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Activities on solar photovoltaics and real time simulation in the smart grid and interoperability laboratory of the Joint Research Centre of the European Commission

"Smart Grid Simulation" traineeship report

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Contents

Foreword

This report summarises my activities in the Smart Grid and Interoperability Lab of the JRC for the needs of my traineeship entitled *"Smart Grid Simulation"* that took place in the C.3 Energy Security, Distribution and Markets Unit of the C. Directorate of Energy, Transport and Climate of the Joint Research Centre of the European Commission during the period between 01.12.2016 and 30.04.2017.

The importance of this work lies on the fact that it summarises the prevailing situation for the technical infrastructure serving the electricity distribution sector in the member states of the European Union.

Relevant stakeholders of the electricity distribution sector and policy makers in the European Union are now equipped with a report that clarifies the big picture for PV power penetration and contracted power levels for the residential sector in the European Union.

Proposals for restructuring the electricity distribution sector in a number of countries aiming the increase of efficiency of the design process for the electricity distribution systems in the European Union are also provided.

Additionally, my involvement in laboratory activities including the installation and configuration of the Elgar TerraSAS ETS 1000 PV Simulator that is available in the laboratory and my familiarization with the Real Time Digital Simulator (RTDS Technologies), i.e. development of simple power system circuits and simulation in the hardware platform of RTDS, are presented in a comprehensive way too.

Acknowledgements

I would like to thank Dr. Alexandre Lucas for the guidance that he offered and for the conversations that we have had for the needs of my traineeship entitled "Smart Grid Simulation" at the C.3 Energy Security, Distribution and Markets Unit of the C. Directorate of Energy, Transport and Climate of the Joint Research Centre of the European Commission. I am grateful for the time that Dr. Lucas devoted during the process of evaluation of the references that are used in this report in order to support its credibility. Scientific integrity and professionalism are two words that are synonyms with his approach on how the work towards the completion of projects should flow.

I am grateful to Dr. Evangelos Kotsakis, my supervisor during my stay in Ispra, for accepting my application for this traineeship and for the help that he has offered for the needs of it. It was a great opportunity for me to get involved with state of the art hardware and software tools and witness their significant importance towards the deployment of the resilient and robust electricity infrastructure systems of the future, in the EU.

Last but not least, I would like to thank all the staff of the C.3 Energy Security, Distribution and Markets Unit of the C. Directorate of Energy, Transport and Climate of the Joint Research Centre of the European Commission for the meaningful conversations and constructive time that we have had during my stay in Ispra (VA), Italy.

Abstract

This technical report aims to investigate the upper limit of single phase (1Φ) PV power connection (kWp) the low voltage (LV) electricity distribution system and the single phase (1Φ) contracted power (kVA) levels in member states of the EU.

One of the key goals during the process of writing this report was to minimise the extent of the provided information with a simultaneous maximization of its efficacy for the end user.

The sources used for the creation of this report are all properly referenced in the respective section of this work. Tables summarizing the current state for the upper limit of PV power connection (kWp) to the low voltage (LV) electricity distribution system in the EU are provided. Bar charts visualizing the single phase (1Φ) contracted power (kVA) levels in the EU member states are also provided.

Additionally, in order to create a macroscopic view of the situation regarding the upper limits of the single phase (1Φ) PV power (kWp) connection to the low voltage (LV) electricity distribution system and the single phase (1Φ) contracted power (kVA) levels for the EU Member States, a bar chart and a coloured map, summarizing and visualizing the findings of the research that took place for the needs of this traineeship, are provided too.

The significant importance of the website RES LEGAL [1] (Legal sources on Renewable Energy), an initiative of the European Commission, has to be acknowledged. The information provided in the website of RES LEGAL acted as an important starting point during the process of searching the relevant legislative documents of DSOs regarding the situation for single phase (1Φ) RES penetration (kWp) and single phase (1Φ) contracted power (kVA) levels in the EU member states.

The ratio of installed single phase (1Φ) PV capacity (kWp) over the single phase (1Φ) contracted power (kVA) of a consumer is of importance when planning the penetration of RES to the electricity distribution system in the member states of the EU. For the majority of the member states this ratio is explicitly stated in relevant legislative documents. In case of lack of explicit definition of a coefficient that relates maximum allowable RES power injection (kWp) with contracted power (kVA) levels at the consumption side, this ratio can be calculated.

In the following pages the reader will find relevant information, with respect to the goals of this literature review, for the member states of the EU.

Additionally, work conducted in the laboratory including my involvement with the Elgar TerraSAS ETS 1000 PV Simulator hardware and software tools as well as the simulation of simple power system circuits in the Real Time Digital Simulator (RTDS Technologies) are also presented in respective chapters of this report.

The tools that have been used for the realization of this report were Microsoft Word, Microsoft Excel, Google Search, Google Translate, Map Chart, Elgar TerraSAS PV Simulator Software, RSCAD (software environment for creating power system models to be simulated in the RTDS hardware environment).

1 Introduction

This work is an outcome of the traineeship entitled “Smart System Simulation” that took place in the C.3 Energy Security, Distribution and Markets Unit of the C. Directorate of Energy, Transport and Climate of the Joint Research Centre of the European Commission between 01.12.2016 and 30.04.2017.

The findings of this work can be used as a benchmark in order to evaluate the relation of various electricity distribution systems modelling efforts (urban, semi-urban and/or rural areas etc.) with real world electricity distribution systems.

The EU has set goals for decarbonizing its economy and in order to do so, low carbon power generating technologies should be deployed in large scale. The deployment of these power generating technologies is realised on the distribution level of power systems, leading to a need for assessing the impact of this deployment on the existing electricity distribution systems.

For the needs of this report the Power Factor (PF) of both PV power connection (kWp) to the low voltage (LV) electricity distribution system and the contracted power (kVA) at the consumption side are considered to be equal to 1. The notations kWp and kVA refer to the same quantity, i.e. power, in terms of physical meaning, but in a differentiated way in order to avoid misunderstandings regarding the meaning of each quantity. Special attention should be given to the fact that the notation of kWp refers to power injection from RES at the buses of a studied power network while the notation of kVA refers to power consumption at the buses of the same power network.

The significance of this work lies on the fact that it aggregates, summarises and visualises information that DSOs, acting in the member states of the EU, provide to their customers.

In the following pages, a summary of the prevailing situation regarding the RES penetration (kWp) to the low voltage (LV) electricity distribution system as well as the single phase (1Φ) contracted power (kVA) levels on the consumption side, for the residential sector, in the member states of the EU are presented.

The importance of the ratio of the installed single phase (1Φ) PV power capacity (kWp) over the single phase (1Φ) contracted power (kVA) is underlined and the key findings are summarised coherently in order to effectively assist stakeholders and policy makers of the electricity sector in the EU.

In the Conclusion section of this work, suggestions are given regarding actions that, if taken, can make the design of electricity distribution systems more efficient. These suggestions need to be taken into account when relevant policy making bodies create the legislative framework that brings together contemporary developments in power production technologies, i.e. distributed RES, and DSOs maintaining electricity distribution systems in the EU.

2 EU Member States

This chapter is dedicated to the presentation of the outcomes of the main findings of the literature review done for the member states of the EU with respect to the goals of this report, i.e.

a. investigation of the upper limit of the single phase (1Φ) PV power connection (kWp) to the low voltage (LV) electricity distribution systems in the EU and

b. investigation of the single phase (1Φ) contracted power (kVA) levels in the EU

2.1 Austria

In Austria, electricity production from RES is supported through the following schemes [2]:

- FIT
- Subsidies

Table 1 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Austria.

Table 1. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Austria

Installed capacity	Power connection
≤ 3.68 kWp	Single phase - 1Φ
$\succ 3.68$ kWp and up to ≤ 11.04 kWp	Three phase - 3Φ

Source: [3]

In Austria, the contracted power (kVA) levels for single phase (1Φ) consumers are 2.3kVA, 3.68kVA, 4.83kVA, 5.75kVA, 7.36kVA, 9.2kVA, 11.5kVA. Source: [4] [5] [6]

2.2 Belgium

In Belgium, electricity production from RES is supported through the following schemes [7]:

- Quota system
- Net metering
- Subsidy scheme

Table 2 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Belgium.

Table 2. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Belgium

Installed capacity	Power connection
≤ 5 kWp	Single phase - 1Φ
$\succ 5$ kWp and up to ≤ 10 kWp	Three phase - 3Φ

Source: [8]

In Belgium, the contracted power (kVA) levels for single phase (1Φ) consumers are 3.68kVA, 4.6kVA, 5.75kVA, 7.36kVA, 9.2kVA, 11.5kVA, 14.49kVA [9].

2.3 Bulgaria

In Bulgaria, electricity production from RES is supported through the following schemes [10]:

- FIT

Table 3 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Bulgaria.

Table 3. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Bulgaria

Installed capacity	Power connection
≤ 5 kWp	Single phase - 1Φ
$\succ 5$ kWp and up to ≤ 30 kWp	Three phase - 3Φ

Source: [11]

In Bulgaria, the contracted power (kVA) levels for single phase (1Φ) consumers are 6kVA, 7-15kVA [12] [13].

2.4 Croatia

In Croatia, electricity production from RES is supported through the following schemes [14]:

- FIT
- Loans
- Premium Tariff

Table 4 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Croatia.

Table 4. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Croatia

Installed capacity	Power connection
≤ 5 kWp	Single phase - 1Φ
$\succ 5$ kWp and up to ≤ 30 kWp	Three phase - 3Φ

Source: [15]

In Croatia, the contracted power (kVA) levels for single phase (1Φ) consumers are 4.6kVA, 5,75kVA, 7.36kVA, 9.2kVA, 11.5kVA [16].

2.5 Cyprus (Republic of)

In Cyprus, electricity production from RES is supported through the following schemes [17]:

- Net Metering
- Subsidies

Table 5 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Cyprus.

Table 5. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Cyprus

Installed capacity	Power connection
≤ 4 kWp	Single phase - 1Φ
$\succ 4$ kWp and up to ≤ 5kWp	Three phase - 3Φ

Source: [18]

In Cyprus, the contracted power (kVA) level for single phase (1Φ) consumers is 9.2kVA [19].

2.6 Czech Republic

In Czech Republic, electricity production from RES is supported through the following schemes [20]:

- FIT
- Premium Tariff
- Subsidy Scheme

Micro-power scheme

Table 6 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Czech Republic.

Table 6. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Czech Republic

Installed capacity	Power connection
≤ 3.68 kWp	Single phase - 1Φ
$\succ 3.68$ kWp and up to ≤ 10 kWp	Three phase - 3Φ

Source: [21]

In Czech Republic, the contracted power (kVA) level for single phase (1Φ) consumers is 5.75kVA [22].

2.7 Denmark

In Denmark, electricity production from RES is supported through the following schemes [23]:

- Loan scheme
- Net Metering
- Premium Tariff
- Tenders

Table 7 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Denmark.

Table 7. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Denmark

Installed capacity	Power connection
≤ 3.68 kWp	Single phase - 1Φ
$\succ 3.68$ kWp and up to ≤ 11 kWp	Three phase - 3Φ

Source: [24]

In Denmark, the contracted power (kVA) level for single phase (1Φ) consumers is 5.75kVA [25].

2.8 Estonia

In Estonia, electricity production from RES is supported through the following schemes [26]:

- Premium tariff
- Subsidies
- Micro-production scheme

Table 8 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Estonia.

Table 8. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Estonia

Installed capacity	Power connection
≤ 3.68 kWp	Single phase - 1Φ
$\succ 3.68$ kWp and up to ≤ 11 kWp	Three phase - 3Φ

Source: [27]

In Estonia, the contracted power (kVA) levels for single phase (1Φ) consumers are 1.38kVA, 2.3kVA, 3.68kVA, 4.6kVA, 5.75kVA [28].

2.9 Finland

In Finland, electricity production from RES is supported through the following schemes [29]:

- Premium tariff
- Subsidies
- Micro-generation scheme

Table 9 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Finland.

Table 9. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Finland

Installed capacity	Power connection
≤ 3.68 kWp	Single phase - 1Φ
$\succ 3.68$ kWp and up to ≤ 11 kWp	Three phase - 3Φ

Source: [30]

In Finland, the contracted power (kVA) level for single phase (1Φ) consumers is 5.75kVA [31].

2.10 France

In France, electricity production from RES is supported through the following schemes [32]:

- FIT
- Premium tariff
- Tax regulation mechanisms
- Tenders

Table 10 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in France.

Table 10. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in France

Installed capacity	Power connection
≤ 6 kWp	Single phase - 1Φ
$\succ 6$ kWp and up to ≤ 36 kWp	Three phase - 3Φ

Source: [33]

In France, the contracted power (kVA) levels for single phase (1Φ) consumers are 3kVA, 6kVA, 9kVA, 12kVA, 15kVA, 18kVA [34].

2.11 Germany

In Germany, electricity production from RES is supported through the following schemes [35]:

- FIT
- Loans
- Subsidies
- Tenders

Table 11 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Germany.

Table 11. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Germany

Installed capacity	Power connection
≤ 4.6 kWp	Single phase - 1Φ
$\succ 4.6$ kWp and up to ≤ 13.8 kWp	Three phase - 3Φ

Source: [36]

In Germany, the contracted power (kVA) level for single phase (1Φ) consumers is 4.6kVA [37].

2.12 Greece

In Greece, electricity production from RES is supported through the following schemes [38]:

- FIT & Premium tariff
- Net Metering
- Subsidies
- Tax regulation mechanism & Tenders

Table 12 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Greece.

Table 12. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Greece

Installed capacity	Power connection
≤ 5 kWp	Single phase - 1Φ
$\succ 5$ kWp and up to ≤ 10 kWp	Three phase - 3Φ

Source: [39]

In Greece, the contracted power (kVA) levels for single phase (1Φ) consumers are 8kVA and 12kVA [40].

2.13 Hungary

In Hungary, electricity production from RES is supported through the following schemes [41]:

- FIT
- Green Premium
- Loans
- Net Metering
- Subsidies

Table 13 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Hungary.

