AC home appliances retrofiting for DC microgrids

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***Abstract*—This work demonstrates the possibility of retrofitting the AC home appliances for direct usage in DC microgrids using simple and low-cost methods. Nowadays, most of the appliances are using AC-DC conversion, which creates the possibility of direct connection of home appliances to DC voltage grids. The paper shows the practical results made on an air conditioning/heat pump system, an induction heating cooker and a refrigerator by retrofitting to a 350V DC grid.**

Keywords—home appliances, AC to DC retrofitting

I. INTRODUCTION

DC microgrids are facing unprecedent interest from researchers [1], [2], [3], [4] mainly because of the increasing usage of local renewable sources. Photovoltaic panels are naturally working in direct current, while others, like small wind turbine, can easily be implemented with DC output voltages. The technological development of home appliances used in everyday life has led to the use of continuous current more and more in almost all applications. The general structure of a high-performance home appliance is shown in Fig. 1, where the AC and DC areas are linked by AC-DC converter, which usually is a single-phase diode bridge rectifier.

The AC zone contains: the connection to AC grid, protection elements, EMI (electromagnetic interference) filter, AC load parts and the unidirectional AC-DC converter. The DC zone can contain a capacitive filter and the DC-DC load converter. In application where high quality of the power drawn from the public grid is required the DC aria can also contain an intermediary Boost converter for power factor correction (PFC) and the DC loads parts [3], [5], [6].

The main advantage of using DC power supply for home applications is related to the increased energy efficiency of the hole conversion chain by cancelling some of stages like the AC-DC rectifier and the PFC converter [7], [8], [9]. One of the main restrictions for commonly adopting DC microgrids is closely related with the availability of DC loads. The present paper is analyzing the possibility of transforming regular AC home appliances into DC ready loads. The objective is to demonstrate that a home appliance producer of different AC load devices can easily make them work also in DC microgrids.

The adaptation for a DC microgrid can be achieved in some cases by directly connecting the AC load to the DC power supply. Impediments for this conversion could be represented by the purely AC load parts, the AC grid monitor or the power factor correction converter which is used in medium and high-power home applications.

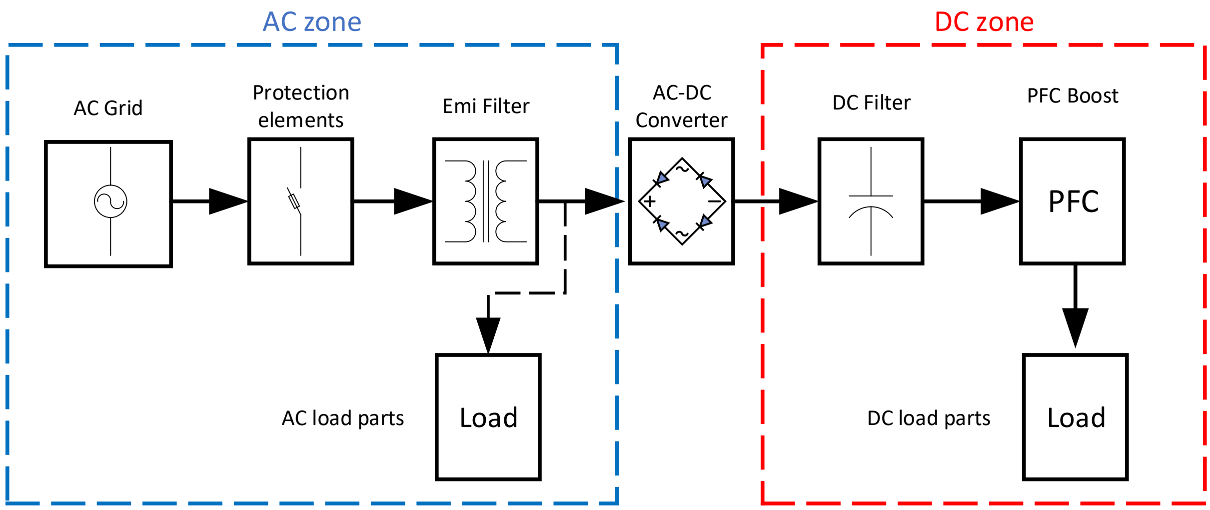

Fig. 1. The generalized structure of home appliances.

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II. HOME APPLIANCES DC RETROFIT

In the following, an air conditioning system with heat pump function, an inductive heating cooker and a refrigerator are being analyzed and transformed for proper function with DC power supply. It is important to specify that the appliances selected are inverter-based structures.

