Modularized, Reconfigurable and Bidirectional Charging Infrastructure for Electric Vehicles with Silicon Carbide Power Electronics (MoReSiC)

Deliverable D1.5 (Month 42)

Title: " Efficiency oriented algorithm implemented in PFLC"

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Executive summary

The Deliverable includes the description of the efficiency-oriented control algorithm that considers several converters from the advanced charging station and alters some parameters, e.g., DC-link voltage, to maximize the possible efficiency, which leads to lower power losses, less heat dissipation, and helps to preserve energy. The concept is shown and described for the grid converter interconnected with a single isolated DC-DC EV converter, and the idea is validated via experimental tests. Even though the concept is investigated for a specific two-converter connection, a similar approach can be adopted for all the converters in the system. Thus, the total energy efficiency of the advanced charging station can be slightly improved. However, the gain in efficiency is not huge, and the possible problems with the need to lower the DC-link capacitance to provide proper dynamics for the variability of the voltage deem the solution questionable in practice.

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1. Efficiency-oriented control method with variable DC-link voltage

Conventionally, when two or more converters are interconnected via a DC-link circuit, the voltage at the DC-link capacitor is constant. This is also the case for the advanced charging system considered within the MoReSiC project, where the voltage reaches up to 1500 V. However, there is a concept to control the DC-link voltage variably to possibly alter the operating points of the converters connected to the DC-link, which may affect several core performance indicators, e.g., power losses or current ripples. To this end, such an approach has been investigated within the project and is summarized in this Deliverable.

2. Interconnection of the AC-DC grid converter and the isolated DC-DC converter with the loss-optimized algorithm

To validate the concept of variable DC-link voltage in a simple form, the considered situation is reduced to the power flowing from the grid to an EV via the AC-DC grid converter and the isolated DC-DC converter (with a power of up to 10 kW). The scheme of the system of interest is depicted in Fig. 1, where the grid converter is in the ANPC topology, and the isolated DC-DC converter is founded on the ANPC leg on the primary side and H-bridge on the secondary side.

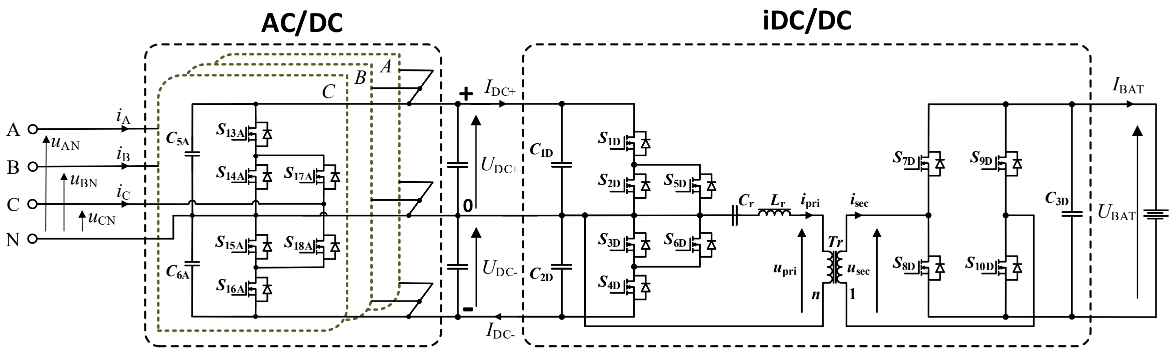


Fig. 1 Scheme of the two-stage AC-DC system consisting of an ANPC grid converter and ANPC-HB isolated DC-DC converter with a common three-pole DC-link circuit.

The block scheme of the efficiency-oriented control for this specific two-stage conversion system is shown in Fig. 2. The general concept of the method is founded on the idea that based on known efficiency characteristics for each converter [$\eta=f(U_{DC})$] which can be either assessed analytically or via a series of experiments, the main power flow controller gives a reference value of a specific DC-link voltage U_{DC} to improve the sum efficiency of the conversion system (from the safe operating range of the system). Then, the AC-DC converter operates in such a way as to follow this reference voltage and provide optimal conditions for itself, and the isolated DC-DC converter is interconnected to the same DC-link, which results in improved performance in terms of efficiency.

In general, this method does not affect the basic operation of the DC-DC converter, which has to follow a specific characteristic in terms of establishing appropriate battery-side voltage U_{BAT}. This characteristic – a load profile – can be assumed either in the function of the battery voltage (see Fig. 3a) or according to the state of charge (SOC) of a battery (as depicted in Fig. 3b).

