European Research Infrastructure supporting Smart Grid and Smart Energy Systems Research, Technology Development, Validation and Roll Out – Second Edition

Project Acronym: **ERIGrid 2.0**

Project Number: **870620**

Technical Report Lab Access User Project

Investigating the Effect of Third Generation Photovoltaics (Large Scale Perovskite Solar Cells) Penetration in Electric Grid (IETGPSC)

Access Duration: 11/07/2022 to 26/07/2022

Funding Instrument:	Research and Innovation Action
Call:	H2020-INFRAIA-2019-1
Call Topic:	INFRAIA-01-2018-2019 Integrating Activities for Advanced Communities
Project Start:	1 April 2020
Project Duration:	54 months

User Group Leader: Alaa Ahmed Zaky Hussein (Electrical Engineering Department Faculty of Engineering- Kafrelsheikh University Egypt)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 870620.

Report Information

Document Administrative Information	
Project Acronym:	ERIGrid 2.0
Project Number:	870620
Access Project Number:	05.153-2022
Access Project Acronym:	IETGPSC
Access Project Name:	Investigating the Effect of Third Generation Photovoltaics (Large Scale Perovskite Solar Cells) Penetration in Electric Grid
User Group Leader:	Alaa Ahmed Zaky Hussein (Electrical Engineering Department Faculty of Engineering- Kafrelsheikh University Egypt)
Document Identifier:	ERIGrid2-Call-5-LabAccess-Report-No-153-Investigating the Effect of Third Generation Photovoltaics-v1.3
Report Version:	V1.3
Contractual Date:	11/07/2022
Report Submission Date:	dd/10/2022
Lead Author(s):	Alaa Hussein (Electrical Engineering Department Faculty of Engineering-Kafrelsheikh University Egypt)
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Keywords:	Nanotechnology, Perovskite solar cells, third generation photovoltaics, electric grids, European Union (EU), H2020, Project, ERIGrid 2.0, GA 870620
Status:	draft

Change Log

Date	Version	Author/Editor	Summary of Changes Made
22/09/2022	v1.0	Alaa Ahmed Zaky Hussein	Draft report
13/10/2022	v1.1	Alkistis Kontou, Dimitris Lagos	1st Review
13/11/2022	v1.2	Alaa Ahmed Zaky Hussein	Draft report incorporating the review
9/01/2023	v1.3	Alaa Ahmed Zaky Hussein, Alkistis Kontou, Dimitris Lagos	2nd Review

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List of Abbreviations

NTUA	National Technical University of Athens (host facility)
PHIL	Power Hardware in the Loop [test]
RTDS	Real-Time Digital Simulation
RSCAD	Development software for the RTDS simulator (trademark)
PSCs	Perovskite Solar Cells
ETL	Electron Transporting Layer
TEG	Thermo- Electric Generator

Executive Summary

The lab-access user project "Investigating the Effect of Third Generation Photovoltaics (Large Scale Perovskite Solar Cells) Penetration in Electric Grid (IETGPSC)" was conducted at the host lab of National Technical University of Athens (NTUA) in the time period 11/07/2022 to 26/07/2022.

The IETGPSC project investigated the effect of third generation solar cells namely perovskite solar cells to the electric grid at normal case of operation, fault case and islanding case of operation and examine the performance of the grid stability. The results also compared with silicon based solar cells under the same conditions of operations. Where the power hard ware in loop (PHL) methodology has been used to integrate the solar cells and the inverter to the electric grid and the real time digital simulator (RTDS) also has been used to obtain the on time signals of the system.

1 Lab-Access User Project Information

1.1 Overview

The lab-access user project “Investigating the Effect of Third Generation Photovoltaics (Large Scale Perovskite Solar Cells) Penetration in Electric Grid] (IETGPSC)” was conducted at the host lab of National Technical University of Athens (NTUA) in the period 11/07/2022 to 26/07/2022. The user Group Leader: Alaa Ahmed Zaky Hussein (Electrical Engineering Department Faculty of Engineering- Kafrelsheikh University Egypt) used PC with RSCAD and SASCONTROL programmes, regatron, inverters and RTDS in the lab and was assisted by the scientific personnel of the host lab (Alkistis Kontou and Dimitrios Lagos) during the access days.