A. Air condition / heat pump system

This appliance consists of internal and external units (Fig.2) and is based on 3D Inverter structure, meaning that all the motor used are controlled by electronic converters. The indoor unit electronic board presented in Fig. 3 is divided in three main sub-circuits, according to the types of electrical currents involved:

a) AC circuits zone contains: the connection to AC grid, protection elements, electromagnetic interference filter - EMI and full bridge rectirier.

b) DC circuits zone contains: the power supply for cooling ventilator and the power supply for low current circuits.

c) Low currents circuits provide the necessary command and control signals for heating or cooling operating modes and the communication between the outdoor and indoor units.

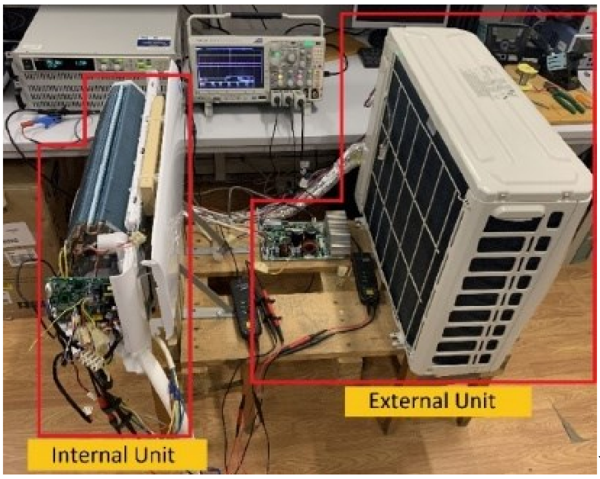

Fig. 2. Air condition – heat pump experimental stand.

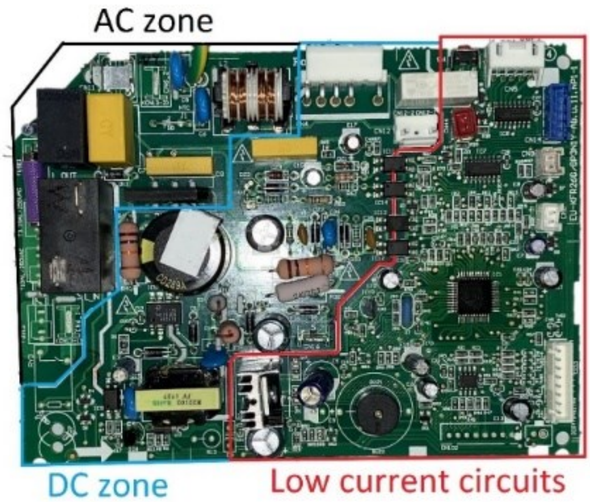

Fig. 3. Internal unit electronic board of air condition / heat pump system.

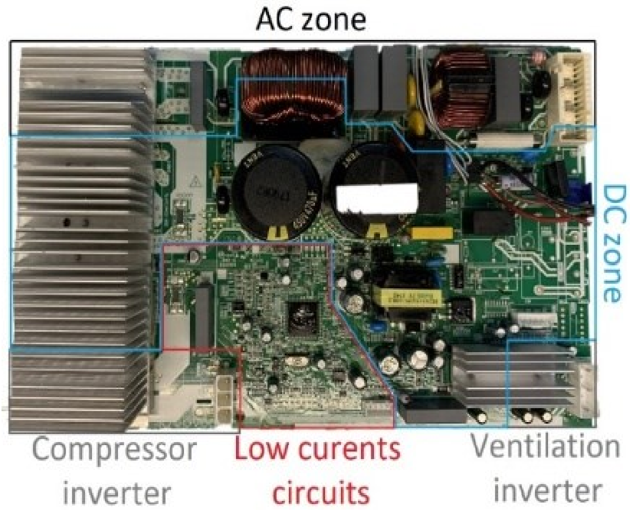

Fig. 4. External unit electronic board of air condition / heat pump system.

The structure and the functionalities of the external unit electronic board (Fig. 4) are related with the type of electric currents and is divided in three zones:

a) AC circuits zone: the connection to AC public grid, protection elements, EMI (electromagnetic interference) filter and the diode bridge rectirier.

b) DC circuits zone contains: the Boost converter for power factor correction, two DC-AC converter for ventilation and compressor motors and DC-DC power supply for the low currents circuits.

c) Low currents circuits provide the necessary controlling signals for heating or cooling operating mode and the communication between units.

