European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out

TRANSNATIONAL ACCESS
USER PROJECT FACT SHEET

USER PROJECT	
Acronym	PVGRIDHIL
Title	Design of the vector control algorithms for photovoltaic grid-connected systems in distorted utility grids using the Controller-Hardware-in-the-Loop Simulation technique
ERIGrid Reference	04.003-2018
TA Call No.	**4**

HOST RESEARCH INFRASTRUCTURE			
Name	SmartEST, Austrian Institute of Technology (AIT)		
Country	**Austria**		
Start date	**30.09.2018**	**Nº of Access days**	**19**
End date	**28.10.2018**	**Nº of Stay days**	**29**

USER GROUP	
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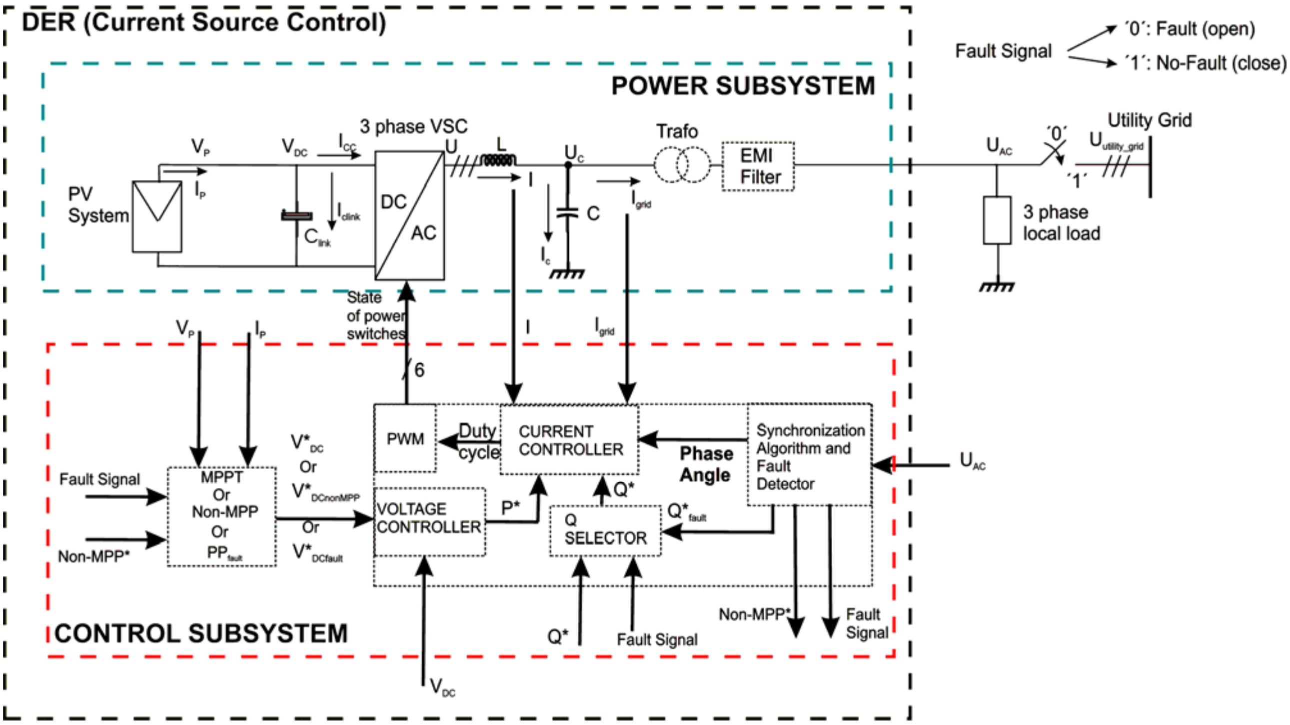
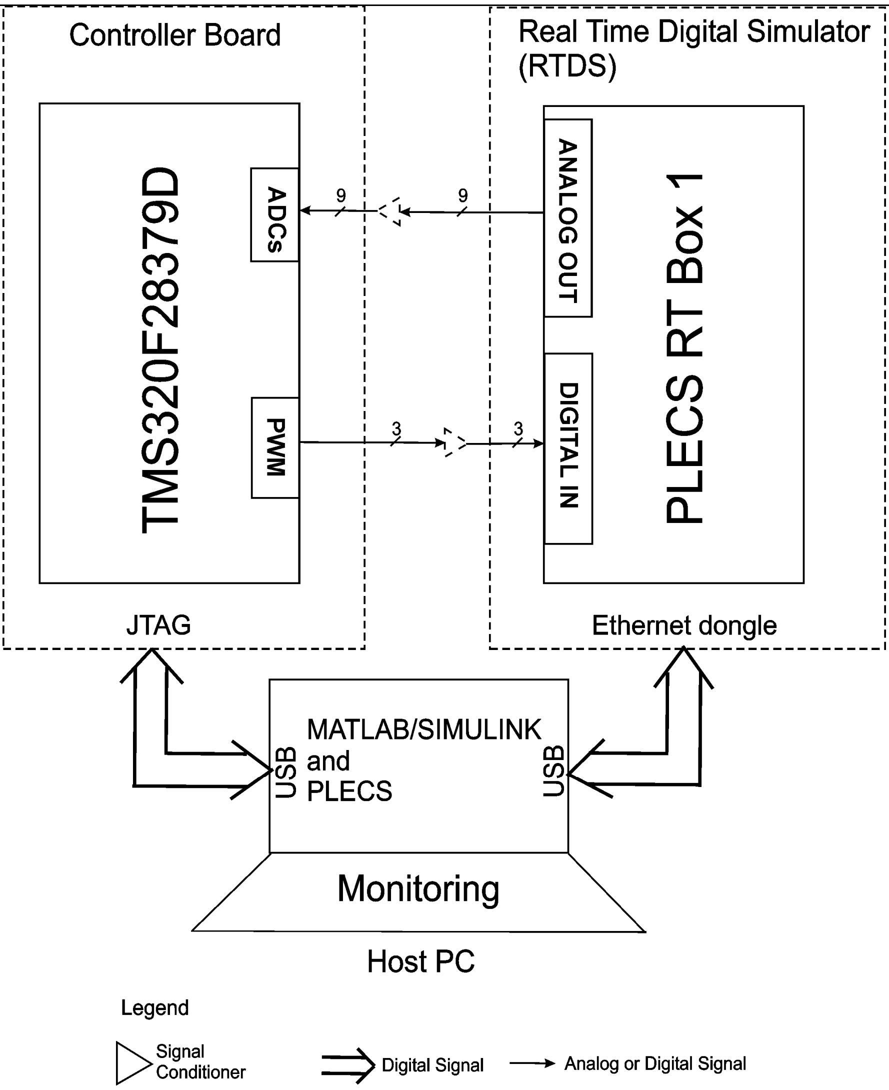
1. USER PROJECT SUMMARY (objectives, set-up, methodology, approach, motivation)