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1.2 Research Motivation, Objectives, and Scope

The large scale third generation perovskite solar cells will be fabricated based on nanotechnology principle, then it will be characterized experimentally via auto lab and solar simulator. After that the devices will be integrated to an electric grid via Power hardware in the loop techniques and real time digital simulator. In the selected laboratory in National Technical of Athens there are the suitable facilities (PHIL, CHIL, MICROGRID, RTDS , Regatron) where we can enter the experimental current voltage characteristics of the fabricated perovskite solar cell device point by point and integrate it to the electric grid via real inverter. Series of experiments will be implemented in the lab like simulating the perovskite solar cells on the point by point solar simulator, PHIL tool for integrating the simulated perovskite solar cells to the electric grid and notice the power flow in the grid, the faults cases and the islanding effect. After the project finish the results will be published for the scientific and manufacturing societies via publishing in international scientific journal. After the results spreading it could help and pave the way for commercializing the perovskite third generation solar cells recent technologies that base on nanotechnology principle in fabrication where it has a very good absorption coefficient and fabricated at very low temperature and cost making it suitable alternative for silicon solar cells. Techno economic study between conventional silicon solar cells and the third generation solar cells will be conducted in this project via do the same experiments for both technologies and compare the results from both the technical and economic point of view. The normal performance of perovskite and silicon solar cells under uniform and different partial shading scenarios will be implanted beside the effect of the different of fault types and investigating the effect of islanding and how to mitigate all these obstacles. There will be a highlight for the importance of the third generation perovskite solar cells a suitable alternative for silicon solar cells and encourage the researchers for more and more research on this very recent technology which started only in 2009 with 3.8% as a power conversion efficiency and reached to 25.5% in 2022. Making this technology very hopeful for future use taking the benefit of low temperature and cost of fabrication to save money.

1.3 Structure of the Document

This document is organised as follows: Section 2 briefly outlines the state-of-the-art/state-of-technology that provides the basis of the realised Lab Access (LA) User Project (UP). Section 3 briefly outlines the performed experiments whereas Section 4 summarises the results and conclusions. Potential open issues and suggestions for improvements are discussed in Section 5.

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2 State-of-the-Art/State-of-Technology

The demand of energy is increasing all over the world although fossil fuel resources are limited. Moreover, emission of CO2 from such resources is the main source of the climate change. Therefore, there is a strong demand to green energy, which uses renewable energy resources especially solar energy. Solar energy is the most sustainable energy resource for future energy supplies. Conventional solar cells, needs high temperatures for their fabrication and production leading to expensive processes [1]. The main challenges, to overcome the high cost problem, are finding suitable materials and cost-effective techniques to fabricate PV systems. Thus, third generation solar cells (perovskite solar cells) are promising alternative for conventional solar cells due to their low fabrication cost, long diffusion length and low fabrication temperature. Perovskite solar cells are in the forefront of third-generation of photovoltaics and gained a lot of attention as a very promising green technology toward direct solar energy conversion to electricity. They present certified high power conversion efficiency is 25.5%, enabling them to be attractive alternative to the silicon based devices [2-4].

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3 Executed Tests and Experiments

3.1 Test Plan, Standards, Procedures, and Methodology

3.1.1 Proposed Host Lab/Research Infrastructure – Justification

Low Voltage Microgrid: A main component of the laboratory is the single phase microgrid that includes a PV generator, a small Wind Turbine, battery energy storage, controllable loads and a controlled interconnection to the local LV grid. The battery unit, the PV generator and the Wind Turbine are connected to the AC grid via fast-acting DC/AC power converters. Laboratory SCADA: The laboratory SCADA is implemented using a PLC (Programmable Logic Controller) system with LabVIEW/CoDeSys software. It provides measurements on the AC and DC side of the inverters, environmental measurements (irradiation, wind speed etc.), control of the DGs and load profile programming. **Power Hardware-in-the-Loop (PHIL) simulation environment:** The PHIL facility developed at ICCS-NTUA provides an efficient environment for studying interactions between hardware DER power devices and various simulated networks. A rack of the commercially available Real Time Digital Simulator RTDS® is operated. A Switched-Mode Amplifier by Triphase and a linear amplifier by Spitzenberger & Spies (PAS 5000) are used as a Power Interfaces between the RTDS and physical equipment to perform PHIL simulation. The Triphase power electronic converter platform allows the user to design in Matlab/Simulink the control algorithms. PHIL experiments are performed, where hardware equipment (loads, PV inverters, etc) are connected to simulated distribution networks..