For proper functioning of the air condition/ heat pump system, the processors of the indoor and outdoor units must communicate, the signals of the data communication protocol it is transmitted in both directions on the AC line wires. For the retrofit of the air conditioning DC power supply the right signals for the data communication are needed (Fig. 5). For this to be accomplished the N (neutral) wire of the AC grid must be connected to the negative (-) DC power supply, whereas the L (line) wire to the positive (+) DC power supply. The right polarity for the DC zone is achieved due to full bridge diode rectifier.

Because of power quality standards, the outdoor unit has a boost type power factor correction (PFC) circuit. In the case of using a DC power supply this intermediary circuit is unnecessary.

In view of this, in the Fig. 6-9, proper analyses are made to establish the right retrofit approach:

1) AC grid supply without PFC (power factor correction) case (Fig. 6): this situation occurs at low power when the compressor engine is at low speeds (starting it), the transistor in the Boost converter composition is not controlled. V_{CE} is the voltage between the collector and emitter of the Boost transistor, V_{dc} represents the continuous supply voltage and I_{ac} is the alternative current absorbed from the public grid.

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2) AC grid supply with PFC case (Fig. 7): this case occurs when the electrical power absorbed by the system is high. The Boost PFC circuit is active and the input curent is quasi sinusoidal.

3) DC power supply without bypassing the PFC circuit (Fig. 8): when the output voltage of the PFC converter (V_{PFC}) is above 400 V, the current absorbed from the DC grid is zero. In this approach the electronic circuit is not working properly.

4) DC power supply bypassing the PFC circuit (Fig. 9): to eliminate the interruptions operation from the previous case, the elements of the PFC Boost converter are canceled. The supply current I_{dc} is more lineat then the previous case.

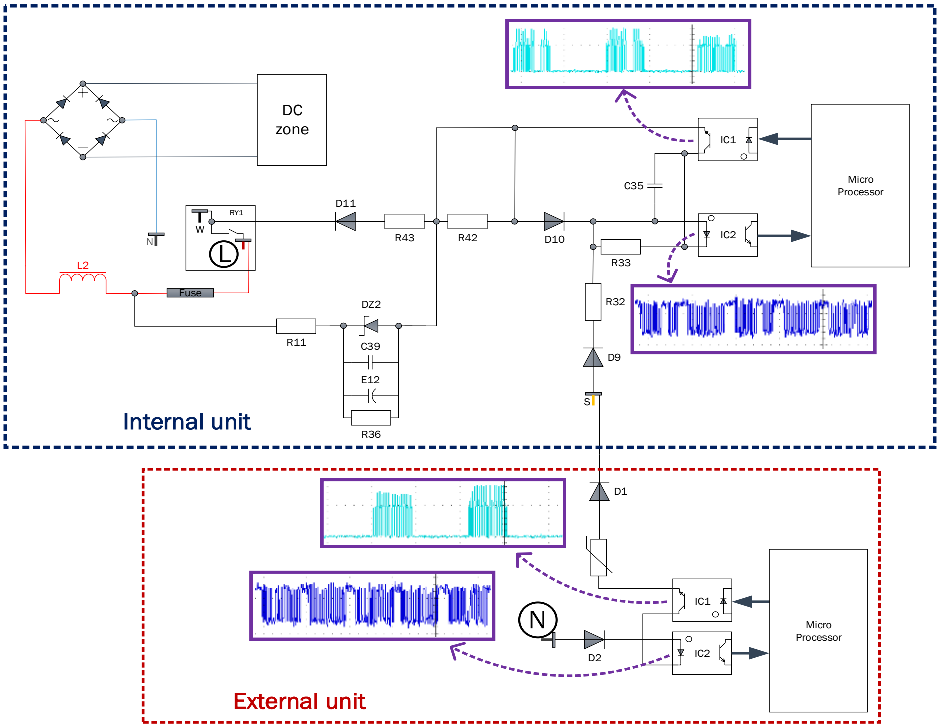

Fig. 5. Communication circuits specific for air condition / heat pump system.

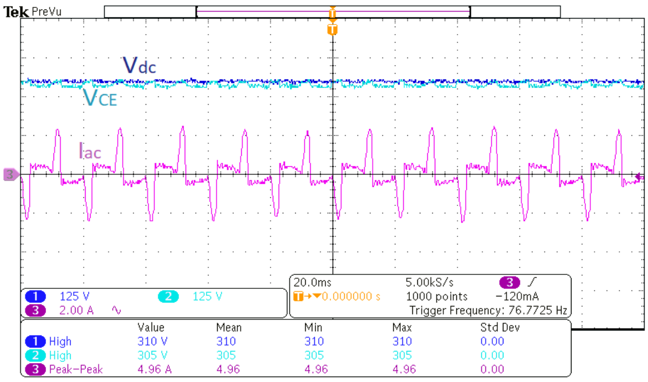

Fig. 6. AC grid supply without PFC (power factor correction).

