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FACULTY OF TECHNOLOGY
LUT ENERGY
ELECTRICAL ENGINEERING

EXECUTIVE SUMMARY OF THE MASTER’S THESIS

CONNECTING POWER GENERATION TO THE LOW-VOLTAGE NETWORK – REGULATIONS AND ELECTRICAL SAFETY

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Abstract of the Master's Thesis

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Connecting power generation to the low-voltage network – regulations and electrical safety

Master's thesis
2012
123 pages, 34 pictures, 9 tables and 7 appendixes

Examiners: Professor Jarmo Partanen and M.Sc. Tero Kaipia

Keywords: small-scale generation, microgeneration, low-voltage network, electrical safety, interconnection, standardization

Smart grids aim at the more efficient use of electricity. Small-scale generation is one of the most important elements of Smart Grids. However, for several reasons, interest in producing electricity has not yet arisen among customers in Finland. Nevertheless, the role of small-scale generation will be significant in the future network. This thesis investigates the requirements for the adoption of small-scale generation and its connection to the low-voltage network. The potential and profitability of different forms of small-scale generation are introduced. The focus of this thesis is on the regulations and electrical safety of the interconnection. At the low-voltage distribution level, generation shows as a new feeding point and causes for instance challenges in the network protection. Furthermore, the subject is still new and the procedures are incomplete in Finland. In this study, the most significant challenges related to small-scale generation, their importance and possible solutions are discussed. There are no obvious technical obstacles for small-scale generation to become more common also in Finland.

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Abbreviations and symbols

AMR	Automatic Meter Reading
CHP	Combined Heat And Power
DG	Distributed Generation
DIN	Deutsches Institut für Normung
DSO	Distribution System Operator
ENTSO-E	European Network of Transmission System Operators for Electricity
LV	Low-Voltage
LoM	Loss-of-Mains
MV	Medium-Voltage
PV	Photovoltaic
SFS	Finnish Standards Association SFS ry
SG	Smart Grids
SSDG	Small-Scale Distributed Generation
VDE	Verband der Elektrotechnik, Elektronik und Informationstechnik

1 Introduction

The direction of the electricity transmission has traditionally been from large generating plants towards customers. Because of the environmental aspects, objectives and agreements also the distribution business has to reply to the changing needs. Smart Grids (SG) aim for the more efficient use of electricity and they are also an enabler for the new services. Small-scale distributed generation (SSDG) is an essential element of the SG. Also the society is more electricity dependent and networks, built in the 60's and 70's, need to be rebuilt, which means massive investments to the network in the near future.

SSDG cannot necessarily satisfy the need of electricity entirely and all the time. Thus, the connection to the public low-voltage (LV) network has to remain. The current act of electricity markets does not directly support SSDG (Electricity market act 1995). According to the law generating unit has to be connected but there must be a buyer for the produced electricity, if it is fed to the network (Electricity market act 1995). Also the planning of the network protection is based on the principle of fault currents coming from the network towards customers. Thus, the production connected to the customer site means a great change both technically and also from the market point of view.

If the number of SSDG is supposed to become more common the incentives and the process of interconnection has to be more clear. The price and payback time of the investment, political signals and legislation have a great impact on the attractivity of the SSDG. The topic includes yet uncertainty from many point of view.

1.1 Objectives

The purpose of the thesis was to research the requirements for the generating unit to be connected to the network, especially in terms of protection and electrical safety. In the thesis, a simulation model was created for analysis of the phenomena. Also analysis of profitability of different form of generation was done.

Comparison between Finland and European countries, especially with Germany was made. The most remarkable challenges of interconnection were pointed out. The structure of the thesis is described in Fig. 1.1.