Table 13. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Hungary

Installed capacity	Power connection
≤ 5 kWp	Single phase - 1Φ
$\succ 5$ kWp and up to ≤ 50 kWp	Three phase - 3Φ

Source: [42]

In Hungary, the contracted power (kVA) levels for single phase (1Φ) consumers are 1.38kVA, 2.3kVA, 3.68kVA, 4.6kVA, 5.75kVA, 7.36kVA, 9.2kVA, 11.5kVA, 14.49kVA, 18.4kVA [43].

2.14 Ireland

In Ireland, electricity production from RES is supported through the following schemes [44]:

- FIT

Table 14 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Ireland.

Table 14. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Ireland

Installed capacity	Power connection
≤ 5.75 kWp	Single phase - 1Φ
$\succ 5.75$ kWp and up to ≤ 11kWp	Three phase - 3Φ

Source: [45]

In Ireland, the contracted power (kVA) levels for single phase (1Φ) consumers are 12kVA and 16kVA [46].

2.15 Italy

In Italy, electricity production from RES is supported through the following schemes [47]:

- FIT
- Net Metering
- Premium tariff
- Tax regulation mechanisms
- Tenders

Table 15 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Italy.

Table 15. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Italy

Installed capacity	Power connection
≤ 6 kWp	Single phase - 1Φ
$\succ 6$ kWp and up to ≤ 20kWp	Three phase - 3Φ

Source: [48]

In Italy, the contracted power (kVA) levels for single phase (1Φ) consumers are 1.5kVA, 3kVA, 4.5kVA, 6kVA [49].

2.16 Latvia

In Latvia, electricity production from RES is supported through the following schemes [50]:

- FIT
- Net Metering

Micro-generation scheme

Table 16 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Latvia.

Table 16. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Latvia

Installed capacity	Power connection
≤ 3.68kWp	Single phase - 1Φ
$\succ 3.68$ kWp and up to ≤ 11kWp	Three phase - 3Φ

Source: [51]

In Latvia, the contracted power (kVA) levels for single phase (1Φ) consumers are 3.68kVA, 4.6kVA, 5.75kVA [52].

2.17 Lithuania

In Lithuania, electricity production from RES is supported through the following schemes [53]:

- Loans & Tenders
- Net Metering
- Feed in premium
- Subsidies & Tax regulation mechanisms

Table 17 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Lithuania.

Table 17. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Lithuania

Installed capacity	Power connection
$\leq X$ kWp(*)	Single phase - 1Φ
$\succ X$ kWp(*) and up to ≤ 10 kWp	Three phase - 3Φ

Source: [54] *(*) No credible data for single phase (1Φ) PV power installations*

In Lithuania, the contracted power (kVA) levels for single phase (1Φ) consumers are 3kVA, 4kVA, 5kVA, 6kVA, 7kVA, 8kVA, 9kVA, 10kVA [55].

2.18 Luxembourg

In Luxembourg, electricity production from RES is supported through the following schemes [56]:

- FIT
- Premium tariff
- Subsidies & Tax regulation mechanisms

Table 18 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Luxembourg.

Table 18. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Luxemburg

Installed capacity	Power connection
$\leq X$ kWp (*)	Single phase - 1Φ
$\succ X$ kWp (*) and up to ≤ 30 kWp	Three phase - 3Φ

Source: [57] *(*) No credible data for single phase (1Φ) PV power installations*

In Luxembourg, the contracted power (kVA) levels for three phase (3Φ) consumers are 9.2kVA, 11.5kVA, 14.49kVA, 18.4kVA, 23kVA [58].

2.19 Malta

In Malta, electricity production from RES is supported through the following schemes [59]:

- FIT
- Investment grant

Table 19 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Malta.

Table 19. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Malta

Installed capacity	Power connection
≤ 3.68 kWp	Single phase - 1Φ
$\succ 3.68$ kWp and up to ≤ 11.04 kWp	Three phase - 3Φ

Source: [60]

Installations larger than 3.68kWp per phase need to be authorised by the Regulator of Energy and Water Services of Malta. In Malta, the contracted power (kVA) level for single phase (1Φ) consumers is 9.2kVA [61].

2.20 Netherlands

In the Netherlands, electricity production from RES is supported through the following schemes [62]:

- Loan scheme
- Net Metering
- Premium tariff
- Tax regulation mechanisms
- Tenders

Table 20 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in the Netherlands.

Table 20. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in the Netherlands

Installed capacity	Power connection
≤ 5kWp	Single phase - 1Φ
$\succ 5$ kWp and up to ≤ 55kWp	Three phase - 3Φ

Source: [63]

In the Netherlands, the contracted power (kVA) levels for single phase (1Φ) consumers are 1.38kVA, 2.3kVA, 3.68kVA, 5.75kVA, 8.05kVA, 9.2kVA [64].

2.21 Poland

In Poland, electricity production from RES is supported through the following schemes [65]:

- Loan & Quota system
- Subsidy & Support scheme
- Tax regulation mechanism
- Tenders

Micro-installation scheme

Table 21 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Poland.

Table 21. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Poland

Installed capacity	Power connection
≤ 4.6 kWp	Single phase - 1Φ
$\succ 4.6$ kWp and up to ≤ 10 kWp	Three phase - 3Φ

Source: [66]

In Poland, the contracted power (kVA) levels for single phase (1Φ) consumers are 1.38kVA, 2.3kVA, 3.68kVA, 4.6kVA, 5.75kVA, 7.36kVA, 9.2kVA, 11.5kVA [67].

2.22 Portugal

In Portugal, electricity production from RES is supported through the following schemes [68]:

- FIT

Micro-generation scheme

Table 22 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Portugal.

Table 22. Upper limits, of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Portugal

Installed capacity	Power connection
≤ 5.75 kWp	Single phase - 1Φ
$\succ 5.75$ kWp and up to ≤ 11.04 kWp	Three phase - 3Φ

Source: [69]

In Portugal, the contracted power (kVA) levels for single phase (1Φ) consumers are 1.15kVA, 2.3kVA, 3.45kVA, 4.6kVA, 5.75kVA, 6.9kVA, 10.35kVA, 13.8kVA [70].

2.23 Romania

In Romania, electricity production from RES is supported through the following schemes [71]:

- Quota system
- Subsidies

Table 23 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Romania.

Table 23. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Romania

Installed capacity	Power connection
$\leq X$ kWp (*)	Single phase - 1Φ
$\succ X$ kWp (*) and up to 10 kWp	Three phase - 3Φ

Source: [72] *(*) No credible data for single phase (1Φ) PV power installations*

In Romania, the contracted power (kVA) levels for single phase (1Φ) consumers are <3kVA, 3-6kVA, >6kVA [73].

2.24 Slovakia

In Slovakia, electricity production from RES is supported through the following schemes [74]:

- Feed in Tariff
- Subsidy scheme
- Tax regulation mechanisms

Table 24 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Slovakia.

Table 24. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Slovakia

Installed capacity	Power connection
≤ 4.6 kWp	Single phase - 1Φ
$\succ 4.6$ kWp and up to ≤ 10 kWp	Three phase - 3Φ

Source: [75]

In Slovakia, the contracted power (kVA) level for single phase (1Φ) consumers is 5.75kVA [76].

2.25 Slovenia

In Slovenia, electricity production from RES is supported through the following schemes [77]:

- FIT
- Premium tariff
- Loan scheme
- Subsidy scheme

Micro-production scheme

Table 25 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Slovenia.

Table 25. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Slovenia

Installed capacity	Power connection
≤ 4.6 kWp	Single phase - 1Φ
$\succ 4.6$ kWp and up to ≤ 10 kWp	Three phase - 3Φ

Source: [78]

In Slovenia, the contracted power (kVA) levels for single phase (1Φ) consumers are 3kVA, 6kVA, 8kVA [79].

2.26 Spain

In Spain, electricity production from RES is supported through the following schemes [80]:

- Tenders

Table 26 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Spain.

Table 26. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Spain

Installed capacity	Power connection
≤ 5 kWp	Single phase - 1Φ
$\succ 5$ kWp and up to ≤ 10 kWp	Three phase - 3Φ

Source: [81]

In Spain, the contracted power (kVA) levels for single phase (1Φ) consumers are 0.35kVA, 0.69kVA, 0.81kVA, 1.15kVA, 1.73kVA, 2.3kVA, 3.45kVA, 4.6kVA, 5.75kVA, 6.9kVA, 8.05kVA, 9.2kVA, 10.35kVA, 11.5kVA, 14.49kVA [82].

2.27 Sweden

In Sweden, electricity production from RES is supported through the following schemes [83]:

- Quota system
- Subsidy scheme
- Tax regulation mechanisms

Micro-production scheme

Table 27 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, in Sweden.

Table 27. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Sweden

Installed capacity	Power connection
≤ 2 kWp (*)	Single phase - 1Φ
$\succ 2$ kWp (*) and up to ≤ 10 kWp	Three phase - 3Φ

Source: [84] (*) May be extended to 4kWp depending on the contracted power (kVA) of the consumer

In Sweden, the contracted power (kVA) levels for single phase (1Φ) consumers are 3.68kVA, 4.6kVA, 5.75kVA, 8.05kVA, 11.5kVA, 14.49kVA [85].

2.28 Great Britain

In Great Britain, electricity production from RES is supported through the following schemes [86]:

- Contracts for Difference (CfD) scheme
- FIT
- Quota system
- Tax regulation mechanism & Tenders
- Small Scale Embedded Generation (SSEG) scheme

Table 28 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, under the Small Scale Embedded Generation (SSEG) scheme, in Great Britain.

Table 28. Upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Great Britain

Installed capacity	Power connection
≤ 3.68 kWp	Single phase - 1Φ
$\succ 3.68$ kWp and up to ≤ 11.04 kWp	Three phase - 3Φ

Source: [87]

Micro-generation scheme

Table 29 summarises the information that was gathered regarding the upper limits of PV power connection (kWp) to the low voltage (LV) electricity distribution system for residential installations, under the Micro-generation scheme, in Great Britain.

Table 29. Upper limits of PV power connection (kWp) to low the voltage (LV) electricity distribution system for residential single phase (1Φ) and three phase (3Φ) installations in Great Britain

Installed capacity	Power connection
≤ 17 kWp	Single phase - 1Φ
$\succ 17$ kWp and up to ≤ 50 kWp	Three phase - 3Φ

Source: [88]

In Great Britain, the contracted power (kVA) levels for single phase (1Φ) consumers are 5.75kVA, 13.8kVA, 15kVA, 18.4kVA, 23kVA [89] [90].

3 Ratio of kWp over kVA

Traditionally, electricity distribution systems were developed in order to meet the various types of electricity demand needs of final consumers i.e. the sizing of the equipment (MV/LV transformers, cabling infrastructure, etc.) serving these needs was performed based on standards [91] [92] for maximum allowable voltage drops across the cabling infrastructure serving consumption needs etc.

The large scale integration of RES in the low voltage (LV) electricity distribution system has as an externality the need for investigating the performance of cabling infrastructure which, while originally developed to withstand the consumption needs of consumers, nowadays has also to deal with the power injection (kWp) taking place at the premises of "prosumers". EU goals for increased share of renewable energies in the energy mix of the union [93] and the anticipated growth of small scale installations justify the needs for performing research in the field of low voltage electricity distribution systems with increasing RES penetration.

Because of the fact that the performance of cabling infrastructure is different when considering on the one hand the power demand/consumption and on the other hand the power production/injection, DSOs have realised that there is a need to impose either explicitly or implicitly a coefficient that determines the relation of the maximum allowable installed PV capacity (kWp), i.e. the maximum allowable instantaneous power injection, with the contracted power (kVA) at the premises of consumers.

In a number of countries there is an explicit definition of the relation between kWp and kVA. For a small number of countries the explicit determination of this coefficient does not exist. In this case, the ratio of kWp over kVA can be calculated by the division of relevant quantities for the power injection (kWp) and the contracted power (kVA).

In Ireland, the maximum allowable installed PV capacity (kWp) is determined at the level of MV/LV transformer serving the needs of the respective area. The maximum value of the ratio of aggregated PV capacity (kWp) installed in an area over the nominal kVA of the transformer serving that area is 40% [94].

In Greece, the explicit definition of this coefficient (50%) is applicable for PV power installations higher than 20kWp [95]. These installations, typically, are three phase (3Φ) installations and thus out of scope of this report. For single phase (1Φ) installations the calculation of this coefficient gives as output the value of 62.5% relation between maximum installed kWp and contracted kVA at the premises of consumers.

In Portugal, the installed PV capacity of single phase (1Φ) micro-generation units cannot be higher than 50% of the contracted power (kVA) at the premises of consumers and in any case higher than 5.75kWp [96].

In the Netherlands, for single phase (1Φ) installations the ratio of installed PV capacity (kWp) over the contracted power (kVA) of the consumer can be either 100%, 87%, 62.5% or 50% based on the value of single phase (1Φ) contracted power (kVA) of the consumer [97].

The range of installed single phase (1Φ) PV power capacity (kWp) over the single phase (1Φ) contracted (kVA) of a consumer in the member states of the EU varies between 40% and 100%.

4 Summary of findings

Table 30 summarises the findings for the upper limit of the single phase (1Φ) PV Power connection (kWp) to the low voltage (LV) electricity distribution system, the single phase (1Φ) contracted power (kVA) levels and the RES penetration schemes that are available in the EU Member States.