Objectives: The main objective in this proposal was the implementation of the vector control algorithms to a photovoltaic grid-connected 3-phase Voltage Source Inverter (VSI). The VSI will be used as the power conditioner for the primary photovoltaic (PV) renewable energy source connected to the low voltage 3-phase utility grid with disturbances. The block diagram of the proposal is depicted in the next figure.



Set-up: The setup was built with two hardware units: the PLECS RT Box 1 working as the Real Time Digital Simulator (RTDS) for the Power subsystem, and the TMS320F28379D Dual-Core Delfino Microcontroller for the Control subsystem. The former is programmed by its own software environment, meanwhile the latter is programmed using MATLAB/SIMULINK in a Model-Based design environment using SIMULINK blocks in order to model the control algorithms. Both units were run in real time and several measurements of the output signals of the corresponding voltages, currents, instantaneous active and reactive powers of the model, among others, were displayed and recorded in the host PC for monitoring purposes. The block diagram of the implemented set-up is depicted in the next figure.



Methodology: The algorithms were tested by using **the Controller-Hardware-in-the-Loop (CHIL)** Simulation technique in which the power subsystem (including the PV Generator, the 3-phase, the inverter, the L filter and the utility grid) were modelled using the software of PLECS RT Box 1, meanwhile the control subsystem were modelled using SIMULINK blocks. In both cases the C-codes were generated using the Model-Based design method and downloaded into the Real Time Digital Simulator (RTDS) for the former, and into the real microcontroller for the latter, running both in real time.

Approach: Firstly, the behaviour of the grid-connected PV system under harmonic distortions of the 3-phase utility grid voltages were tested in order to find out its influence in the Power Quality of the inverter grid connection. Secondly, the effect of the unbalanced in the 3-phase utility grid voltages were also investigated, mainly its effect on the second order harmonics in the DC bus voltage and in the detected fundamental frequency. Third, the effect of several sags in the 3-phase grid voltages were investigated, as well as the Low-Voltage-Ride-Through (LVRT) capability of the control algorithms according to international Grid Codes. Finally, the influence of the variation of the fundamental nominal frequency were also tested.