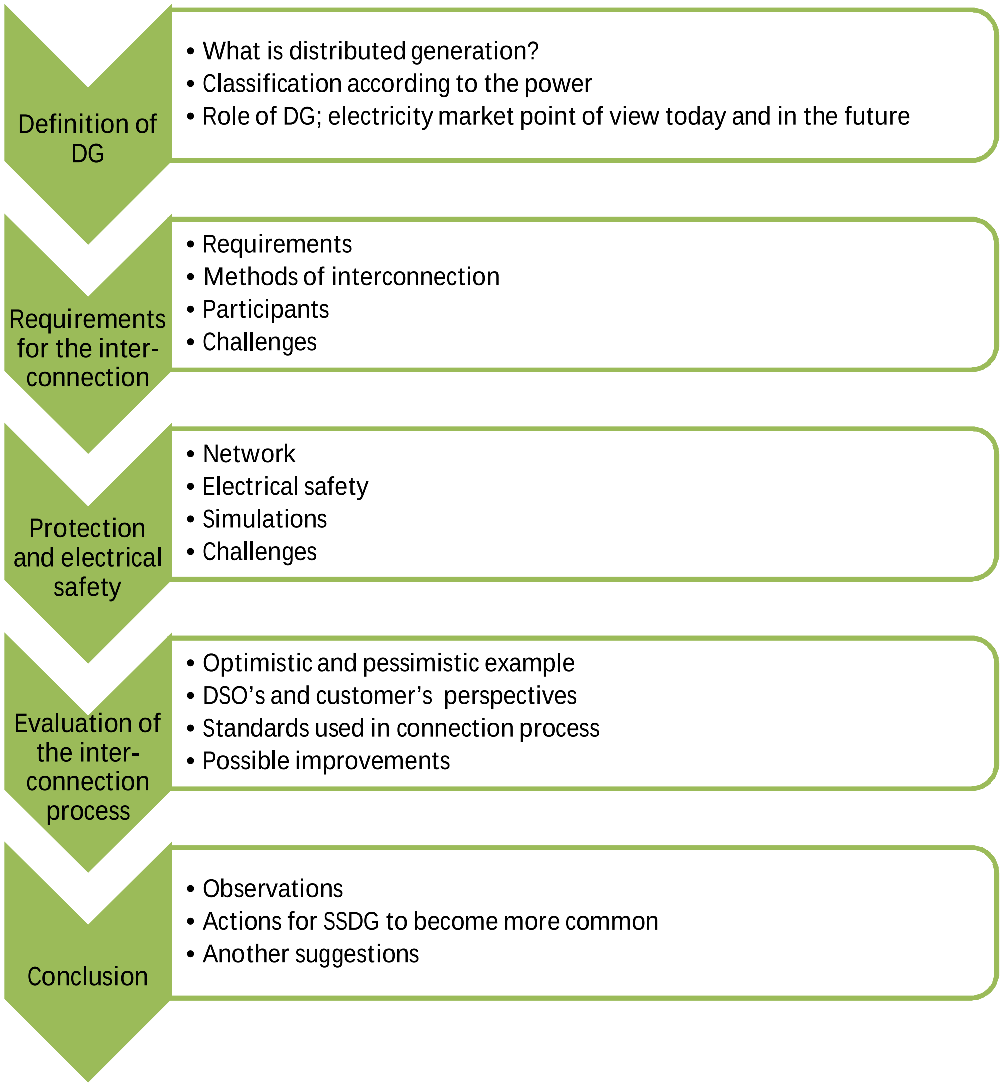

Fig. 1.1. Structure of the thesis.

The first and the second paragraph of the thesis introduce the subject, especially the background and different forms of generation. The third chapter describes the exploitability and future views of the SSDG. The fourth chapter discusses the requirements for the interconnection. Fifth paragraph deals with issues concerning protection and electrical safety. Sixth chapter is evaluation of the connection process nowadays. Conclusion is the seventh and summary the eight paragraph.

2 Small scale distributed generation

The concept *distributed generation* is wide and it can be interpret many ways. It was necessary to define how SSDG is related to DG in general. Also the role of SSDG nowadays and in future was discussed.

2.1 Classification of generating units

The concept of DG is not clear because it does not define the power and connection point clearly. The interest of the thesis was in generation which is connected to the low-voltage network. Based on the existing limits and definitions, the following classification was made in the thesis (Electricity market act 1995; SFS-EN 50438; Lehto 2009).