Table 30. Summary of the upper limit of single phase (1Φ) PV Power connection (kWp) to the low voltage (LV) electricity distribution system, the single phase (1Φ) contracted power (kVA) levels and the RES penetration schemes in the EU Member States

EU Member State	Upper Limit of Single Phase (1Φ) PV Power connection to LV network (kWp)	Single Phase (1Φ) Contracted Power (kVA) Levels	Renewable penetration schemes
Austria	3.68	2.3, 3.68, 4.83, 5.75, 7.36, 9.2, 11.5	FIT, Subsidies
Belgium	5	3.68, 4.6, 5.75, 7.36, 9.2, 11.5, 14.49	Quota system, Net Metering, Subsidy scheme
Bulgaria	5	6, 7-15	FIT
Croatia	5	4.6, 5.75, 7.36, 9.2, 11.5	FIT, Premium Tariff, Loans
Cyprus	4	9.2	Net Metering, Subsidies
Czech Republic	3.68	5.75	FIT, Premium Tariff, Subsidy scheme
Denmark	3.68	5.75	Loan scheme, Net Metering, Premium Tariff, Tenders
Estonia	3.68	1.38, 2.3, 3.68, 4.6, 5.75	Premium Tariff, Subsidies
Finland	3.68	5.75	Premium Tariff, Subsidies
France	6	3, 6, 9, 12, 15, 18	FIT, Tenders, Tax regulation mechanisms, Tenders
Germany	4.6	4.6	FIT, Loans, Subsidies, Tenders
Greece	5	8, 12	FIT, Net Metering, Premium tariff, Subsidies, Tax regulation mechanisms, Tenders

EU Member State	Upper Limit of Single Phase (1Φ) PV Power connection to LV network (kWp)	Single Phase (1Φ) Contracted Power (kVA) Levels	Renewable penetration schemes
Hungary	5	1.38, 2.3, 3.68, 4.6, 5.75, 7,36, 9.2, 11.5, 14.49, 18.4	FIT, Green Premium, Loans, Net Metering, Subsidies
Ireland	5.75	12, 16	FIT
Italy	6	1.5, 3, 4.5, 6	FIT, Net Metering, Premium Tariff, Tenders, Tax regulation mechanisms
Latvia	3.68	3.68, 4.6, 5.75	FIT, Net Metering
Lithuania	<10 (3Φ)	3, 4, 5, 6, 7, 8, 9, 10	Loans, Net Metering, Feed in Premium, Subsidies, Tax regulation mechanisms, Tenders
Luxembourg	<30 (3Φ)	9.2, 11.5, 14.49, 18.4, 23 (3Φ)	FIT, Premium tariff, Subsidies, Tax regulation mechanisms
Malta	3.68	9.2	FIT, Investment grant
Netherlands	5	1.38, 2.3, 3.68, 5.75, 8.05, 9.2	Loan scheme, Net Metering, Premium Tariff, Tax regulation mechanisms, Tenders
Poland	4.6	1.38, 2.3, 3.68, 4.6, 5.75, 7.36, 9.2, 11.5	Loan scheme, Quota system, Subsidy scheme, Support scheme, Tax regulation mechanism, Tenders
Portugal	5.75	1.15, 2.3, 3.45, 4.6, 5.75, 6.9, 10.35, 13.8	FIT
Romania	10 (3Φ)	<3, 3-6, >6	Quota system, Subsidies
Slovakia	4.6	5.75	FIT, Subsidy scheme, Tax regulation mechanisms
Slovenia	4.6	3, 6, 8	FIT, Premium tariff, Loan scheme Subsidy scheme

EU Member State	Upper Limit of Single Phase (1Φ) PV Power connection to LV network (kWp)	Single Phase (1Φ) Contracted Power (kVA) Levels	Renewable penetration schemes
Spain	5	0.35, 0.69, 0.81, 1.15, 1.73, 2.3, 3.45, 4.6, 5.75, 6.9, 8.05, 9.2, 10.35, 11.5, 14.49	Tenders
Sweden	2 and 4	3.68, 4.6, 5.75, 8.05, 11.5, 14.49	Quota System, Subsidy scheme, Tax regulation mechanisms
Great Britain	3.68 and 17	5.75, 13.8, 15, 18.4, 23	Contracts for Difference (CfD) scheme, FIT, Quota system, Tax regulation mechanism, Tenders

Source: Summary of the outcomes of this report

A careful review of Table 30 is helpful for determining the efficiency of the design process of electricity distribution systems. The availability, or not, of multiple contracted power (kVA) levels for single phase installations (1Φ) has a significant impact in the overall electricity systems' design process.

For the needs of this work an adequate number of multiple single phase (1Φ) contracted power (kVA) levels is considered to be four (4 levels).

Table 31 presents the number of countries having more than four (≥ 4) levels of single phase (1Φ) contracted power (kVA) and the number of countries having less than $(\prec 4)$ levels.

Table 31. Number of EU countries having more (or less) than 4 single phase (1Φ) contracted power (kVA) levels.

Number of countries having ≥ 4 levels	Number of countries having $\prec 4$ levels
16	12

Source: Outcome of this report

Regulatory authorities acting in countries that have less than 4 contracted power (kVA) levels need to restructure the design process for electricity distribution systems. Categorization of the, to be electrified, spaces (e.g. garages, single room flat, multiple room flats etc.) in different categories in terms of the contracted power (kVA) that can possibly be assigned to them is "sine qua non" for a transition towards efficient design process of electricity distribution systems.

If such a shift takes place, it will lead to economies of scale in terms of primary materials (copper, plastics etc.) used in order to create and maintain electricity distribution systems offering high quality services to consumers.

As an example, the reader should consider a situation where a consumer wants to electrify a garage, where a typical value of single phase (1Φ) contracted power of 1.5kVA would be enough, but the available options of contracted power (kVA) offered from DSOs are much higher (e.g. 5.75kVA or 8kVA or 12kVA). This is a perfect demonstration of a loose way for designing technical systems because it will lead to unnecessarily oversized equipment (MV/LV transformer, cabling infrastructure, etc.) used in order to provide electricity to consumers. This situation has to be reformed by proper policy making actions.

Additionally, a comparatively low upper limit of contracted power (kVA) can potentially increase the affordability of electricity services for consumers due to the fact that a low upper limit of contracted power (kVA) can increase energy awareness and thus have as a positive externality, the decreased annual energy consumption (kWh).

5 Big Picture of the Upper Limit

of PV power connection (kWp) to the low voltage (LV) electricity distribution system for single phase (1Φ) installations in the member states of the EU

Table 32 presents the upper limit for single phase (1Φ) PV power connection (kWp) to the low voltage (LV) electricity distribution system in the EU member states and Table 33 summarises the number of countries per kWp level for single phase (1Φ) PV power installations in the EU member states.

Table 32. Upper limit of the single phase (1Φ) PV power connection (kWp) to the low voltage (LV) electricity distribution system in the EU

AT	BE	BG	HR	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PL	PT	RO	SK	SI	ES	SE-1	SE-2	GB-1	GB-2
3.68	5	5	5	4	3.68	3.68	3.68	3.68	6	4.6	5	5	5.75	6	3.68	(*)	(*)	3.68	5	4.6	5.75	(*)	4.6	4.6	5	2	4	3.68	17

Source: Outcome of this report (*) No credible data for single phase (1Φ) PV power (kWp) installations

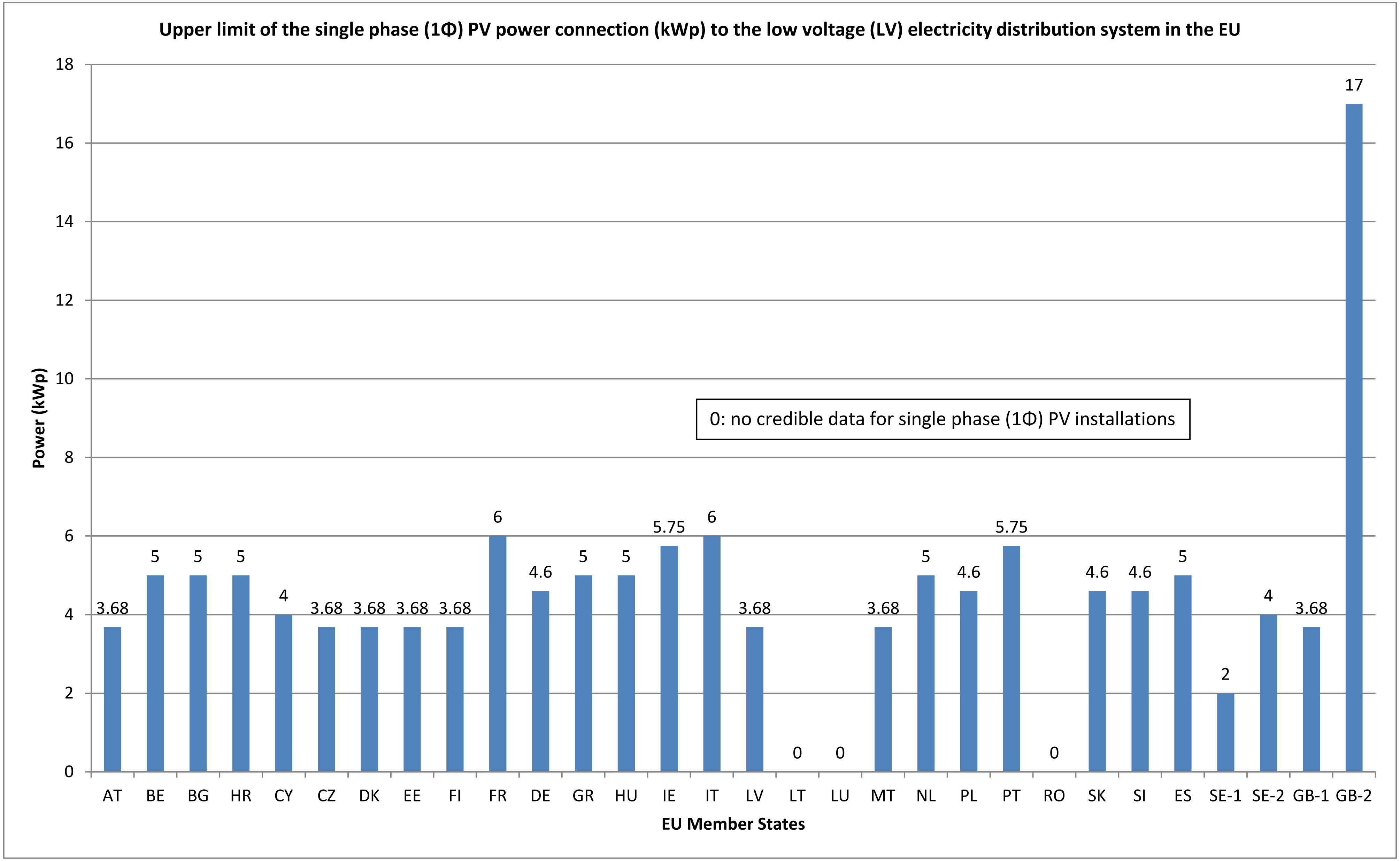
Table 33. Statistics of the upper limit of PV power connection (kWp) to the low voltage (LV) electricity distribution system in the EU

Single phase (1Φ) PV power connection (kWp) level	Number of countries
3.68 (**)	8
4 (***)	2
4.6	4
5	7
5.75	2
6	2
10 (3Φ)	2
30 (3Φ)	1

Source: Outcome of this report. (**) For Great Britain the value of 3.68kWp was taken into account (***) For Sweden the value of 4kWp was taken into account

Figure 1 presents the Bar Chart of the information provided in the Table 32 in order to visualise the situation for the single phase (1Φ) PV power connection (kWp) to the low voltage (LV) electricity distribution system in the EU. The Big Picture of the variation of the key variable under investigation, i.e. PV power connection (kWp) to the low voltage (LV) electricity distribution system in the EU, has been clarified.

Figure 1. Big picture of the upper limit of single phase (1Φ) PV power connection (kWp) to the low voltage (LV) electricity distribution system in the EU



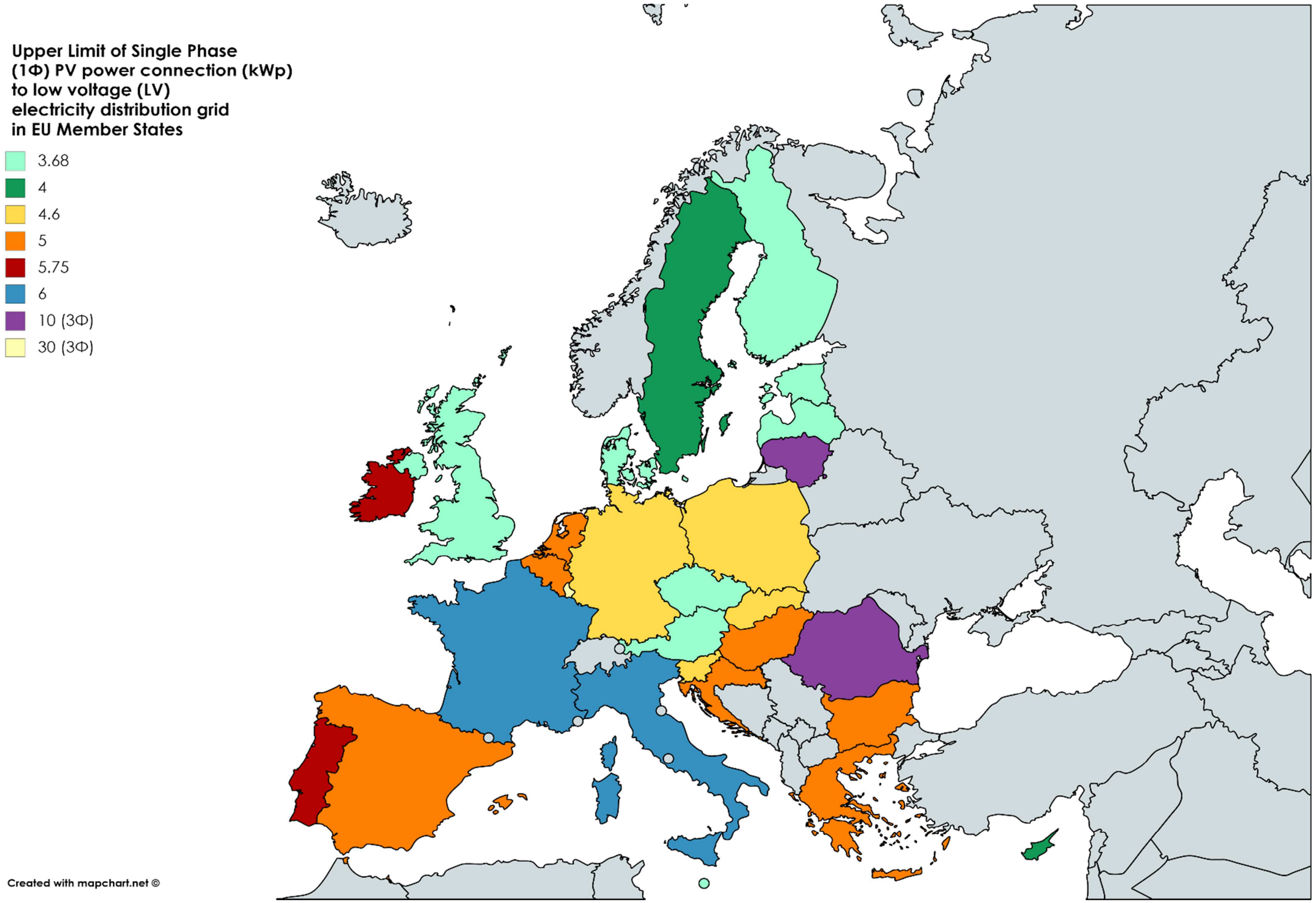
Source: Outcome of this report

6 Coloured Map of the Upper Limit

of PV power connection (kWp) to the low voltage (LV) electricity distribution system for single phase (1Φ) PV installations in the member states of the EU

Figure 2 presents a coloured map version of the findings of this report regarding the upper limit of PV power connection (kWp) to the low voltage (LV) electricity distribution system in the EU member states.