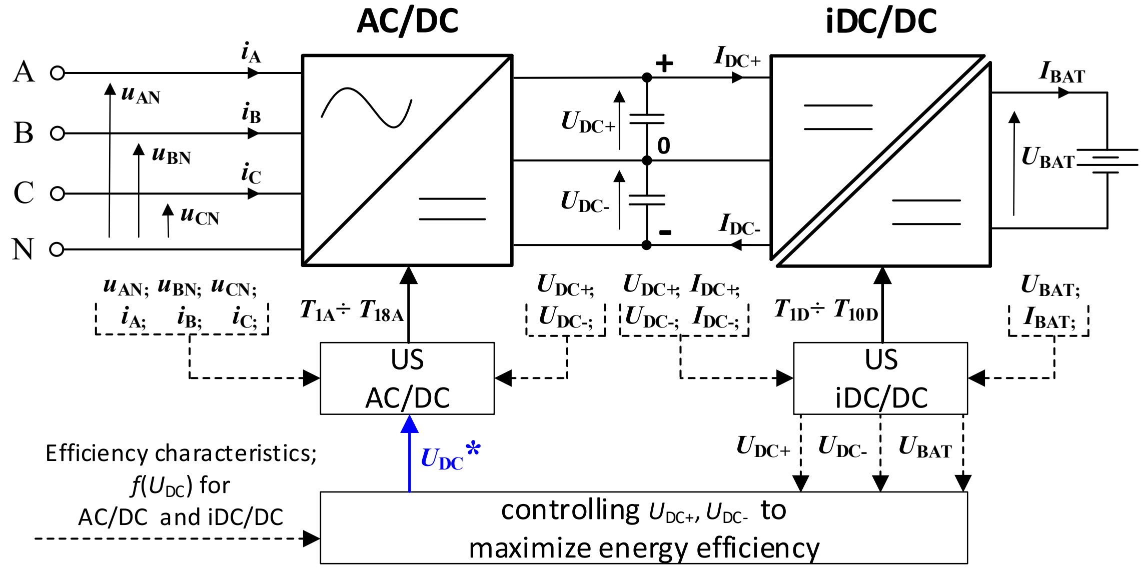


Fig. 2 Scheme of the efficiency-oriented algorithm for an interconnection of a grid converter and an isolated DC-DC converter.

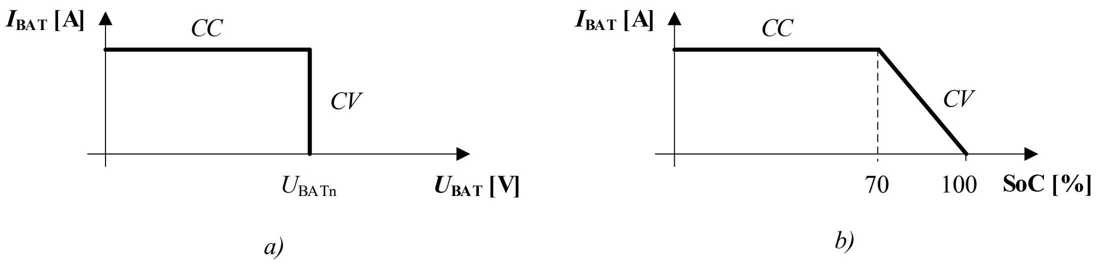


Fig. 3 Assumed charging profiles for the battery: (a) based on battery voltage, (b) according to SOC.

3. Experimental validation

To validate this concept, a series of experimental tests have been performed. The converters built for the system have been employed here. The grid AC-DC converter in ANPC topology allows for bidirectional operation with a maximum power of 20 kW, and is shown in Fig. 4. Furthermore, the isolated series-resonant dual-active bridge (SRDAB) acting as the isolated DC-DC converter is bidirectional as well, however with a maximum power of 10 kW. The converter is exhibited in Fig. 5. Given the limit induced by the DC-DC converter, the performed study was limited to up to 10 kW. A detailed description of each of the converters employed can be found in other WPs. Specifically, the grid converter is explained in WP4, and the isolated DC-DC converter is investigated in WP3. The efficiency measurements were taken using a precise WT5000 Yokogawa power analyzer.

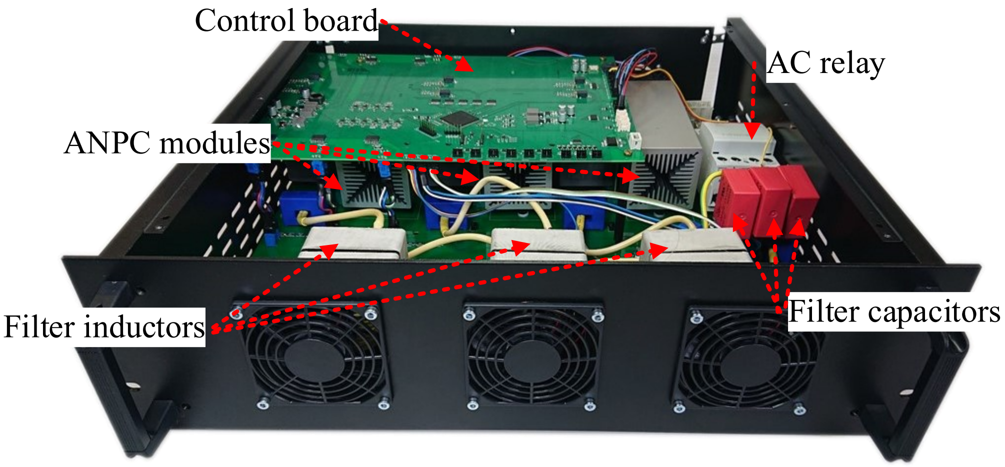


Fig. 4 Photograph of the experimental model of the grid converter.