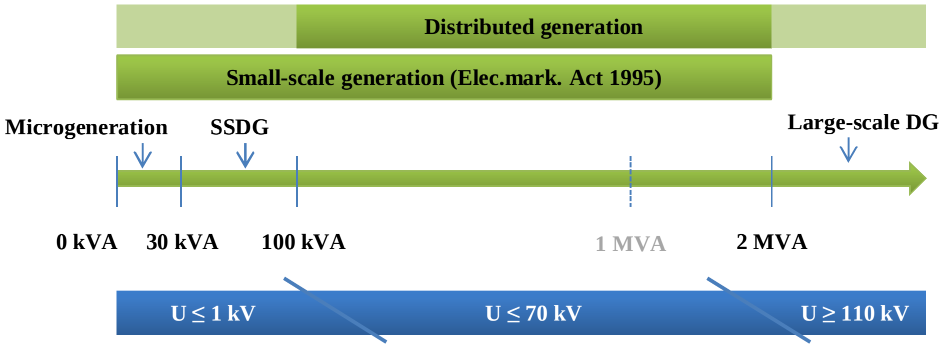

Fig. 2.1. The definition of DG and SSDG according to nominal power and voltage of the connection point

The most important class is SSDG which in the thesis means production below 100 kVA, connected to LV-network. SSDG includes also microgeneration (<30 kVA). Both are also distributed generation and below 2 MVA “small-scale generation” defined by Electricity Market Act (Electricity Market Act 1995).

2.2 Current potential and future view of SSDG

There are several methods of producing electricity in small-scale. Solar power is least dependent on the site and thus the easiest form of production for everyone. Very few have a possibility for producing hydropower. Bio- and small-scale-CHP are most suitable for farms and such environment. Wind power also is most suitable for sites, in which it does not disturb visually other people and environment. Intermittent power sources such as diesel generators are rather reserve power for blackouts than way of producing electricity. Current volume of SSDG in Finland is small and economic incentives are poor (Finlex 2010). Also the lack of the supportive market model exists. Current solution in which the DSO allows feeding the excess power to grid the has to be seen as a temporary solution. However, the role of the DG is remarkable in SG future visions and the situation has to change. The change appears to be inevitable and requires time because of many other subjects related. It has to be seen as a process towards the targets rather than change from point to another. AMRs appear as a gateway for further objectives.

3 Connecting small-scale generation to low-voltage network

DG can cause both positive and negative influences on the network. Therefore there are regulations concerning the generating unit itself and also the connection process. SSDG can be connected to the network directly or via power electronics. SSDG also affects the protection of the network. Some of the common cases were simulated and analysed.

3.1 Regulations

In general it can be said that the generating unit should not weaken the quality of electricity in its connection point (Energiateollisuus 2011). Negative influences can be either disturbances or safety hazards. Important documents defining the regulations for the connection are for example SFS-EN 50438, SFS-EN 50160, SFS-6000, SFS-6002 and guides written by Finnish Energy Industries (Energiateollisuus in Finnish). Also the European Network of Transmission System Operators for Electricity (ENTSO-E) has a grid code draft, which was examined only for the category A devices, which means ”*A Synchronous Generating Unit or Power Park Module is of Type A if its Connection Point is below 110 kV and its Maximum Capacity is 400 W or more.*” (ENTSO-E 2012). The units have to be capable of reducing active power in overfrequency situations (ENTSO-E

2012). The text of the draft may change but for now, there were not any other remarkable requirements.