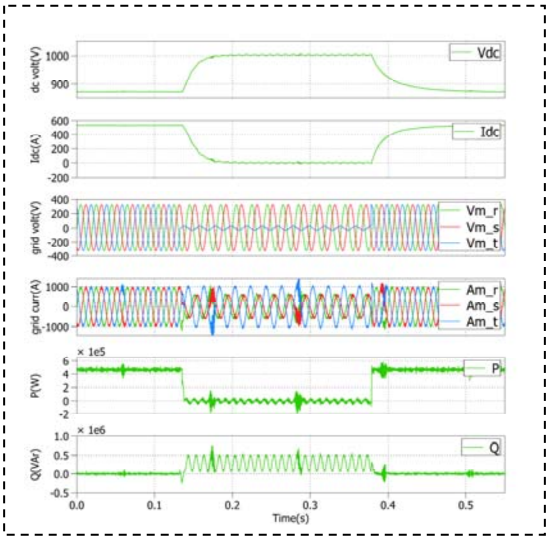
Motivation: The setup scheme used in this project embed the control algorithms in a real microcontroller for its validation. So, the use of its peripherals will increase the reliability of the obtained results because the second order effects such as the quantization error of the ADCs, the computational and PWM delays, the dead time of the power switches of the inverter, the real utility grid with its output impedance, etc., will be considered, and what is more important, the same real microcontroller (with the same hardware resources) could be used in a future real photovoltaic system with minor changes.

Although the experimental platform was built for an only one renewable source, the approach of this Project can be extrapolated when several renewable sources are scaled in order to build a Distributed Generation (DG) system. So, after the validation of the tests carried out in the CHIL setup for one PV renewable source, other renewable sources such as critical loads, storage elements, wind turbines, etc. can be easily added in order to test the interaction between them, the perturbation on the voltage and frequency profile of the public utility grid, but at the same time the safety of the whole system and operators might be guaranteed.

Finally, it is worth noting that a more powerful RTDS with more hardware resources and smaller sample times, i.e. using FPGA devices must be employed if the testing of a DG system is needed.

2. MAIN ACHIEVEMENTS (results, conclusions, lessons learned)

The CHIL Simulation technique was successfully implemented for the 3-phase PV grid-connected system using the PLECS RT Box 1 as the Power Subsystem and the TMS320F28379D Dual-Core Delfino Microcontroller as the Control Subsystem.



Several tests were carried out in order to validate the control algorithms tested only with SIMULINK models before its implementation in this project.

Specifically, the LVRT capability was tested when several voltage sags were imposed to the 3-phase utility grid voltages (in the Figure a deep voltage sag (0.1 pu) is imposed in phase 3: the DC bus voltage increases to look for the available active power in the PV system, in this case zero, without exceeding the limits of the output inverter currents and injecting reactive power in order to improve the profile of the utility grid voltages; after the voltage sag, the DC voltage decreases until the MPP is attained, meanwhile the reactive power is set to zero for unity power factor operation).

The influence of the variation of the nominal frequency was also tested in two situations: for the conventional Positive Sequence Detector + synchronous reference frame PLL and with the enhance MSOGI-FLL algorithm. The latter guarantees the unity power factor operation due to its adaptive resonant filter when the nominal frequency of the 3-phase utility grid voltages varies.

It is worth noting that during the stay at the SmartEST Lab, the user group realized that the PLECS

RT Box 1 is limited in its hardware resources, mainly in the sample time of the Power Subsystem. With a sample time of around 5µs and the model of the PV Panels, a 3-phase inverter, the L filter and the 3-phase utility grid voltages with harmonics, together with the input/output signal interfaces to the Control subsystem, the use of the hardware resources was around the 75%. So, the implementation of a more complex plant with several Distributed Energy Resources (DER) would be impossible if PLECS RT Box1 were used. Then, a more powerful RTDS with more hardware resources and smaller sample times, i.e. using FPGA devices, might be employed if the testing of a DG system is needed. On the contrary, no restrictions arose with the use of the TMS320F28379D Dual-Core Delfino Microcontroller as the Control Subsystem in which the control algorithms were tested.

3. PLANNED DISSEMINATION OF RESULTS (journals, conferences, others)

It is the intention of User Group to write at least two papers with the expected results in this project in order to possibly published them in one of the following, among others, scientific journals and/or conferences.

Journals:

- IEEE Transactions on Industry Applications
- IEEE Transactions on Industrial Informatics
- ELSEVIER Electric Power Systems Research
- ELSEVIER Energy Conversion and Management
- ELSEVIER International Journal of Electrical Power & Energy Systems

Conferences:

- IEEE International Power Electronics and Motion Control Conference (PEMC)
- IEEE International Symposium on Industrial Electronics
- Seminario Anual de Automática, Electrónica Industrial e Instrumentación (SAAEI), Spain