Figure 2. Coloured Map for the upper limit of single phase (1Φ) PV power connection (kWp) to the low voltage (LV) electricity distribution system in the EU



Source: Outcome of this report

7 Elgar TerraSAS ETS 1000 PV Simulator

The manuals that were used in order to acquire the knowledge needed to carry out the tasks of this assignment are the following:

a. Elgar TerraSAS Software, Installation and User Manual Rev G [98]

b. ETS 1000 Photovoltaic Simulator, Operation and Maintenance Manual [99]

My work with respect to the PV Simulator included the following:

a. Mastering the content of above mentioned manuals

b. IP configuration of the Host PC on which the Elgar TerraSAS software was installed

c. Connection to the PV Simulator via an Ethernet cable

d. Upgrade of the firmware running on the PV Simulator hardware

The main field of application of PV Simulators is the testing of inverters used in real world PV power installations. It is of importance for manufacturers of this kind of equipment to study the performance and response of inverters based on rapid changes on irradiance profiles and thus PV power output.

The manufacturer of the PV Simulator provides a DEMO version of the Elgar TerraSAS Software in order to help engineers to familiarise themselves with the environment of the software. Detailed explanation on how to use the software can be found in the manuals that were mentioned above.

Figure 3 presents a view of the Elgar TerraSAS PV Simulator that is available in the Smart Grid and Interoperability Lab of the JRC of the European Commission.

Figure 3. View of the Elgar TerraSAS PV Simulator

Source: AMETEK Programmable Solutions

7.1 ETS 1000 Photovoltaic Simulator Specifications

Table 34 presents the specifications of the ETS 1000 PV simulator that is available in the Smart Grid and Interoperability Lab of the JRC of the European Commission.

Table 34. Specifications of the ETS 1000 PV Simulator

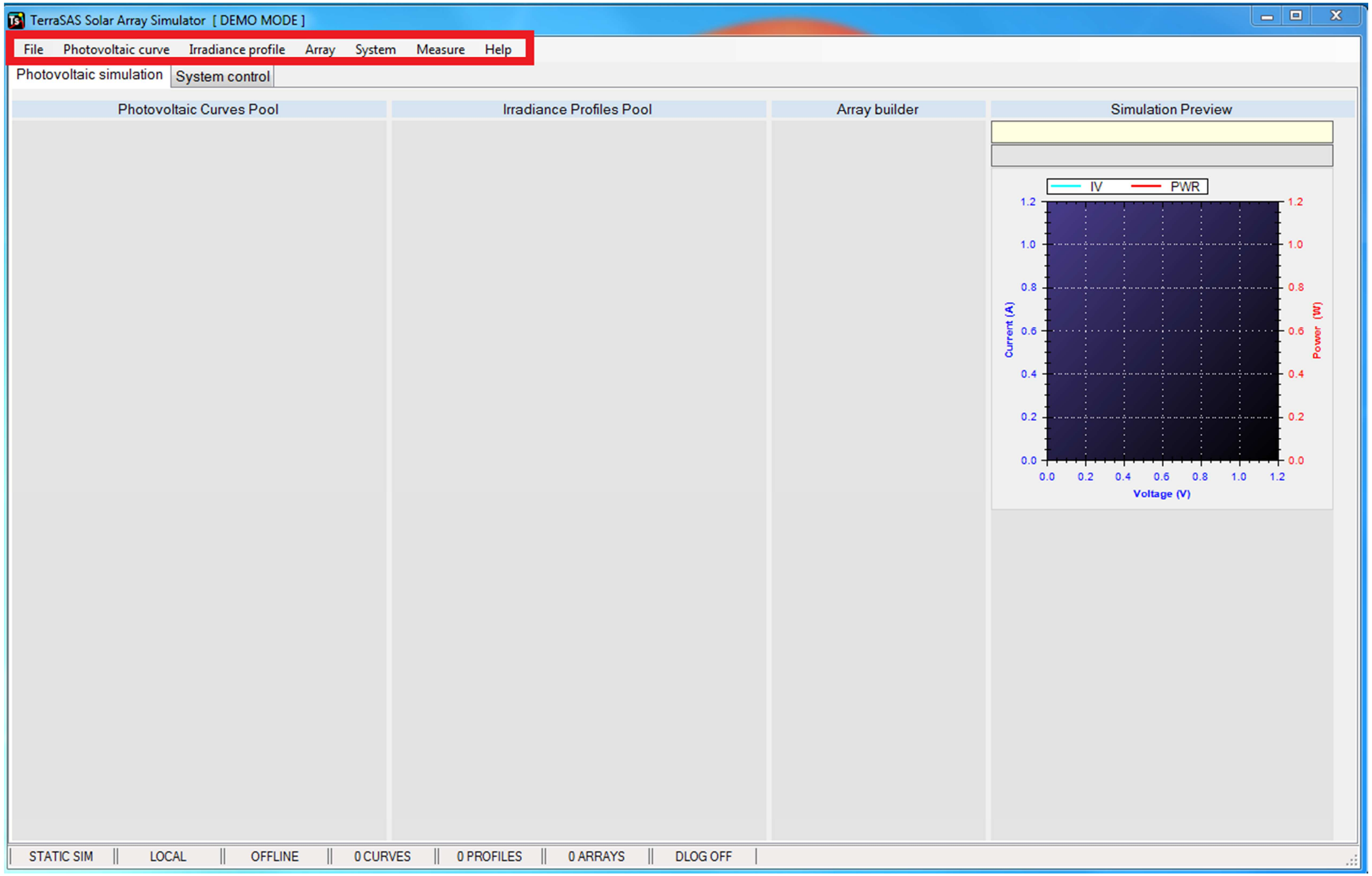
Model	**ETS 1000V/10A**
Output Voltage, V_{OC} (V)	1000
Maximum Output Voltage (V)	1100
Output Current, I_{SC} (A)	10
Maximum Output Power (kWp), $FF = 0.85$	8.5
MPP tracking speed (Hz)	200
I-V curve resolution (# of pts)	1024
Output capacitance (μF)	$\prec 40$
Output isolation, V_{pk}	± 1400
Available I/O	Ethernet
Remote sense (V)	10
Input Voltage (V_{AC})	D: 342-440
Input Frequency (Hz)	47-63
Power Factor	$\succ 0.9$ typical
Output noise	$\prec 0.6V_{PP}$
Operating temperature	0-50 degrees C
Physical dimensions	71.8x13.3x48.3 cm3, 27kg

Source: [100]

7.2 Elgar TerraSAS Software

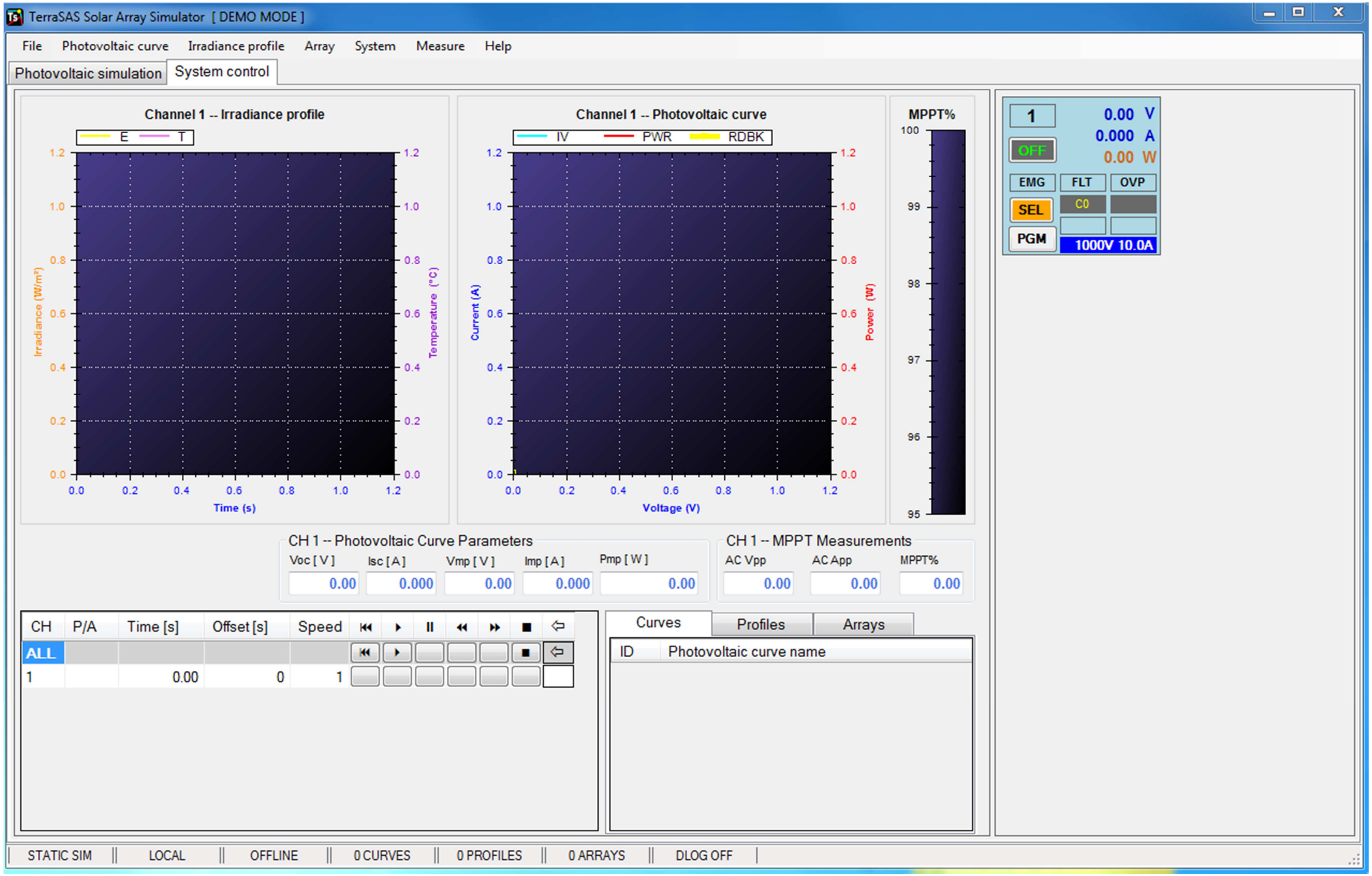
In this section, screenshots presenting the capabilities of the Elgar Terra SAS Software are provided.

Figure 4. Introductory screen of the DEMO version of TerraSAS software (Photovoltaic simulation tab)



Source: Elgar TerraSAS Software environment

Figure 5. Introductory screen of the DEMO version of TerraSAS software (System control tab)



Source: Elgar TerraSAS Software environment

As can be seen, in Figure 34, there are four different sections that the operator can observe and configure based on the needs of the, to be simulated, case. These are

a. Photovoltaic Curves Pool
b. Irradiance Profiles Pool
c. Array Builder
d. Simulation Preview (Static)

In Figure 35, seven sections (the purpose of each section is straightforward) can be identified. These are:

a. Channel 1 – Irradiance profile
b. Channel 1 – Photovoltaic curve
c. MPPT%
d. CH1 – Photovoltaic curve parameters
e. CH1 – MPPT Measurements
f. Section for monitoring time clock and its offset
g. Section acting as pool for photovoltaic curves, irradiance profiles, and PV arrays' configuration

The red rectangle highlights all the different configuration that can be made and alter the performance of the simulated PV array.