The generating unit must have accessible disconnector which have visible and lockable open contacts. If there is a possibility of islanding, a switch is needed to disconnect the customer from the network. In Loss-of-Mains (LoM) situations the disconnection must be done within 5 seconds (SFS-EN 50438). (Energiateollisuus 2011)

3.2 Connection methods

SSDGs can be connected to network either directly (synchronous- , asynchronous generators) or via power electronics. Synchronous generators can both produce and consume reactive power and thus affect the voltage of the network. They can also run without existing voltage in the network. Asynchronous generators need reactive power and they have problematic behaviour in fault situations from the network point of view. However, inverters are the most common connection method for small-scale DG. They usually feed fault current only a little more than nominal current. Inverters also have many protective features which can be used instead of separate devices. Typically, inverters used in connecting DG are so called grid-tie inverters. Grid-tie inverter is practically incapable of feeding islands. In theory it is though possible but very unlikely. This is because production and consumption should match almost perfectly and there should not be any variations neither in consumption nor in production and none of the protective functions should work. Inverters can also have a positive impact on the voltage quality, for instance, because they can be used as compensators.

3.3 DG effects on protection and working safety

DG sets challenges for the network protection. Traditionally the fault currents have been flowing “downwards” from the feeding network towards the customers. Because LV-network protection is based on fuses and sufficient earthings there is no case-dependent decision-making. Only sufficient fault current will burn the fuse. SSDG can reduce the fault current seen by the fuse in the beginning of the LV-line, but the actual fault current can be greater than without the generator. Also the direction of the fault current can change. Simulation model was created to model some of the common examples of problems.

Microgeneration which connects via power electronics can be usually connected without blinding problems. Faults which occur on adjacent line and to which generator participates feeding fault current, are unlike to cause burning of the generator line fuse. Asynchronous generators are more probable to cause problems but universal answer cannot be given. The situation is always case dependent but at least in case of power electronics coupled production which usually is microgeneration will not cause problems. There are certainly some feeders which are problematic and the analysis has to be done by DSO in every case.

The electrical risk due to failure of the LoM-protection is very unlike to happen because the load and consumption should match, fault should occur and also none of the protective functions should work. In theory it is possible but according to the literature the probability is $< 1 \cdot 10^{-6}$ (Verhoeven 2002; Ranade et al. 2007, Adrianti et al. 2011). Instead, for example, the illegal installations form a hazard already now. According to SFS-6002 standard earthings for work are not necessarily required in LV-networks (SFS-6002). The use of earthings also in LV-network and even both sides of the working site might however nowadays be wise. The opening of the customer generator disconnectors should instead be done via AMRs, if possible, to reduce excess labour and to guarantee that also the generators not known by the DSO are disconnected from the network before starting the work.

4 Evaluation of current connection process

The purpose of this paragraph is to analyse which are the most remarkable challenges in the connection process nowadays in Finland.

4.1 Challenges for the customers and DSOs

From the customer point of view the challenges are in the very beginning of the process. The information about possible economic incentives may be difficult to figure out. Also the permission of construction varies, depending on the form of generation and local municipality. Selling the excess electricity is usually not profitable. Therefore, the production should be less than consumption. The contract with the DSO of feeding excess electricity into the network is possible without compensation. DSO may also buy small amounts of excess electricity (Lehto 2009). From the technical perspective, the standard SFS-EN 50438 defines the operational requirements (SFS-EN 50438) for the protection system of the SSDG-units. Furthermore, the SFS 6000 standard series give guidelines for the electrical installations of SSDG-units. However, SSDG manufacturers do not provide equipment that is tested and certified according to the national requirements. Finland is too small market for the manufacturers to start such certification, and moreover, there is no suitable standards defining the test procedures to demonstrate the compliance with the national requirements. Lack of certification increases the fear of investing into improper generating unit and at least does not encourage purchasing one.

From the DSO perspective, the process of interconnection can be done without any problems or it can cause major problems. Connecting a single generating unit of few kilovolt amperes to the LV-network does not affect usually at all. On the other hand, it may be very problematic for the DSO to connect a larger power generating unit or several small units, even though the standard requirements would be fulfilled. The following have essential role in connecting capability:

- Nominal power of distribution transformer
- Power rating and connection method of generating unit
  - directly / power electronics-coupled
- Structure of LV-network and number of customers
  - short circuit currents / voltage quality (voltage flexibility)
  - possible locations for generators