Controller Hardware in the Loop (CHIL) simulation environment: In the context of its involvement with microgrids and dispersed generation, the research group is active in the development and study of advanced control algorithms for power electronic converters (DC/DC, DC/AC, AC/DC/AC, etc.). Based on the real-time simulator (RTDS) and a controller provided by Triphase, it is possible to thoroughly test control algorithms of power converters in an environment that reveals “hidden” weaknesses and faults in the design of these algorithms. Specifically, the design of the control algorithm is performed in the controller of Triphase while the power electronics are simulated in the RTDS. The communication between the two systems is achieved through analogue and digital signals.

3.2 Test Set-up(s)

Two solar cells array have been tested silicone one and the perovskite based one under normal, fault and islanding conditions. The test implemented based on power hardware in loop methodology. The Object under Investigation was a single-phase solar inverter (Figure 1). The inverter was connected on its DC side to a PV simulator (Figure 2), featuring maximum power point (MPP) tracking. The AC side was connected to a linear amplifier for the interfacing with the RTDS simulator (Figure 3).

The test was carried out as a PHIL simulation. For the first function under test (normal operation of solar cells penetration on electric grid under different irradiation levels), parallel operation of the solar inverter with a synchronous generator is assumed. Since the object under test was a single-phase inverter, it is necessary to read the terminal current of the inverter

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and artificially model the inverter in the two other phases also the grid current, voltage and power beside the same signals for the PV and batteries. The AC bus of the micro-grid of the lab has been used for the connection of the PV inverter with the amplifier as shown in Figure 4. The single line diagram (SLD) as used in RSCAD is shown in Figure 5 below. Again the work is repeated under fault and islanding case of operation.

Fig1.The single-phase solar inverter

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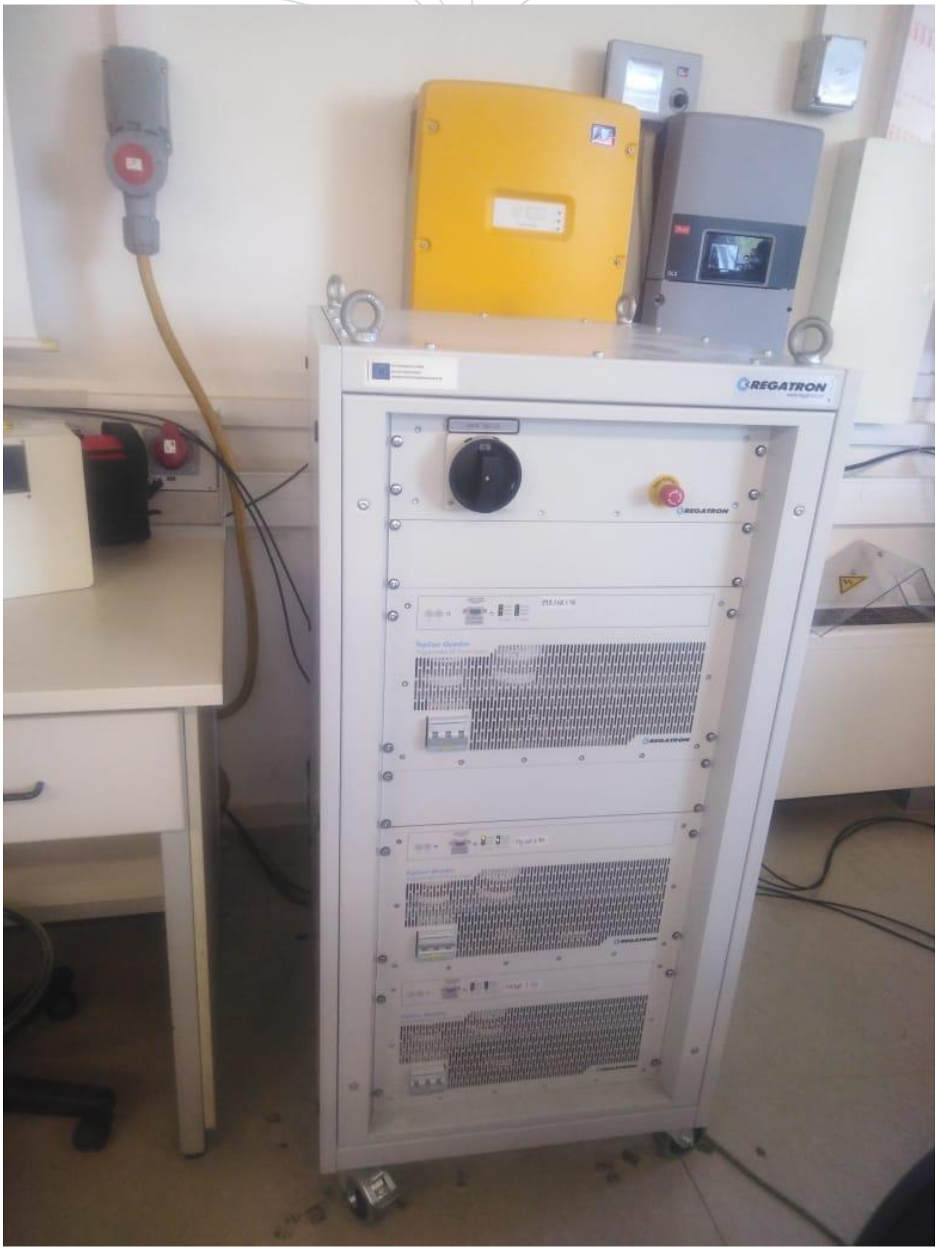