The *File* menu has the following submenus:

a. Load test session
b. Save test session

The *Photovoltaic curve* menu has the following submenus

a. Load (SNL)
b. Import (SAM)
c. Create (SNL)
d. EN 50530:2010
    i. Create/Update curve
    ii. Edit coefficients
e. Remove
    i. All
    ii. Selected

The *Irradiance profile* menu has the following submenus

a. Load
b. Remove
    i. All
    ii. Selected
c. Create

The *Array* menu has the following submenus

a. Add
b. Remove

i. All
ii. Selected

The *System* menu has the following submenus

a. Configure
    i. PV Simulators
    ii. Settings
    iii. Import inverter data
b. Reset
c. Debug
    i. Show SCPI traffic
    ii. Show timing
    iii. Show errors
    iv. Show external inputs
d. Data logging
e. Channels grouping setup
f. I/L Energy monitor

The *Measure* menu has the following submenus

a. Time
    i. MPPT recovery
b. Energy

The *Help* menu has the following submenus

a. About TerraSAS

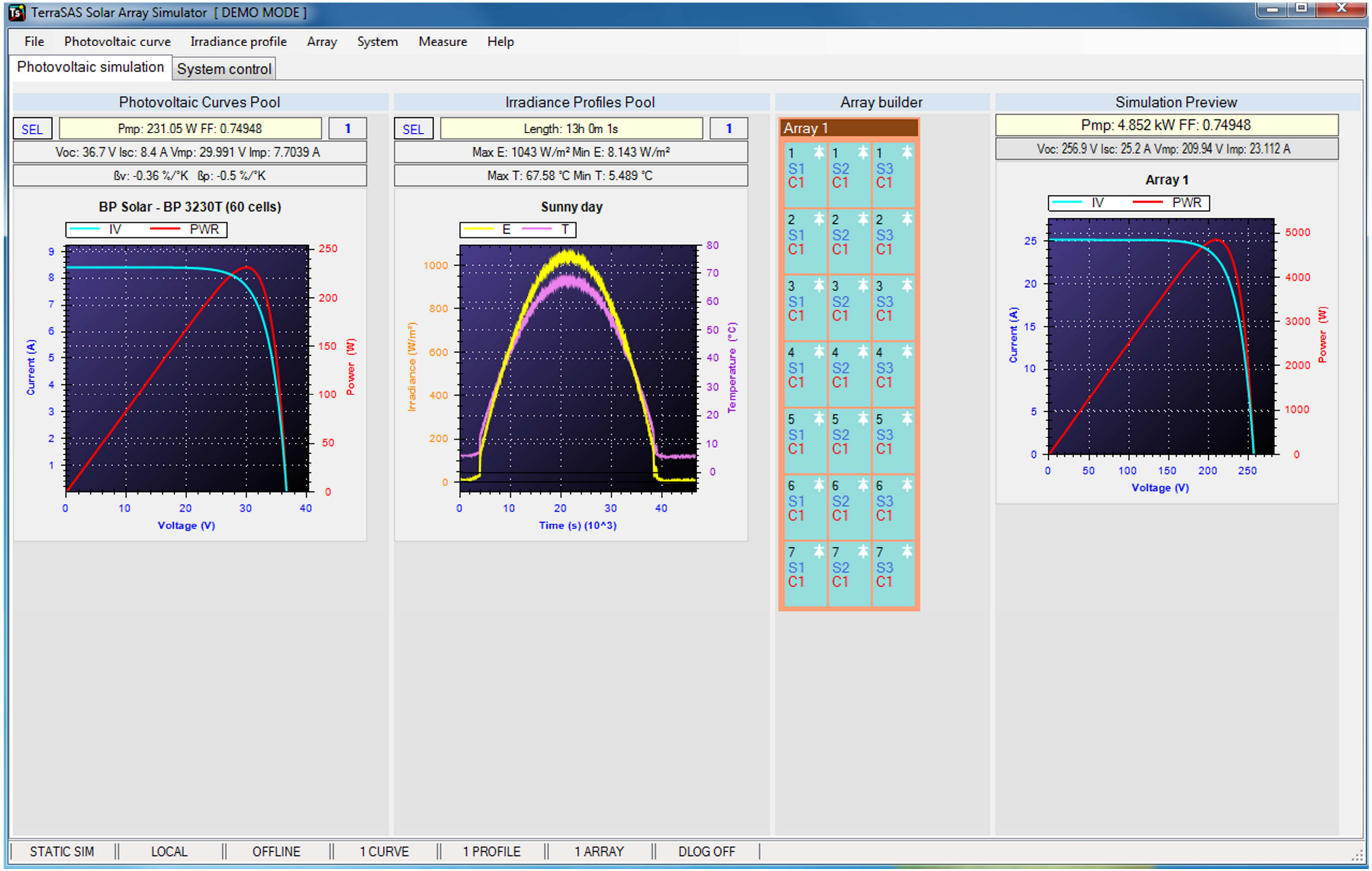
The purpose of the menus and submenus is straightforward and thus there is no need for further explanations.

In Figure 6 an I-V curve, irradiance profile (sunny day) and an array configuration have been added resulting to the PV system presented under the *Simulation Preview* menu (static simulation). Variables ($V_{OC}, I_{SC}, V_{MP}, I_{MP}$) characterising the performance of the PV power system are calculated by the software and presented in a comprehensive way. Figure 7 corresponds to a Static Simulation. Later in this section, screenshots from a dynamic simulation will be presented too.

Figure 8 and Figure 9 present the dynamic simulation of a PV module where the performance of the PV module is based on the irradiance profile that has been added earlier. The I-V curve is adjusted dynamically based on the maximum power point tracking (MPPT) principle. The instantaneous value of MPPT is also monitored and presented in the software.

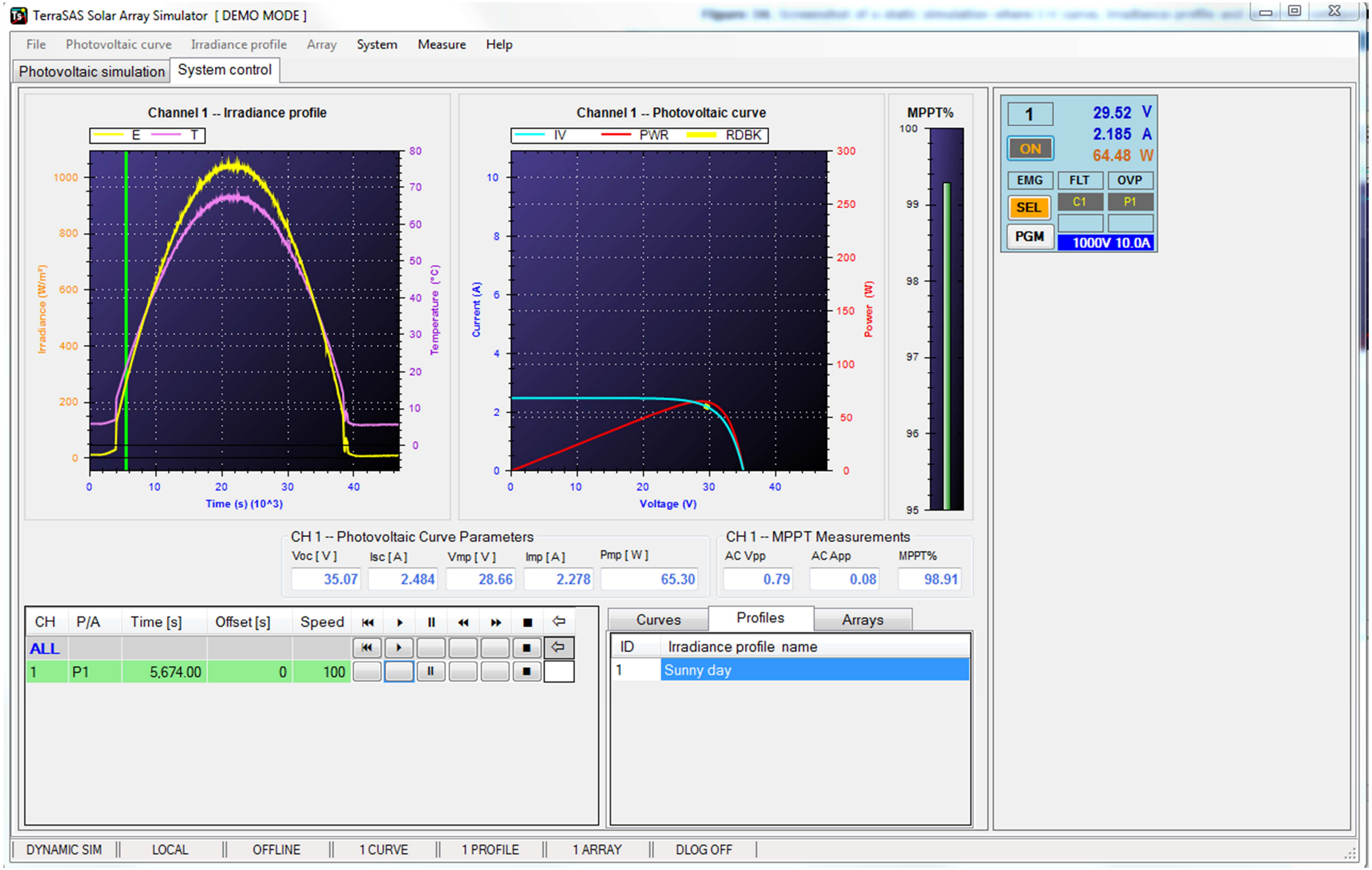
It has to be mentioned that extensive presentation of the capabilities of the Elgar TerraSAS PV Simulator is out of scope of the current report. The reader shall consult the documents presented in [98] and [99] in order to get familiar with the full range of capabilities of the PV Simulator.

Figure 6. Screenshot of a static simulation where the I-V curve, the irradiance profile and an array configuration have been added



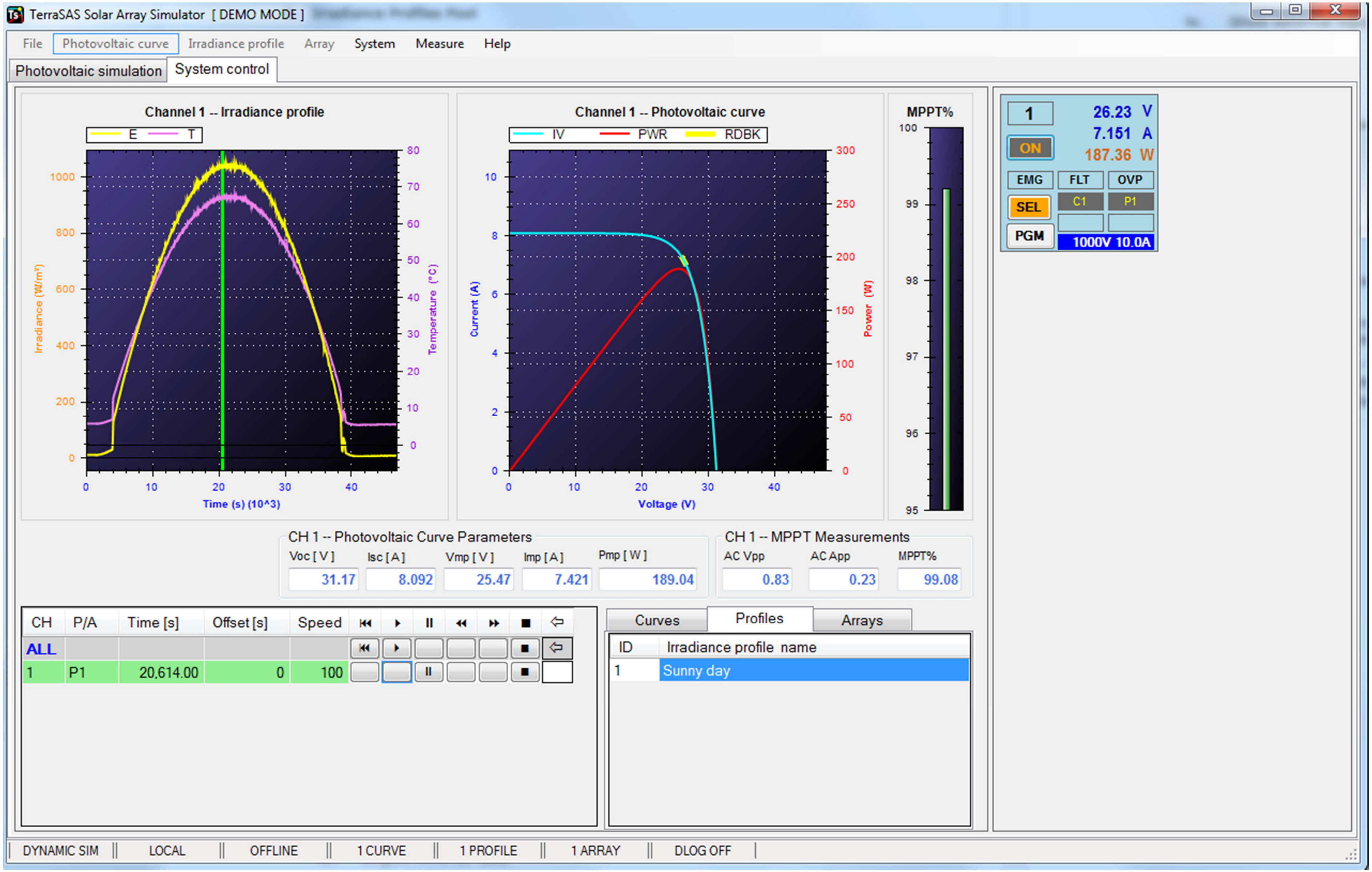
Source: Elgar TerraSAS Software environment

Figure 7. Dynamic Simulation of the performance of a PV module (screenshot for low irradiance)



Source: Elgar TerraSAS software environment

Figure 8. Dynamic Simulation of the performance of a PV module (screenshot for high irradiance)

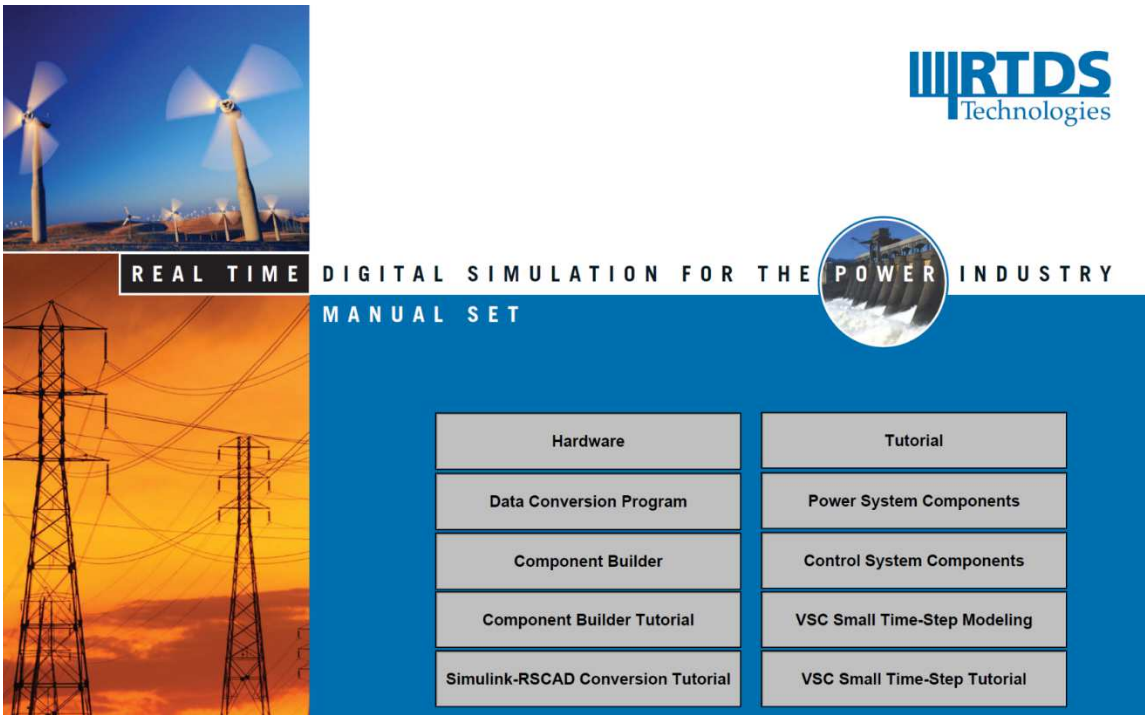


Source: Elgar TerraSAS software environment

8 Real Time Digital Simulator (RTDS)

RTDS hardware and RSCAD software environment are state of the art tools used for simulating and studying Electromagnetic Transient (EMT) phenomena in power systems. In the website of RTDS Technologies [101] plethora of information regarding the fields of power systems engineering where the RTDS Simulator can be used are presented.
Because of the availability of large amount of documentation both on hardware and on the RSCAD software used for real time simulations, the RTMF approach was used in this case too.
Figure 9 presents the manual set that is provided by the RTDS Technologies in order to help their customers to familiarise themselves with the RTDS Simulator.

