20 722 4374

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ISBN 978-951-38-7264-9 (soft back ed.)
ISSN 1235-0605 (soft back ed.)
ISBN 978-951-38-7265-6 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 1455-0865 (URL: http://www.vtt.fi/publications/index.jsp)