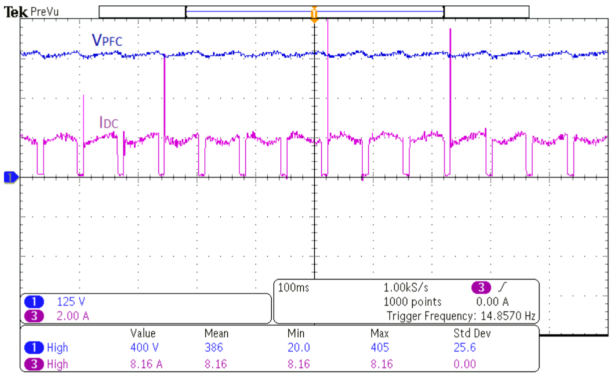

Fig. 8. DC power supply without bypassing the PFC circuit.

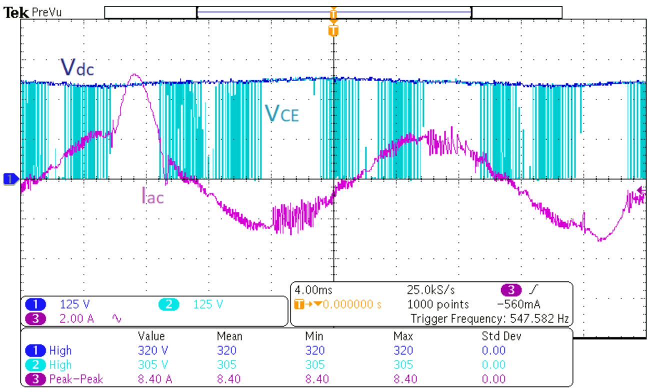

Fig. 7. AC grid supply with PFC (power factor correction).

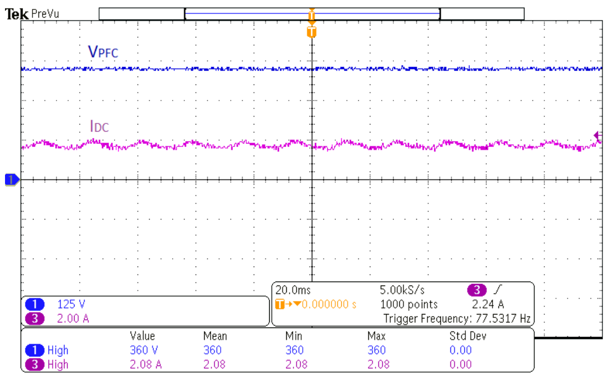

Fig. 9. DC grid supply without PFC Boost converter.

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B. *Induction heating cooker*

The induction heating appliance from Fig. 10 is with two cooking areas with maximum electric powers equal to 3500 watts. This appliance has two identical: electric main boards, control panels and induction coils, one for each cooking areas.

The structure of the electronic circuits (Fig. 11) is respecting the general structure of home appliances (Fig. 1), without the power factor correction converter. The circuit is divided in three zones according to the type of currents being circulated, these are the following:

a) AC circuit zone consisting of AC grid connection elements, overcurrent and overvoltage protections, inductive and capacitive filters and the full bridge diodes rectifier.

b) DC circuit zone contains the rectifier capacitive filter and the power electronics converter with parallel resonant circuit.

c) Low currents circuits contains the elements of monitoring and control of the entire induction heating system. The whole process is controlled by a microcontroller.

The resonant converter works using the zero voltage switching (ZVS). More, in order to comply with the power quality standards, the circuit involves the continuous zero-crossing detection of the AC grid voltage and the switching is done accordantly to provide high power factor (Fig. 12). This voltage detection is becoming an issue when retrofitting to DC power supply. The solution adopted is to emulate this signal by a pulse width modulation (PWM) signal with the double switching frecvency (f_{switch}=100 [Hz]) and a 98 % duty cycle and applied for testing with AC input voltage (Fig. 13).

The waveforms retrofit results by using a DC power supply are being shown in Fig. 14.

Fig. 10. Induction heating cooker experimental stand.