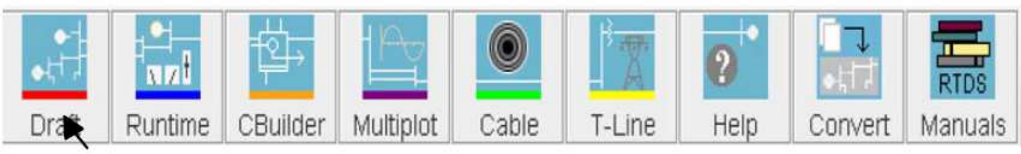
Figure 9. RTDS manual set



Source: RTDS Technologies

Figure 10 presents all the modules that are available in the RSCAD Software environment.

Figure 10. RSCAD software modules



Source: RSCAD Software environment

Table 35 summarises the scope of each module available in the RSCAD software environment.

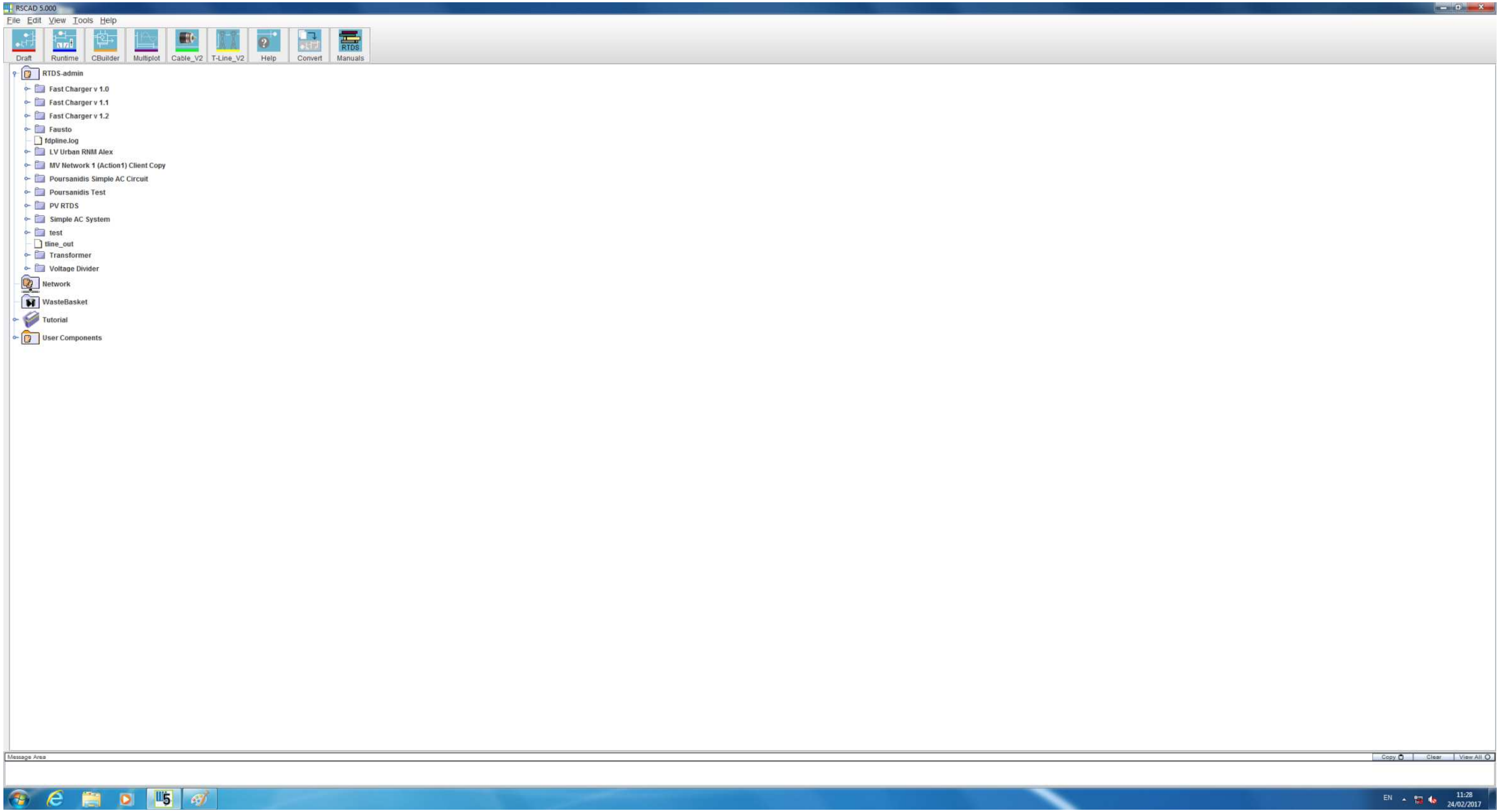
Table 35. RSCAD Software modules and their description

Module	Description
Draft	Used for designing the schematic diagrams of power systems to be simulated in the RTDS
Runtime	Used for monitoring under investigation variables based on "events" taking place in the simulated power system
CBuilder	Component builder environment based on C programming language for development of custom components to be used in simulations
Multiplot	Used for multi-plotting purposes
Cable	Used to customise the parameters of cables that are being inserted into the simulation environment
T-Line	Used to customise the transmission lines that are being inserted into the simulation environment
Help	Used for finding information for components used in simulations
Convert	Used to convert models that have been designed in Simulink into a format accessible by RSCAD
Manuals	Gives access to the Manual Set of RSCAD software environment

Source: RTDS Technologies

Figure 11 presents a screenshot of RSCAD introductory page environment. Based on the scope of the work conducted by the user the respective module should be chosen. The user can either choose to open a directory of on-going project or create a new project in the environment of interest for his work.

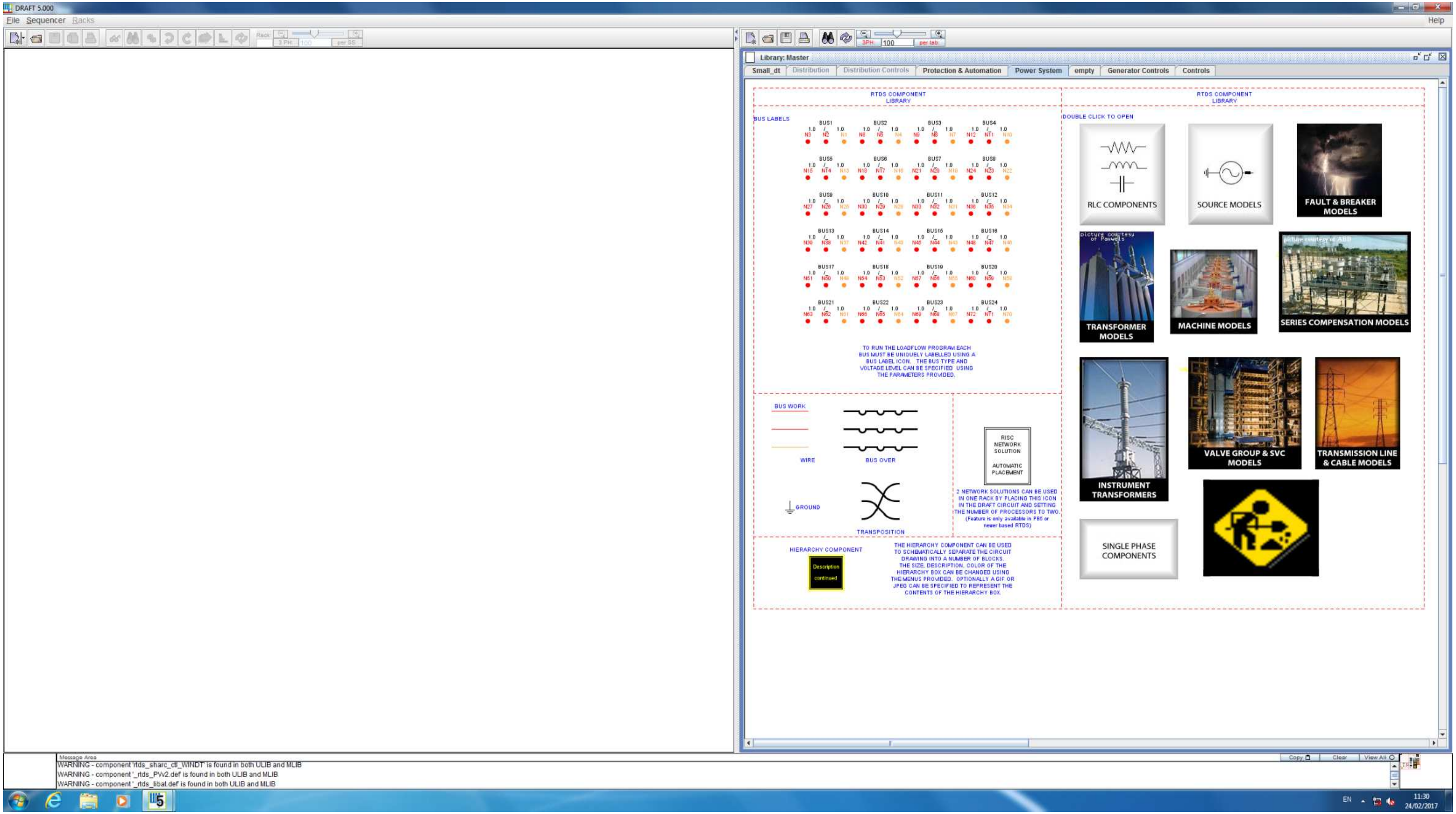
Figure 11. RSCAD software environment



Source: RSCAD Software environment

Figure 12 presents the RSCAD Draft environment where the Power Systems tab has been selected and no drawing has taken place yet. The Draft environment is used for creating the model of a power system configuration to be studied. Components from the Power System tab, Protection and Automation tab, Generator Controls tab and Controls tab can be added in order to represent properly the case that the user wants to simulate.

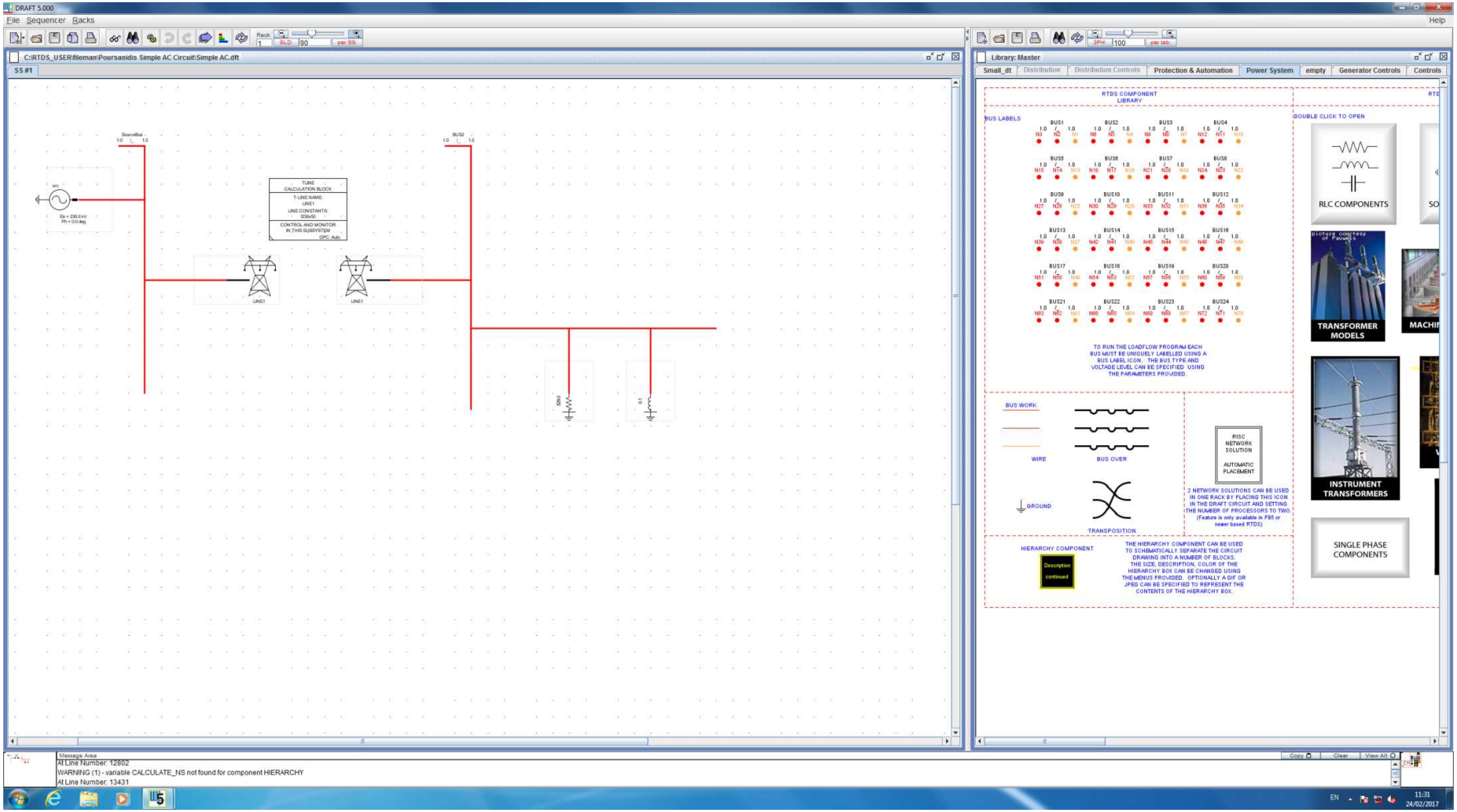
Figure 12. RSCAD Software Draft environment



Source: RSCAD Software Draft environment

Figure 13 presents the RSCAD Draft environment where a simple power system containing a generator, a transmission line and a load have been modelled and interconnected. Based on the number of available racks (RTDS hardware Simulator) a maximum number of modules can be added to the RSCAD Draft environment.