    - customer types / probable generator sizes
    - earthing conditions, touch voltages
- Age of the network
    - need of reinforcements, costs and current replacement costs
    - durability of the components

From the DSO's point of view, connecting SSDG may end up to be costly or technically problematic. First, customers acquire and install SSDG to reduce their electricity bill reducing the income of the DSO. Second, connecting SSDG may require reinforcements to the network to guarantee the correct operation of the protection (electric safety reasons) or to guarantee sufficient voltage quality. Third, the SSDG cannot be considered to lower the (dimensioning) peak power of the low voltage network, so no benefits are probably found during the renovation either (at least as long as any benefits can not be found through intended islanding, that is not considered in this thesis).

To make the situation easier for the DSOs, one essential thing is to make sure that the SSDGs are not able to feed large short circuit currents at least for long periods so that the fuse-based protection remains functional. This is ensured quite well by the in force standardisation and national guidelines, especially when the SSDGs are dominantly connected through converters. However, we lack the standards for compliance testing and corresponding certification. Proper certification would help DSOs during the technical evaluation of a SSDG-unit. Proper certification would thus help both the DSO and the end-customer. The other issues, like DSO's loss of income, are more difficult to affect without causing market-blocks and are not considered further in this thesis. However, possibility of creating unnecessary market-blocks should also be acknowledged when considering possible certification or test standardisation.

4.2 Comparsion of the Finnish and German standards

In Finland, the standard SFS-EN 50438 gives the technical specification and setting values of the protection functions (SFS-EN 50438). Standards of SFS-6000 series are for *Low-Voltage Electrical Installations* (SFS-6000). For example, the solar systems are discussed in SFS-6000-7-715 (SFS-6000). The documentation and testing of solar systems are discussed in standard SFS-EN 62446, *Grid connected photovoltaic systems. Minimum requirements for system documentation, commissioning tests and inspections.* Testing of the LoM-protection is discussed in SFS-EN 62116 *Test procedure of islanding prevention measures for utility-interconnected photovoltaic inverters.* However, there is not clear description of the whole testing process of the protective functions. Figure 4.1. depicts the situation.

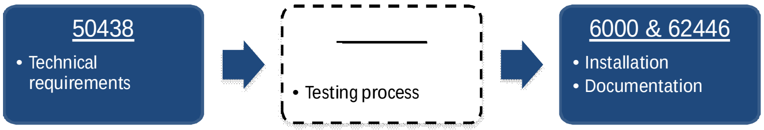

Fig. 4.1. Standards which are applied in the connecting process. The need of testing standard is obvious.

The Low-Voltage Directive says that if there are not existing national standards, IEC or another applicable national standards should be applied (Tukes 2012). The "path" of applying standards is thus as follows in Figure 4.2.

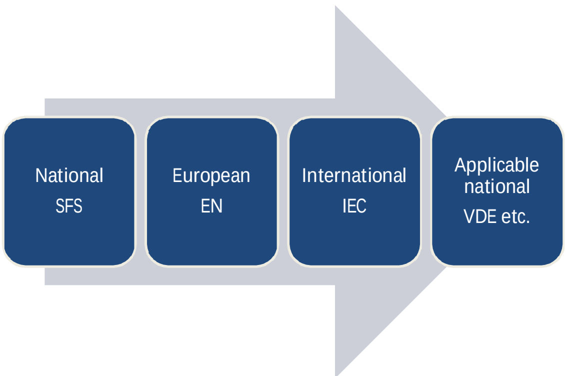

Fig. 4.2. The "path" of applying standards.

In this case, the German standards cannot be bypassed. In Germany the standard VDE-1-1-0126 *Automatic disconnection device between a generator and the public low-voltage grid* has been widely used. The new German low-voltage grid code VDE AR-N-4105 has been valid since beginning of year 2012 for PVapplications and for all other generators it is binding 1.7.2012 onwards (VDE 2012). Manufacturers have tested their appliances according to the German standards and will adopt the new requirements as Germany is very important market especially for solar systems. The setting values according to SFS-EN 50438, VDE-1-1-0126 and VDE AR-N-4105 are depicted in Table 4.1.