Fig2.The PV simulator

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Fig3.The amplifier and RTDS simulator

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Fig4.The Low-voltage microgrid in the host lab

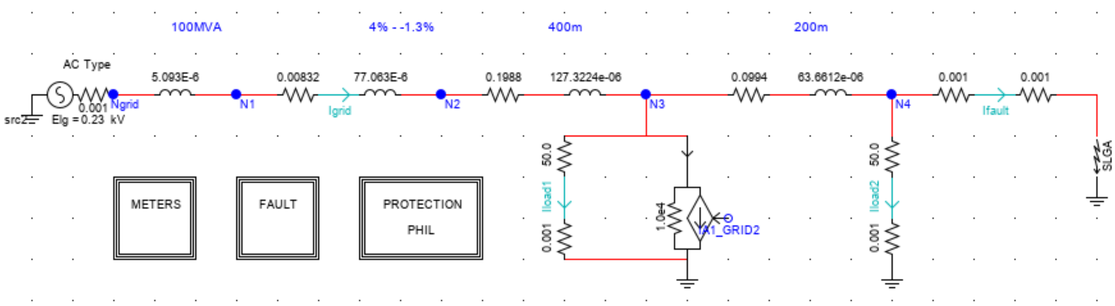

Fig5 The complete system RSCAD model

3.3 Data Management and Processing

As can be seen from the sections above, the test plan consisted of several small-scale tests with the objective to gain hands-on experience on the equipment and highlight questions for further investigation. In addition, the time duration of the lab access was not designed with the

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aim of running extensive tests and, thus, generating lots of data. Data management and processing did not represent any challenge during the lab access project. Data was stored locally on the personal computer of the user group member and processed using MATLAB and MS Excel. The data used is the I-V characteristic curves of the solar cells array both the silicon and the perovskite one. These curves fed to the SASCONTROL programme to connect the simulated panels to the grid.

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4 Results and Conclusions

4.1 Discussion of Results

In the beginning the silicon solar cells was tested then the new perovskite solar cells was teted under the same conditions. The results obtained clearly show that the perovskite solar cells which is new technology based fabricated solar cells with high efficiency and low cost succeeded to supply the load at normal operation and work also properly during both fault and islanding conditions compared with the silicon one where it shows better performance.

The report presents the results for perovskite solar cells case since the silicon solart cells results are published before in literature via the ICCS-NTUA LAB staff (N. Hartizargiriou research group).

Three cases were examined namely normal operation, fault case and islanding.

Normal operation case:

The perovskite solar cells module and the silicon solar cells module were emulated via regatron and SASControl and connected to the inverter DC side while the inverter AC side was connected to the simulated AC grid designed on RTDS via the amplifier. The current, voltage and power of the PV, Inverter and the grid were measured in both using perovskite and silicon based solar cells cases under different irradiation levels (500 W/m2, 750 W/m2 and 1000 W/m2).