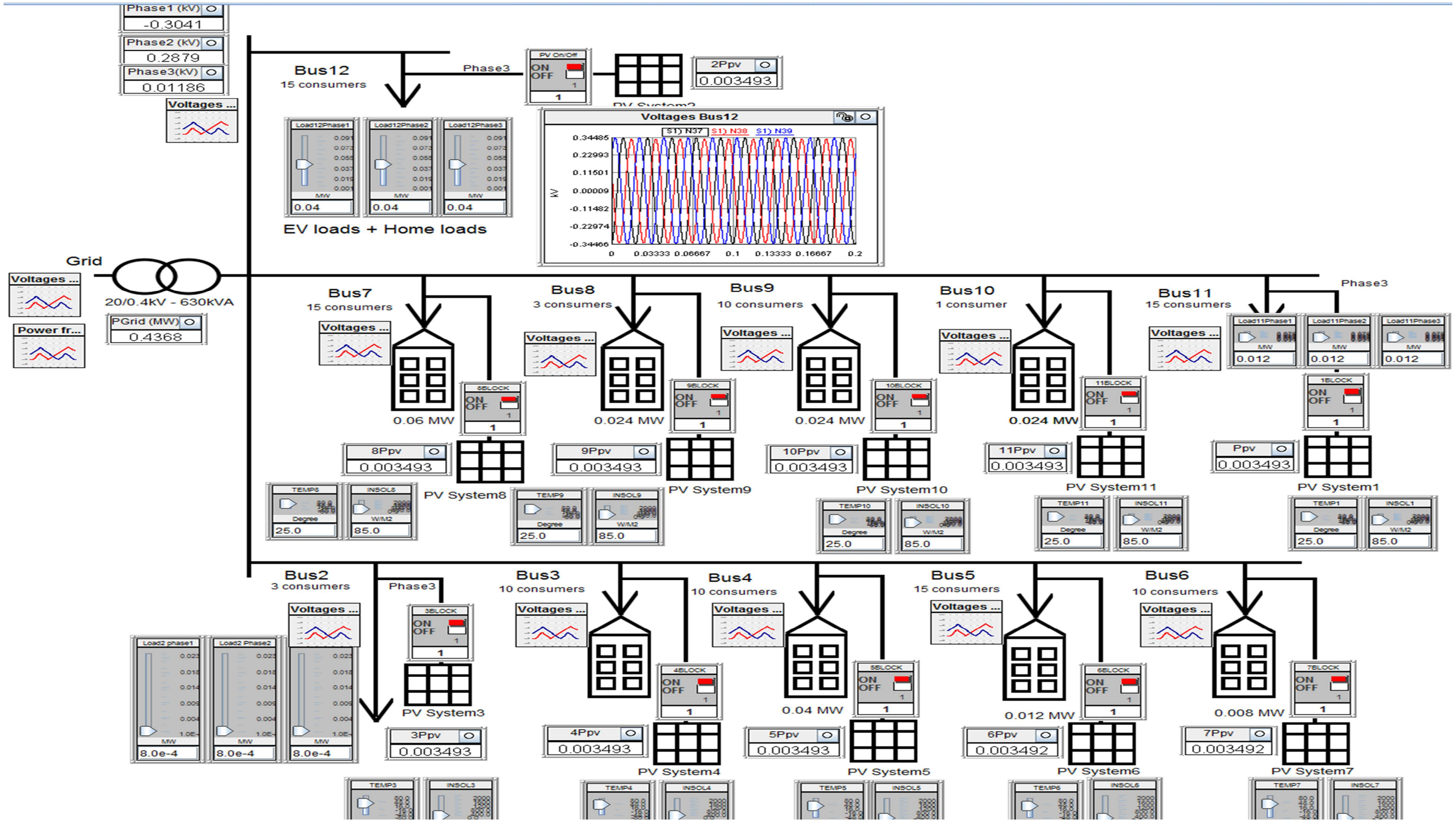
Figure 13. RSCAD Draft environment where a simple power systems circuit has been modelled



Source: RSCAD Software Draft environment

Figure 14 presents the RSCAD Runtime environment were the Case #12, i.e. urban low voltage network, of Reference Network Models [102] that were studied in the Smart Electricity Systems and Interoperability group of the JRC [103].

Figure 14. RSCAD Software Runtime environment



Source: RSCAD Software Runtime environment (developed by Dr. Alexandre Lucas)

9 Conclusions and Future Work

This report had the aim to summarise the data that DSOs in the member states of the EU provide regarding the penetration of RES (kWp) to the low voltage (LV) electricity distribution system. Relevant bar charts per country as well as a bar chart summarizing the situation in the EU for single phase (1Φ) PV power connection (kWp) to the low voltage (LV) electricity distribution are provided. The coloured map that was presented in a previous section of this work gives a macroscopic view of the same situation for the member states of the EU.

From now and on, policy making bodies of the electricity sector in the EU are equipped with a report that clarifies the big picture of single phase (1Φ) RES penetration (kWp) to the low voltage (LV) electricity distribution system as well as the single phase (1Φ) contracted power (kVA) levels.

The introduction of multiple single phase (1Φ) contracted power (kVA) levels can have a positive side effect on a variety of fields related directly or indirectly with the electricity distribution sector (increased efficiency of design process, economies of scale for used equipment etc.) in the EU member states.

Electricity distribution systems have emerged during the process of electrification of urban, semi-urban, rural areas etc. that took place in 20th century in order to fulfil the various needs of consumers in terms of electricity demand. In the past, power generation processes and plants were located in areas where fossil fuels were available and thus the development of the power system followed a centralised approach. This situation has changed dramatically after the introduction of RES and the transformation of traditional consumers to "prosumers" able to produce electricity in a distributed manner. New research questions emerge and should be studied.

In strict scientific terms, there is a need for the determination of a formula that relates the voltage levels at the buses of a studied electricity distribution system, when considering the penetration of RES, with a variety of variables, i.e. $V_{bus} = f(P_{inj}, A_{cab}, N_{cons}, \ldots)$ where the vector of voltages at the studied buses (V_{bus}) is the dependent variable, while the vector of power injection (P_{inj}) at the buses, cross-section of cables (A_{cab}) serving the needs of consumption, the number of consumers per bus being served (N_{cons}), among other variables, are the independent variables.

The determination of such a formula and its incorporation to decision support systems (DSS) used by DSOs could assist the process of efficient design of electricity distribution systems with a simultaneous maximization of RES penetration potential aiming the smooth decarbonization of the European economy.

The PV Simulator that is available in the Smart Grid and Interoperability Lab of the JRC can be interfaced with the Real Time Simulator (through the utilization of a specific Analogue Input card) that is also present in the Lab, in order to form a so-called Power Hardware in the Loop (PHIL) Simulation.

In this kind of simulations, the operator can witness in real time how changes in the output of the PV Simulator (e.g. different values of irradiance or temperature) affect KPIs of a studied power system. Instead of just having a pure simulation where the modules used to form a given power system are all modelled, with PHIL simulation part of the real time simulation is outcome of the outputs of actual hardware devices.

References

[1]. RES LEGAL [online]. Available: http://www.res-legal.eu/. [Accessed: 29-Mar-2017]

[2]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/austria/tools-list/c/austria/s/res-e/t/promotion/sum/91/lpid/94/. [Accessed: 29-Mar-2017]

[3]. E-CONTROL [online]. Available: https://www.e-control.at/documents/20903/388512/TOR_D4_V2.3+ab+1.7.2016.pdf/1fbc3aff-36a6-4eee-8de5-6027eaa53a89. [Accessed: 29-Mar-2017]

[4]. Netz Oberösterreich GmbH [online]. Available: http://strom.netzgmbh.at/eag_at/resources/284094835607631929_1028631756552887790_4K7KgkNN.pdf [accessed: 29-Mar-2017]

[5]. STW [online]. Available: https://www.stw.at/fileadmin/user_upload/pdf/AGB/AB_Zugang_Verteilernetz_Strom.pdf [accessed: 29-Mar-2017]

[6]. NETZ BURGENLAND STROM [online]. Available: http://www.netzburgenland.at/fileadmin/NB_pdf_NEU/Verordnungen/Allgemeine_Verteilernetzbedingungen_Strom_2014.pdf [accessed: 29-Mar-2017]

[7]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/belgium/tools-list/c/belgium/s/res-e/t/promotion/sum/108/lpid/107/ [accessed: 29-Mar-2017]

[8]. SYNERGRID [online]. Available: http://www.synergrid.be/download.cfm?fileId=C10-11_NL_120604.pdf&language_code=NED [accessed: 29-Mar-2017]

[9]. SIBELGA [online]. Available: http://www.sibelga.be/en/connections-and-meters/new-connection-electricity-with-meter [accessed: 29-Mar-2017]

[10]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/bulgaria/tools-list/c/bulgaria/s/res-e/t/promotion/sum/112/lpid/111/ [accessed: 29-Mar-2017]

[11]. EVN [online]. Available: https://www.evn.bg/getattachment/064bb579-e72b-4ed3-a0c1-09fea42d49c6/Naredba-N6.aspx [accessed: 29-Mar-2017]

[12]. EVN [online]. Available: https://www.evn.bg/SpecialPages/Cena-dostap.aspx#27 [accessed: 29-Mar-2017]

[13]. EVN [online]. Available: https://www.evn.bg/Chastni_klienti/Elektricheska-energia/Uslugi/Novo_prisaed_El/ProuchvaneEl.aspx [accessed: 29-Mar-2017]

[14]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/croatia/tools-list/c/croatia/s/res-e/t/promotion/sum/358/lpid/359/ [accessed: 29-Mar-2017]

[15]. HROTE [online]. Available: http://files.hrote.hr/files/PDF/Dokumenti/MreznaPravilaElektroenergetskogSustava.pdf [accessed: 29-Mar-2017]

[16]. HEP [online]. Available: http://www.hep.hr/ods/UserDocsImages/dokumenti/Obrasci/Zahtjev_za_izdavanje_prethodne_elektroenergetske_suglasnosti.pdf [accessed: 29-Mar-2017]

[17]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/cyprus/tools-list/c/cyprus/s/res-e/t/promotion/sum/116/lpid/115/ [accessed: 29-Mar-2017]

[18]. ELECTRICITY AUTHORITY OF CYPRUS [online]. Available: https://www.eac.com.cy [accessed: 29-Mar-2017]

[19]. ELECTRICITY AUTHORITY OF CYPRUS [online]. Available: https://www.eac.com.cy/ [accessed: 29-Mar-2017]

[20]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/czech-republic/tools-list/c/czech-republic/s/res-e/t/promotion/sum/120/lpid/119/ [accessed: 29-Mar-2017]

[21]. VEOLIA [online]. Available: https://www.eru.cz/documents/10540/2491622/P%C5%99%C3%ADloha+%C4%8D.+4_VEOLIA.pdf/65bedac0-4541-433e-b787-1772086536dc [accessed: 29-Mar-2017]

[22]. PRE [online]. Available: https://www.pre.cz/Files/households/electricity/documents-for-download/price-lists/pre_electricity_komfort/ [accessed: 29-Mar-2017]

[23]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/denmark/tools-list/c/denmark/s/res-e/t/promotion/sum/95/lpid/96/ [accessed: 29-Mar-2017]

[24]. ENERGINET.DK [online]. Available: http://energinet.dk/ [accessed: 29-Mar-2017]

[25]. AURA [online]. Available: http://energitilsynet.dk/fileadmin/Filer/0_-_Nyt_site/EL/Off._tilgaengeligt_register/Registersager/AURA_Net/2016_-_1._kvt/2016-01_-_tilslutningsbestemmelser_engrosmodel_2016.pdf [accessed: 29-Mar-2017]

[26]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/estonia/tools-list/c/estonia/s/res-e/t/promotion/sum/124/lpid/123/ [accessed: 29-Mar-2017]

[27]. ELEKTRILEVI [online]. Available: https://energiatalgud.ee/img_auth.php/1/17/Kaps,_M._Elektrilevi_O%C3%9C._Elektris%C3%BCsteemi_muudatused_elektritarbijast_tarbija-tootjaks_muutumisel..pdf [accessed: 29-Mar-2017]

[28]. ELEKTRILEVI [online]. Available: Elektrilevi [accessed: 29-Mar-2017]

[29]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/finland/tools-list/c/finland/s/res-e/t/promotion/sum/128/lpid/127/ [accessed: 29-Mar-2017]

[30]. ENERGIATEOLLISUUS [online]. Available: https://www.oulunenergia.fi/sites/default/files/attachments/et_verkostosuositus_mikrotuotannon_liittaminen_sahkonjakeluverkkoon.pdf [accessed: 29-Mar-2017]

[31]. ELENIA [online]. Available: http://www.elenia.fi/sites/www.elenia.fi/files/Liittymishinnasto_1.1.2017_web.pdf [accessed: 29-Mar-2017]

[32]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/france/tools-list/c/france/s/res-e/t/promotion/sum/132/lpid/131/ [accessed: 29-Mar-2017]

[33]. ENEDIS [online]. Available: http://www.enedis.fr/sites/default/files/Enedis-PRO-RAC_20E.pdf [accessed: 29-Mar-2017]

[34]. EDF [online]. Available: http://residential.edf.com/energy-at-home/offers/electricity/tarif-bleu-56121.html [accessed: 29-Mar-2017]