Table 4.1. The requirements for the protection according to the standards SFS-EN 50438, VDE-1-1-0126:n and VDE-AR-N 4105:n (SFS-EN 50438; VDE-1-1-0126; VDE-AR-N 4105)

Parameter	**Operating time**	**Finland** SFS-EN 50438	**Germany**	
			VDE-1-1-0126	VDE-AR-N 4105
Overvoltage	≤ 0.2 s	U_N + 10%	U_N + 15%	U_N + 10%*
Undervoltage	≤ 0.2 s	U_N - 15%	U_N - 20%	U_N - 20%
Overfrequency	≤ 0.2 s	51 Hz	50.2 Hz	51.5 Hz**
Underfrequency	≤ 0.2 s	48 Hz	47.5 Hz	47.5 Hz
LoM		≤ 5 s	≤ 0.5 s	≤ 5 s

* Integrated protection, ≤ 30 kVA;
** Beginning at 50.2 Hz reduction of power 40%/Hz

By applying the German standard the certification would remain. It would help both the customer and the DSO. The German standard also matches the frequency reduction set by ENTSO-E draft (ENTSO-E 2012; VDE-AR-N-4105).

5 Conclusion

DG is in remarkable role in answering to the energy efficiency objectives. Nevertheless, there are not clear signals in Finland to increase the amount of SSDG. Also the regulations concerning the construction of power generating plant depends on the local municipality. The Electricity Market Act guarantees the connection of generating unit if it fulfils the technical requirements (Electricity Market Act 1995). However, the act does not guarantee that there will be a buyer for the excess production. A market model is needed instead of the temporary solution.

The lack of testing standard hampers both DSO and the customer. Manufacturer usually has a certificate of compliancy for certain grid requirements. Finland has own requirements, for instance, according to the standard SFS-EN 50438. However, the standard does not define the testing process for compliancy testing needed for certification. We need, for example, decision and permission for allowing the connection of generating units which are tested according German standards. Another possibility would be creation of common European testing procedures demonstrating fulfilment of the requirements on functional level rather than fulfilment of specific values. Due to the small size of the Finnish markets, requiring national certification could be harmful for the markets.

From distribution network perspective, the possible consequences of generating unit are dependent on the generator itself together with the network. Most of the generating units are probably microgenerators and well below the 30 kVA limit. Inverter is the most important method of connecting such units to the network. The protection features of the inverters should be exploited as far as possible, for instance, together with the functionalities of the AMR-meters, to avoid using separate protection devices having overlapping features. Connecting single micro-scale units here and there hardly causes technical problems in the Finnish low voltage networks. However, further studies are still needed regarding the operation of grid-tie inverter protection features by varying number, power and location of generating units in certain LV-network. In practice, it is a DSO’s task to examine the situation during the process of interconnection.

The electrical safety of workers has to be re-evaluated. The decision of not earthing the working site includes risk of electrical hazard due to the generators in the customer site. Also the illegal installations of power generation can cause safety hazards already now. The use of AMR-meters in disconnecting the customers from the network is worth considering. If there were more generating units in the LV-network it would cause lot of extra work to physically visit the customer site and open the disconnectors.

Technically the most important conclusions are: 1) the protection of the network has to be evaluated by DSO when connecting production. Problems are unlikely in connection of microgenerators. 2) the probability of islanding is small 3) earthing for work on the LV-network has to be re-evaluated and if needed, the standard has to be changed 4) AMRs should be utilized in disconnecting customers during the electrical work 5) Problem related to testing has to be solved for example by allowing the connection of generating units tested according the German standard. Also national procedures (guidelines, recommendations) have to be developed to ease the connecting process.