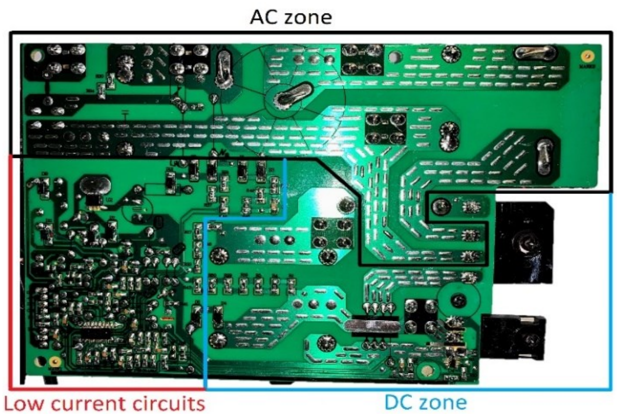

Fig. 11. The structure of electronic board specific for Induction heating cooker.

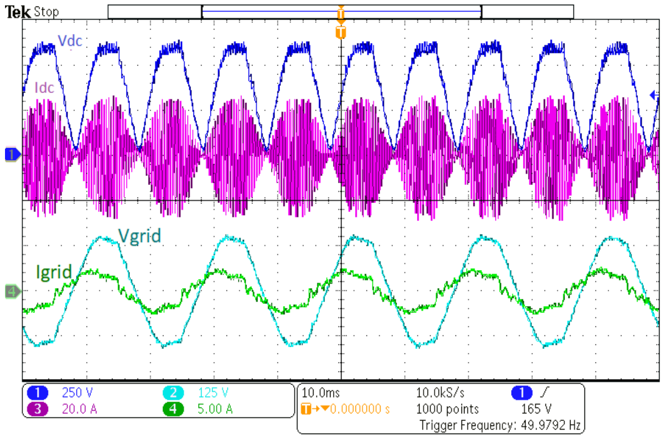

Fig. 12. AC grid power supply waveforms specific for induction heating cooker.

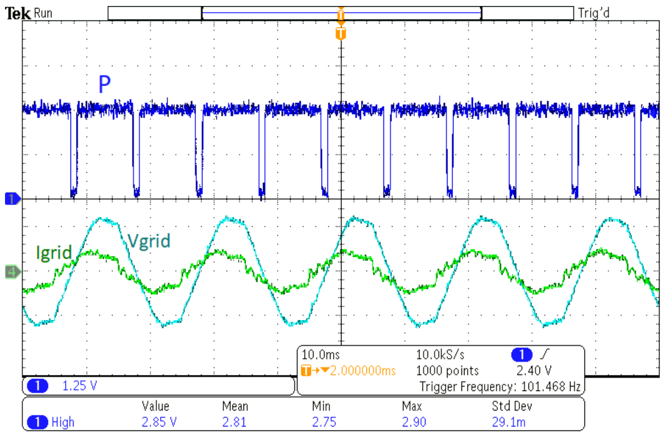

Fig. 13. The emulated of AC grid in case of induction heating cooker.

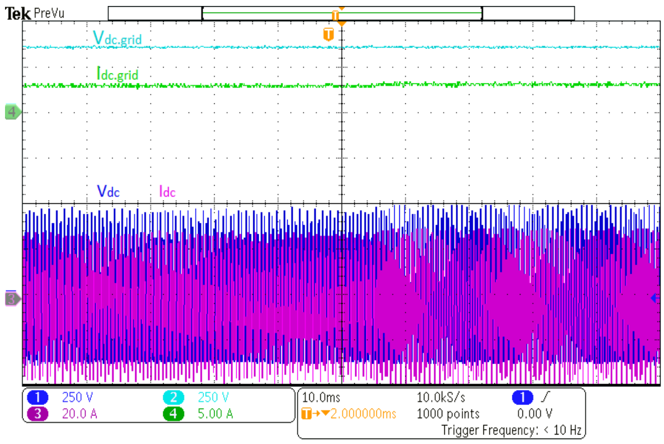

Fig. 14. DC grid power supply waveforms specific for induction heating cooker.

C. *The Refrigerator*

This refrigerator home appliance (Fig. 15) works based on a linear compressor powered by a three-phase inverter and it allows a direct connection of the DC grid power supply. Because of low electric power consumed (220 [kW/year]) this device is not equipped with power factor correction converter which theoretically allows a direct connection to the DC power.

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Fig. 15. The refrigerator experimental stand.