[35]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/germany/tools-list/c/germany/s/res-e/t/promotion/sum/136/lpid/135/ [accessed: 29-Mar-2017]

[36]. VDE [online]. Available: https://www.vde.com/resource/blob/972830/bcb00e83abc88c6ed0d4a26572063f92/hinweis-speicher-data.pdf [accessed: 29-Mar-2017]

[37]. VDE [online]. Available: https://www.vde.com/resource/blob/937632/9c2f2bc4c574aa2c60b21d0a3698dc13/bdew-transmission-code-2007-data.pdf [accessed: 29-Mar-2017]

[38]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/greece/tools-list/c/greece/s/res-e/t/promotion/sum/140/lpid/139/ [accessed: 29-Mar-2017]

[39]. HEDNO [online]. Available: http://www.deddie.gr [accessed: 29-Mar-2017]

[40]. HEDNO [online]. Available: http://www.deddie.gr [accessed: 29-Mar-2017]

[41]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/hungary/tools-list/c/hungary/s/res-e/t/promotion/sum/144/lpid/143/ [accessed: 29-Mar-2017]

[42]. EON [online]. Available: http://www.eon.hu/download.php?url=partnerek_/aram/HMKE_NS_oktatasi_anyag_SzA.ppt [accessed: 29-Mar-2017]

[43]. EON [online]. Available: http://sh-media.hu/fejlesztes/eon-hmke/kalkulator/?mod=kalkulator [accessed: 29-Mar-2017]

[44]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/ireland/tools-list/c/ireland/s/res-e/t/promotion/sum/148/lpid/147/ [accessed: 29-Mar-2017]

[45]. SEI [online]. Available: http://www.seai.ie/Publications/Renewables_Publications_/New_Technologies/consumer_microgen_brochure.pdf [accessed: 29-Mar-2017]

[46]. ESB NETWORKS [online]. Available: https://www.esbnetworks.ie/docs/default-source/publications/connection-to-a-single-domestic-dwelling-or-farm-premises-application-(nc2).pdf?sfvrsn=14 [accessed: 29-Mar-2017]

[47]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/italy/tools-list/c/italy/s/res-e/t/promotion/sum/152/lpid/151/ [accessed: 29-Mar-2017]

[48]. ENEL [online]. Available: http://www.resit.website/wp-content/uploads/2014/04/Guida-alla-connessione-ENEL-V2-21.pdf [accessed: 29-Mar-2017]

[49]. ACEA [online]. Available: https://www.acea.it/it/energia/come-fare-per/gestire-il-contratto/variazione-potenza [accessed: 29-Mar-2017]

[50]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/latvia/tools-list/c/latvia/s/res-e/t/promotion/sum/156/lpid/155/ [accessed: 29-Mar-2017]

[51]. EST [online]. Available: http://www.lvif.gov.lv/uploaded_files/KPFI/11/Seminars/Mikrogeneratori.pdf [accessed: 29-Mar-2017]

[52]. EST [online]. Available: http://sadalestikls.lv/files/tarifi/Ka_izveleties_piesleguma_jaudu.jpg [accessed: 29-Mar-2017]

[53]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/lithuania/tools-list/c/lithuania/s/res-e/t/promotion/sum/160/lpid/159/ [accessed: 29-Mar-2017]

[54]. TEISES AKTU REGISTRAS [online]. Available: https://www.e-tar.lt/portal/lt/legalAct/TAR.FC7AB69BE291/erirvIsPBP [accessed: 29-Mar-2017]

[55]. ESO [online]. Available: https://www.eso.lt/lt/prijungimo-skaiciuokle.html?sr=RVdTSUQ9ZWM5a3NtazJqc3U3NHNvZDJocW1sNTJkZzA [accessed: 29-Mar-2017]

[56]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/luxembourg/tools-list/c/luxembourg/s/res-e/t/promotion/sum/164/lpid/163/ [accessed: 29-Mar-2017]

[57]. ELECTRIS [online]. Available: http://www.electris.lu/files/Dokumente_und_Formulare/20131126_Contrat_type_PV_1.pdf [accessed: 29-Mar-2017]

[58]. ELECTRIS [online]. Available: http://www.electris.lu/files/Dokumente_und_Formulare/20131218_demande_de_raccordement_fr.pdf [accessed: 29-Mar-2017]

[59]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/malta/tools-list/c/malta/s/res-e/t/promotion/sum/168/lpid/167/ [accessed: 29-Mar-2017]

[60]. REWS [online]. Available: http://downloads.rews.org.mt/files/3e56981b-01eb-4f06-91f1-7d169852ed6d_154b1059-86ed-4f7d-92ee-4bda29dcf6d4.pdf [accessed: 29-Mar-2017]

[61]. ENEMALTA [online]. Available: http://www.enemalta.com.mt/enemaltastorage/images/files/network%20code/network%20code%20emc%20approved%20%20october%202013.pdf [accessed: 29-Mar-2017]

[62]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/netherlands/tools-list/c/netherlands/s/res-e/t/promotion/sum/172/lpid/171/ [accessed: 29-Mar-2017]

[63]. LIANDER [online]. Available: https://www.liander.nl/sites/default/files/Aansluitrichtlijnenzonnepanelen.pdf [accessed: 29-Mar-2017]

[64]. LIANDER [online]. Available: https://www.liander.nl/consument/aansluitingen/capaciteit [accessed: 29-Mar-2017]

[65]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/poland/tools-list/c/poland/s/res-e/t/promotion/sum/176/lpid/175/ [accessed: 29-Mar-2017]

[66]. TAURON DYSTRYBUCJA [online]. Available: www.tauron-dystrybucja.pl/SiteCollectionDocuments/dokumenty-przylaczenia/Kryteria_przylaczania_OZE_do_sieci_nN.pdf [accessed: 29-Mar-2017]

[67]. ENERGA OPERATOR [online]. Available: http://www.energa-operator.pl/uslugi/przylaczenie_do_sieci/odbiorcy_1.xml [accessed: 29-Mar-2017]

[68]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/portugal/tools-list/c/portugal/s/res-e/t/promotion/sum/180/lpid/179/ [accessed: 29-Mar-2017]

[69]. EDPSU [online]. Available: https://www.edpsu.pt/pt/PRE/Microproducao/RegulamentaoDocs/Decreto-Lei%2025_2013.pdf [accessed: 29-Mar-2017]

[70]. EDP [online]. Available: http://www.edp.pt/pt/particulares/apoioaocliente/ligacaorede/Pages/NovaLigacaoemBaixaTensao.aspx [accessed: 29-Mar-2017]

[71]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/romania/tools-list/c/romania/s/res-e/t/promotion/sum/184/lpid/183/ [accessed: 29-Mar-2017]

[72]. PVTRIN [online]. Available: http://pvtrin.eu/assets/media/PDF/Publications/project_reports/common_failures_and_improper_practices/248.6_RO.pdf [accessed: 29-Mar-2017]

[73]. EON [online]. Available: https://www.eon-energie-romania.ro/clienti-casnici/informatii-utile/tarife [accessed: 29-Mar-2017]

[74]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/slovakia/tools-list/c/slovakia/s/res-e/t/promotion/sum/188/lpid/187/ [accessed: 29-Mar-2017]

[75]. ZAPADOSLOVENSKA DISTRIBUCNA [online]. Available: http://www.zsdis.sk/documents/239/ZSD_Proces-pripojenia-zariadenia-na-vyrobu-EE-k-DS.pdf [accessed: 29-Mar-2017]

[76]. ZAPADOSLOVENSKA DISTRIBUCNA [online]. Available: http://www.zsdis.sk/documents/470/ZSE-D_Manual_Ako-vyplnit-ziadost_domacnosti_A-long_web.pdf [accessed: 29-Mar-2017]

[77]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/slovenia/tools-list/c/slovenia/s/res-e/t/promotion/sum/192/lpid/191/ [accessed: 29-Mar-2017]

[78]. ELEKTRO GORENJSKA [online]. Available: http://www.elektro-gorenjska.si/resources/files/pdf/Navodila_priklucevanje_elektrarn.pdf [accessed: 29-Mar-2017]

[79]. URADNI LIST [online]. Available: https://www.uradni-list.si/glasilo-uradni-list-rs/vsebina/40230 [accessed: 29-Mar-2017]

[80]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/spain/tools-list/c/spain/s/res-e/t/promotion/sum/196/lpid/195/ [accessed: 29-Mar-2017]

[81]. HC ENERGIA [online]. Available: https://www.hcenergia.com/recursos/doc/Colaboradores/Proveedores/Electricidad/Ingenieria/1667910902_10112009115732.pdf [accessed: 29-Mar-2017]

[82]. IBERDROLA [online]. Available: https://www.iberdrola.es/empresas/info/suministros-baja-tension [accessed: 29-Mar-2017]

[83]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/sweden/tools-list/c/sweden/s/res-e/t/promotion/sum/200/lpid/199/ [accessed: 29-Mar-2017]

[84]. SVENSKO ENERGI [online]. Available: http://www.dalaenergi.se/UserFiles/Dokument/Elnat/35137_MIKRO-Handbok-2014-version2-ny.pdf [accessed: 29-Mar-2017]

[85]. VATENFALL [online]. Available: https://www.vattenfalleldistribution.se/el-hem-till-dig/bestall-offerforfragan/ [accessed: 29-Mar-2017]

[86]. RES LEGAL [online]. Available: http://www.res-legal.eu/search-by-country/united-kingdom/tools-list/c/united-kingdom/s/res-e/t/promotion/sum/204/lpid/203/ [accessed: 29-Mar-2017]

[87]. ENERGY NETWORKS ASSOCIATION [online]. Available: http://www.microhydroassociation.org/uploads/7/7/0/4/7704207/er_g83-2__v5-_the_master_09-07-12_inc_ofgem_comments_-_clean_version.pdf [accessed: 29-Mar-2017]

[88]. ENERGY NETWORKS ASSOCIATION [online]. Available: http://www.amps.org.uk/static/assets/downloads/DraftG5931_170914updatev1280115trackchangev4.pdf?attach [accessed: 29-Mar-2017]

[89]. UK POWER NETWORKS [online]. Available: https://library.ukpowernetworks.co.uk/library/en/g81/Design_and_Planning/Planning_and_Design/Documents/EDS+08-0136+LV+Network+Design+Standard.pdf [accessed: 29-Mar-2017]

[90]. UK POWER NETWORKS [online]. Available: http://www.ukpowernetworks.co.uk/internet/en/our-services/upgrade-fuse/ [accessed: 29-Mar-2017]

[91]. CENELEC [online]. Available: https://www.cenelec.eu/dyn/www/f?p=104:110:663677066633801::::FSP_ORG_ID,FSP_PROJECT,FSP_LANG_ID:1258595,51993,25 [accessed: 29-Mar-2017]

[92]. CENELEC [online]. Available: https://www.cenelec.eu/dyn/www/f?p=104:110:2408094978052001::::FSP_ORG_ID,FSP_PROJECT,FSP_LANG_ID:1258595,48764,25 [accessed: 29-Mar-2017]

[93]. EUROPEAN COMMISSION [online]. Available: https://ec.europa.eu/energy/en/topics/renewable-energy [accessed: 29-Mar-2017]

[94]. ESB NETWORKS [online]. Available: https://www.esbnetworks.ie/docs/default-source/publications/conditions-governing-the-connection-and-operation-of-micro-generation.pdf?sfvrsn=4 [accessed: 29-Mar-2017]

[95]. HEDNO [online]. Available: http://www.deddie.gr/ [accessed: 29-Mar-2017]

[96]. MINISTÉRIO DA ECONOMIA E DO EMPREGO [online]. Available: http://energiasrenovaveis.com/images/upload/DL252013.pdf [accessed: 29-Mar-2017]

[97]. LIANDER [online]. Available: https://www.liander.nl/sites/default/files/Aansluitrichtlijnenzonnepanelen.pdf [accessed: 29-Mar-2017]

[98]. AMETEK PROGRAMMABLE POWER [online]. Available: http://www.programmablepower.com/custom-power-supply/ETS/downloads/M551066-02_rev_G.pdf [accessed: 30-Mar-2017]

[99]. AMETEK PROGRAMMABLE POWER [online]. Available: http://www.programmablepower.com/custom-power-supply/ETS/downloads/Elgar-TerraSAS-Software-V2_0_0_4-and-IVI_driver-V1_0_0-Win78-3264-bit.zip [accessed: 30-Mar-2017]

[100]. AMETEK PROGRAMMABLE POWER [online]. Available: http://www.programmablepower.com/custom-power-supply/ETS/Specifications.htm [accessed: 30-Mar-2017]

[101]. RTDS Technologies [online]. Available: https://www.rtds.com/ [accessed: 30-Mar-2017]

[102]. INSTITUTE FOR RESEARCH IN TECHNOLOGY – UNIVERSIDAD PONTIFICIA COMILLAS [online] Available: http://www.iit.comillas.edu/technology-offer/rnm [accessed: 30-Mar-2017]

[103]. JRC SMART ELECTRICITY SYSTEMS AND INTEROPERABILITY [online]. Available: http://ses.jrc.ec.europa.eu/distribution-system-operators-observatory [accessed: 30-Mar-2017]

List of abbreviations and definitions

kWp	kilo Watt peak, determines the peak value of the power injection of a PV power installation
kVA	kilo Volt Ampere, determines the maximum allowable instantaneous power demand at the premises of electricity consumers
kWh	derived unit of energy
LV	Low Voltage, electricity distribution networks where the nominal voltage is $\leq 1kV$
PV	PhotoVoltaic (effect), direct conversion of sunlight to electricity via the use of semiconductors
RES	Renewable Energy Sources, in this report RES notation refers to PV systems
Prosumers	Consumers of electricity that additionally produce electricity through e.g. PV panels installed at their premises
FIT	Feed in Tariff
1Φ	Single phase
3Φ	Three phase
PF	Power Factor, $\cos\theta = \frac{P}{S}$ where P : real power and S : apparent power
KPI	Key Performance Index
DSS	Decision Support System
PHIL	Power Hardware in Loop
FF	Fill Factor
MPPT	Maximum Power Point Tracking
EMT	Electromagnetic Transient (phenomena)
EU	European Union

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