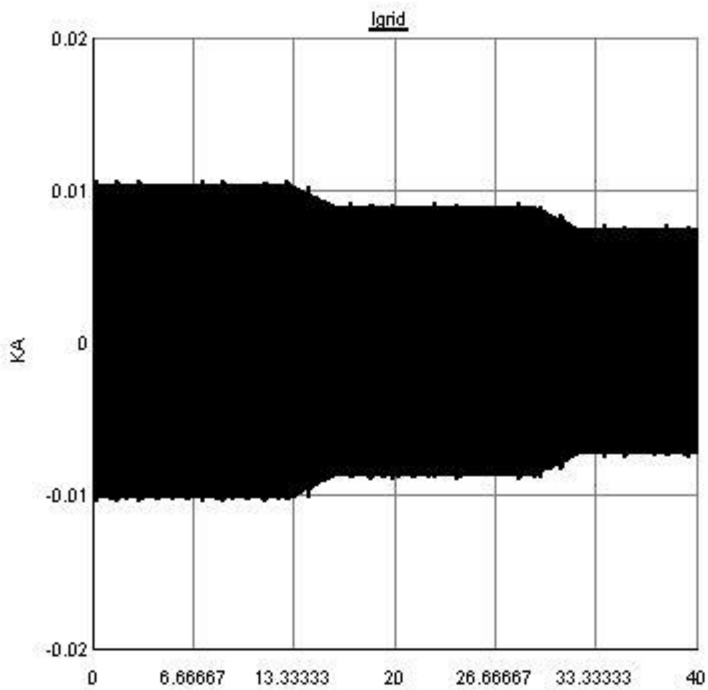

Fig 6. The grid current at normal operation

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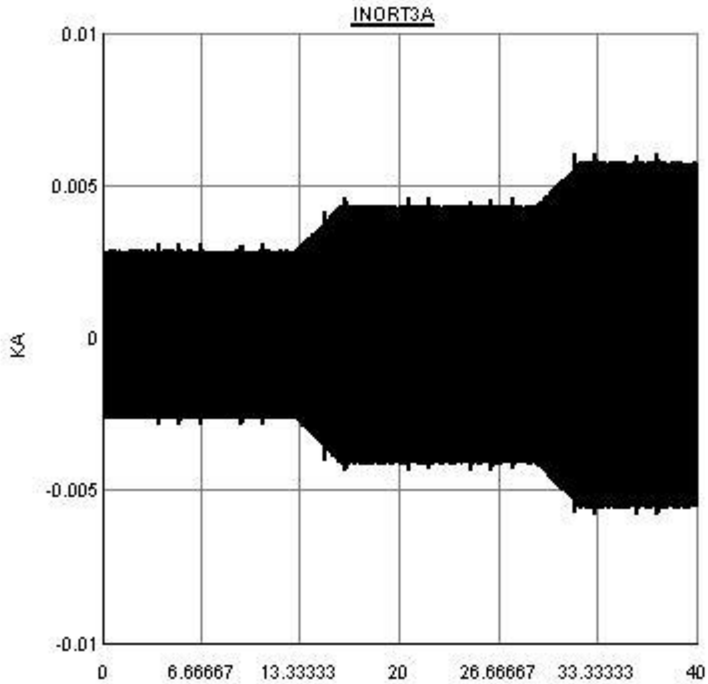