References

Adrianti, -, Dysko, A., Burt, G., 2011, Probability Estimation of the Occurrence of Protection System Failures in Highly Distributed Generation Systems. Universities' Power Engineering Conference (UPEC), Proceedings of 2011 46th International , vol., no., pp.1-6, 5-8 Sept. 2011. [Available at: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6125581&isnumber=6125473, referred 2.5.2012]

Electricity market act, 386/1995. Unofficial translation. Available at: http://www.finlex.fi/en/laki/kaannokset/1995/en19950386.pdf

Energiateollisuus, 2011, Technical appendix 1 to the guidelines ‘connecting an electricity generation installation to the distribution network’ – connecting an installation with a nominal rated capacity of up to 50 kVA [Available at: http://www.energia.fi/sites/default/files/technical_appendix_1_-_up_to_50_kva.pdf, referred: 3.5.2012]

ENTSO-E, 2012, ENTSO-E Draft Network Code for Requirements for Grid Connection applicable to all Generators. Draft. [Available at: https://www.entsoe.eu/fileadmin/user_upload/_library/consultations/Network_Code_RfG/120124_Network_Code_for_Requirements_forGrid_Connection_applicable_to_all_Generators.pdf, referred 2.5.2012]

Finlex, 1397/2010, Valtioneuvoston asetus uusiutuvilla energialähteillä tuotetun sähkön tuotantotuesta. Finnish Decree. [Available at: http://www.finlex.fi/fi/laki/alkup/2010/20101397, referred 3.5.2012]

Lehto, I., 2009, Connecting very small scale electricity production to the public distribution network in Finland. Master’s Thesis (in Finnish). TKK. [Available at: http://lib.tkk.fi/Dipl/2009/urn100081.pdf, referred: 2.5.2011]

Ranade, S.J., Sagi, D.R., Mulpuri, R., Surabhi, R., Mitra, J., 2007, Likelihood of Islanding in Distribution Feeders with Photovoltaic Generation. Power Engineering Society General Meeting, 2007. IEEE , vol., no., pp.1-6, 24-28 June 2007. [Available at: http://ieeexplore.ieee.org/stamp/stamp. jsp?tp=&arnumber=4276004&isnumber=4275199, referred 2.5.2012]

SFS-EN 50438, 2008, Requirements for the connection of micro-generators in parallel with public low-voltage distribution networks. SFS ry. Sesko ry. Finnish standard SFS-EN 50438.

SFS-EN 50160, 2010, Voltage characteristics of electricity supplied by public electricity networks. SFS ry. Sesko ry. Finnish standard SFS-EN 50160.

SFS-EN 62116, 2011, Test procedure of islanding prevention measures for utility-interconnected photovoltaic inverters. SFS ry. Sesko ry. Finnish standard SFS-EN 62116.

SFS-EN 62446, 2010, Grid connected photovoltaic systems. Minimum requirements for system documentation, commissioning tests and inspections. SFS ry. Sesko ry. Finnish standard SFS-EN 62446.

SFS-6000, 2007, Low-voltage electrical installations. SFS ry. Sesko ry. Finnish standard series SFS-6000.

SFS-6002, 2005, Safety at electrical work. SFS ry. Sesko ry. Finnish standard SFS 6002.

TUKES, 2012, Low-voltage directive. Web-page (In Finnish). [Available at: http://www.tukes.fi/fi/Toimialat/Sahko-ja-hissit/Pienjannitedirektiivi--/, referred: 2.5.2012]

VDE-1-1-0126, 2006, Automatic disconnection device between a generator and the public low-voltage grid. VDE. German standard DIN VDE-1-1-0126.

VDE-AR-N 4105, 2011, Power generation systems connected to the low-voltage distribution network. Technical minimum requirements for the connection to and parallel operation with low-voltage distribution networks. FNN. German Application Guide.

VDE, 2012, VDE regulation points the way ahead for the improved network integration of decentralized power generation. Web-page. [Available at: http://www.vde.com/en/fnn/pages/n4105.aspx, referred: 2.5.2012]

Verhoeven, B., 2002, Probability of islanding in utility networks due to grid connected photovoltaic power systems. Report. International Energy Agency.[Available at: http://www.hme.ca/gridconnect/IEA_PVPS_Task_5-07_Probability_of_Islanding_due_to_PVPS.pdf, referred 2.5.2012]