The electronic board divided by the three current types zones is illustrated in Figure 16, whereas:

a) AC circuits zone contain protection and filters elements, the resistors used for defrosting and the single-phase diodes rectifier.

b) DC circuits zone comprising of the capacitive filter, refrigerator cooling fan, LED lighting and the three-phase inverter for the linear compressor.

c) Low currents circuits containing all the control and communication through the Smart Diagnosis function.

The waveforms powered by AC grid and DC grid can be seen in the Fig. 17 and Fig. 18 where V_{grid} and I_{grid} are the grid voltage and current. V_{conv} and I_{conv} are the voltage and current between the inverter and linear compressor.

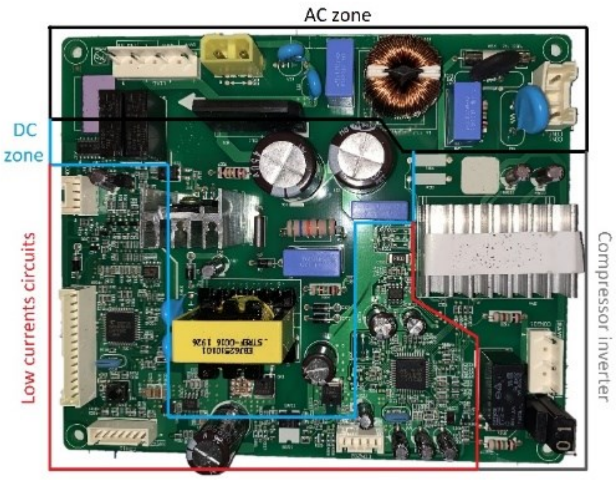

Fig. 16. The refrigerator electronic board.

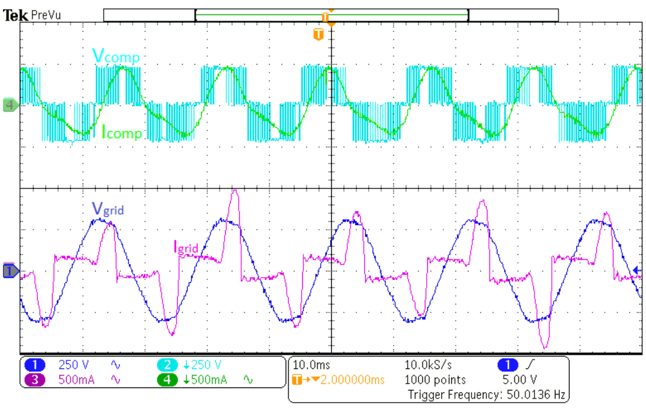

Fig. 17. AC grid power supply waveforms specific for the refrigerator.

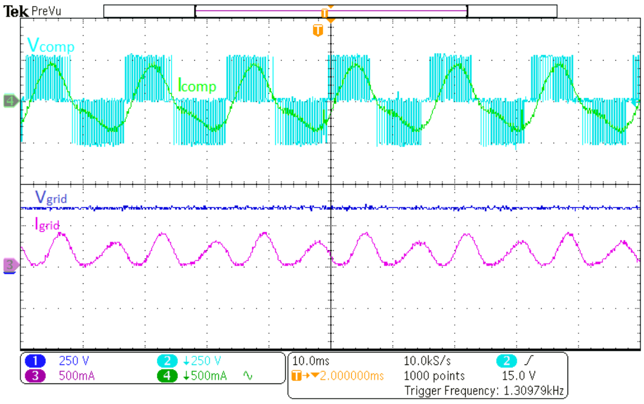

Fig. 18. DC grid power supply waveforms in case of the refrigerator.

III. CONCLUSIONS

This paper presented the DC grid supply retrofit of three home appliances designed to operate powered from the AC grid.

The first appliance was an air conditioning/ heat pump system with power factor correction Boost converter. For the DC power supply retrofit, the PFC Boost converter was bypassed, and care should be taken regarding the proper polarization for the communication circuits between the internal and external units.

The second appliance retrofitted, for working in DC grid, was an induction heating cooker. Its adaptation involved the use of an additional circuits to emulate the zero-cross detection of the AC voltage. That circuit generates a PWM signal at the frequency of 100 [Hz] with a 98 % duty cycle.

The refrigerator appliance retrofit has operated directly powered from the DC grid, the only necessary change being the limitation of the current through the defrosting resistances using a current shunt.

All these three cases prove the possibility of retrofitting the AC home appliances for direct usage in DC microgrids using simple and low-cost methods.

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