Fig 7. The inverter current at normal operation

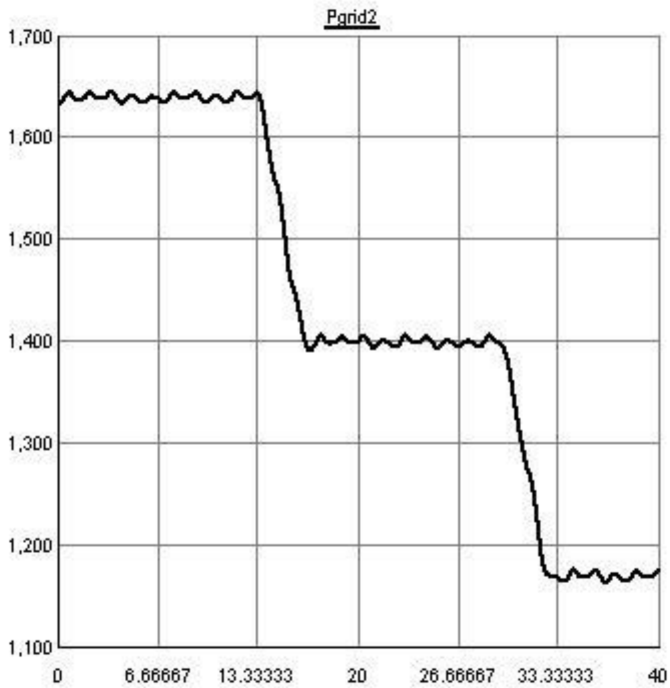

Fig 8. The grid power at normal operation

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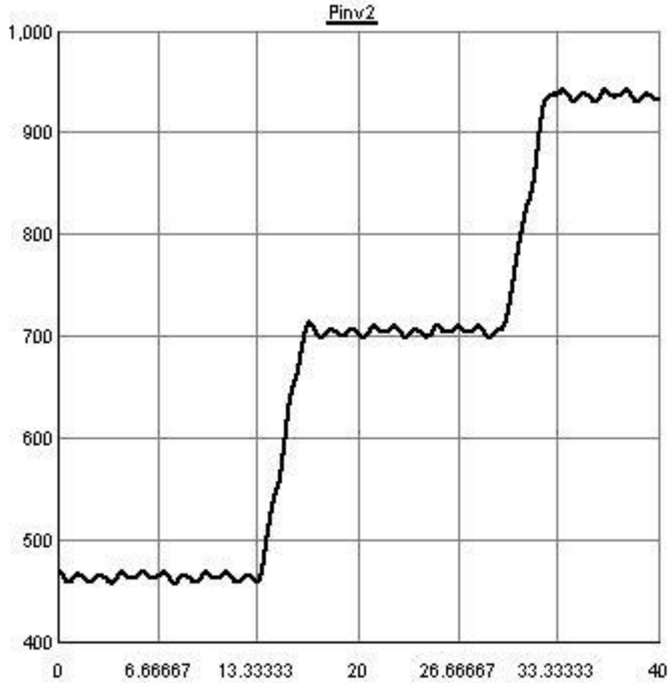

Fig 9. The inverter power at normal operation

Under fault operation case:

The same as normal case has been repeated but a fault has been applied to the grid.

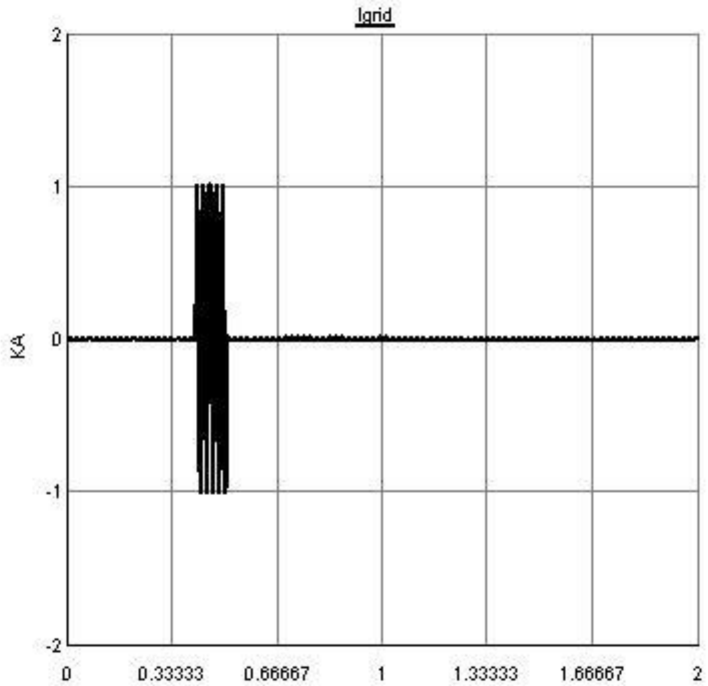

Fig 10. The grid current at fault case

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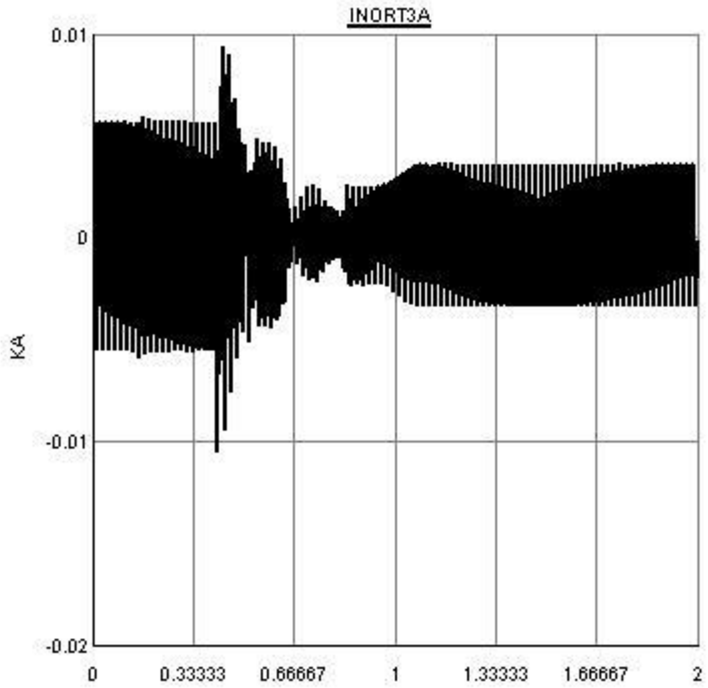

Fig11.The inverter current at fault case

Islanding case:

The next scenario which was tested was a microgrid transition from islanded to grid-connected mode. The microgrid consists of several distributed PV sources, loads, a battery which operates as a grid forming unit when the microgrid is in islanded mode and as grid following when in grid-connected mode. One PV source was used in PHIL setup and a hardware PV inverter together with a PV simulator was utilized.

The effect of islanding has been studied during the connection of perovskite solar cells to the grid.

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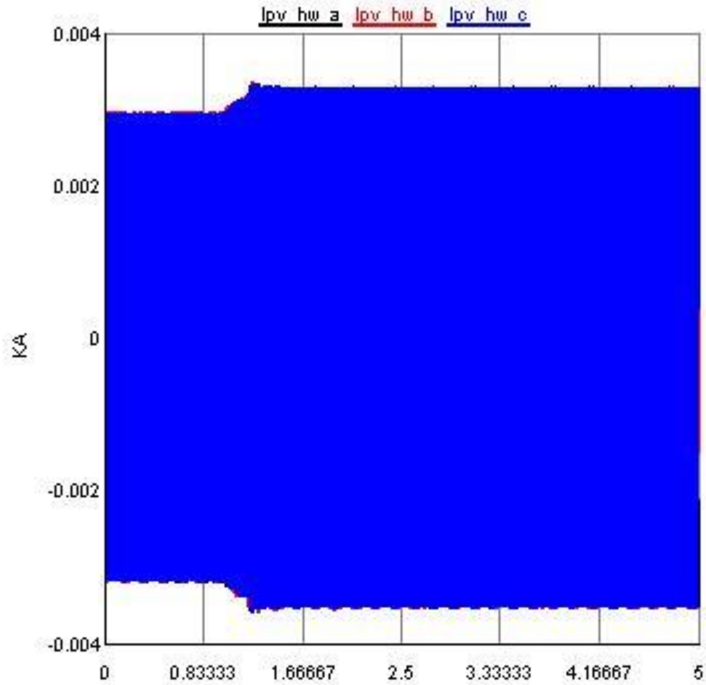

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Fig 12. The PV current

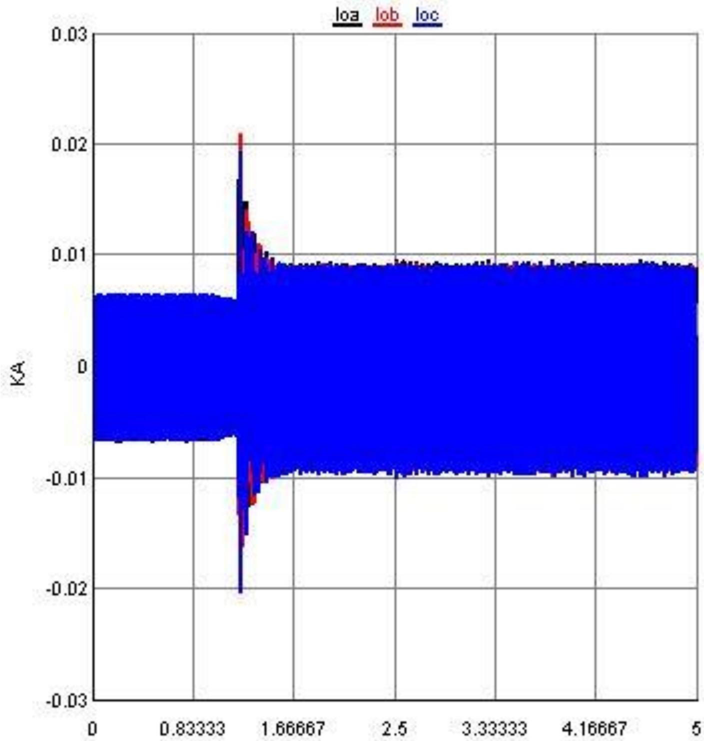

Fig 13. The Battery current

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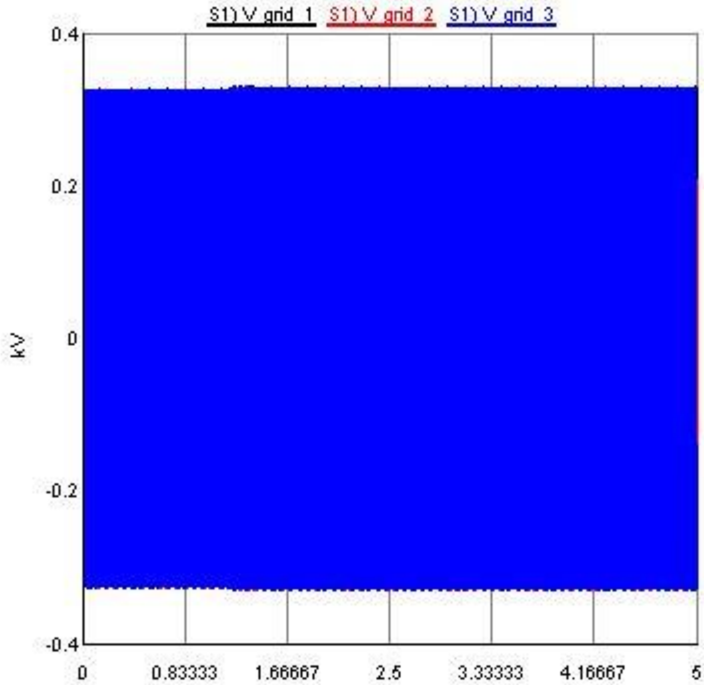

Fig 14. The grid voltage

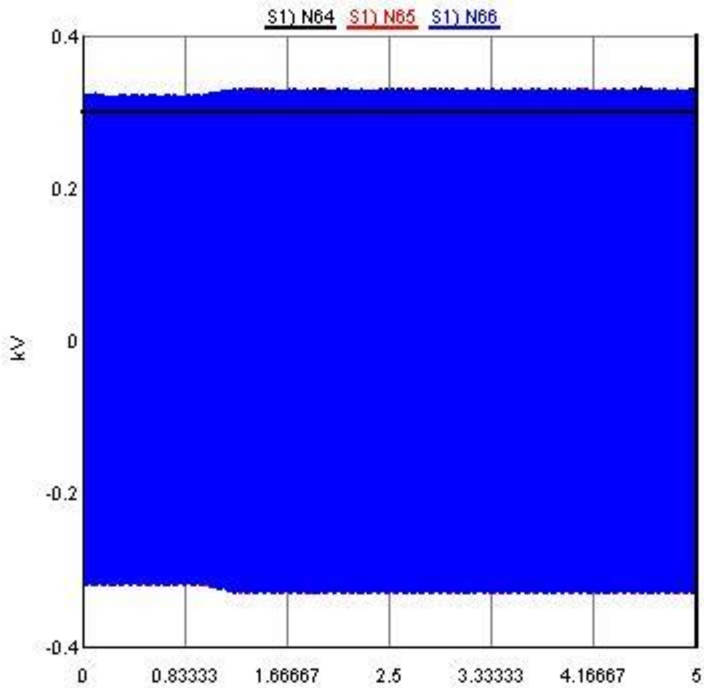

Fig 15. The PV voltage

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4.2 Conclusions

The outcomes behind this mission are:

- Increasing the power conversion efficiency of large scale perovskite solar cells to higher than 25% via interface engineering approach based on dyesenstization of both perovskite/HTL (Organic dyes) and perovskite/ETL (TiO_2 or TiO_2/SnO_2) through Dyes or Porphyrin, also increasing the system overall efficiency via integration of thermo-electric generator in the device back side in order to convert the dissipated heat to electric power.

- Enhancing the long-term stability of perovskite solar cells based on the interface engineering via dyesenstization approach and reducing the photocatalytic degradation of the perovskite solar cells via ETL doping.

- Investigating the perovskite solar cells in real application systems like connecting to electric grid (experimentally (laboratory model) and simulated via MATLAB software) where the perovskite solar cells array will replace a silicon one and a comparison study from the overall system efficiency and cost will be performed (Techno-economic study).

- Publishing scientific articles in high impact international journals.

The society benefit from mission can be showed as follows:

- Contribute to renewable energy sources (solar cell research) for sustainable energy supply.
- Sensitize the society about the importance of reliance on sustainable energy.
- Establishing scientific teamwork collaboration between multidisciplinary researchers.
- Transfer technology and knowhow to young postgraduate Egyptian students (M.Sc and PhD).
It is clear that the most of outcomes could be measure since learned new technology and knowhow will be easily transferred to students and the results will be published in high impact international journals.

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5 Open Issues and Suggestions for Improvements

During the lab access project, the user group member identified some issues for further work:

- Testing the solar cells under real conditions outdoor not only the emulated conditions via the softwares.

- More grid connections cases like voltage sag and voltage swell cases to study its effect on both the grid and the solar cells.

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