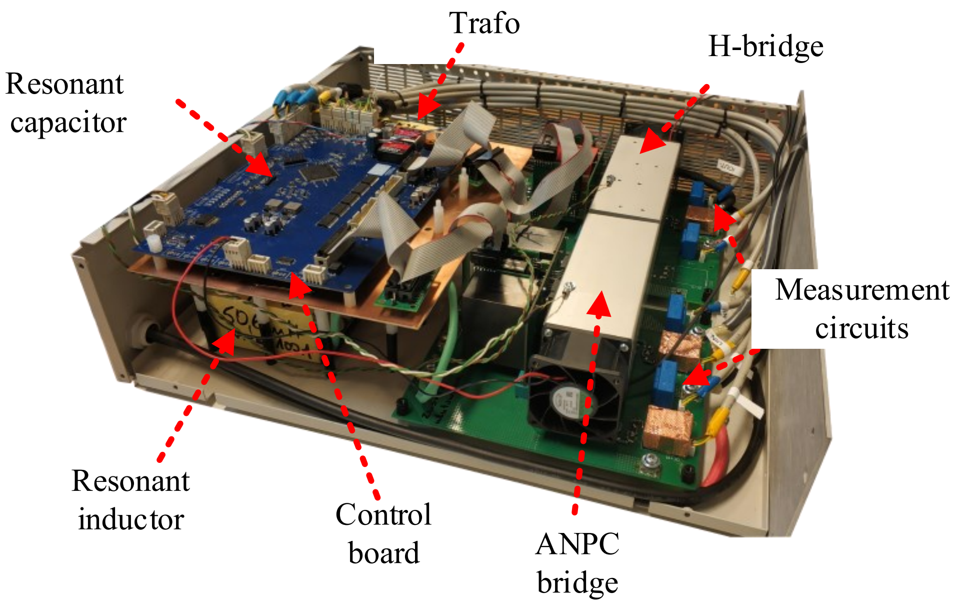
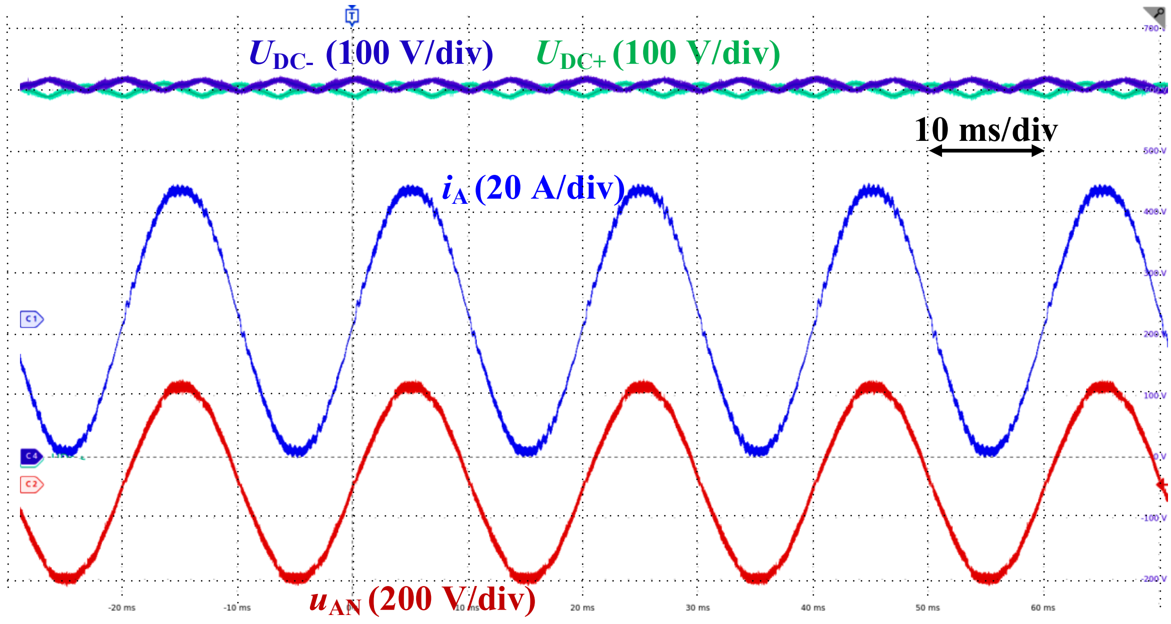
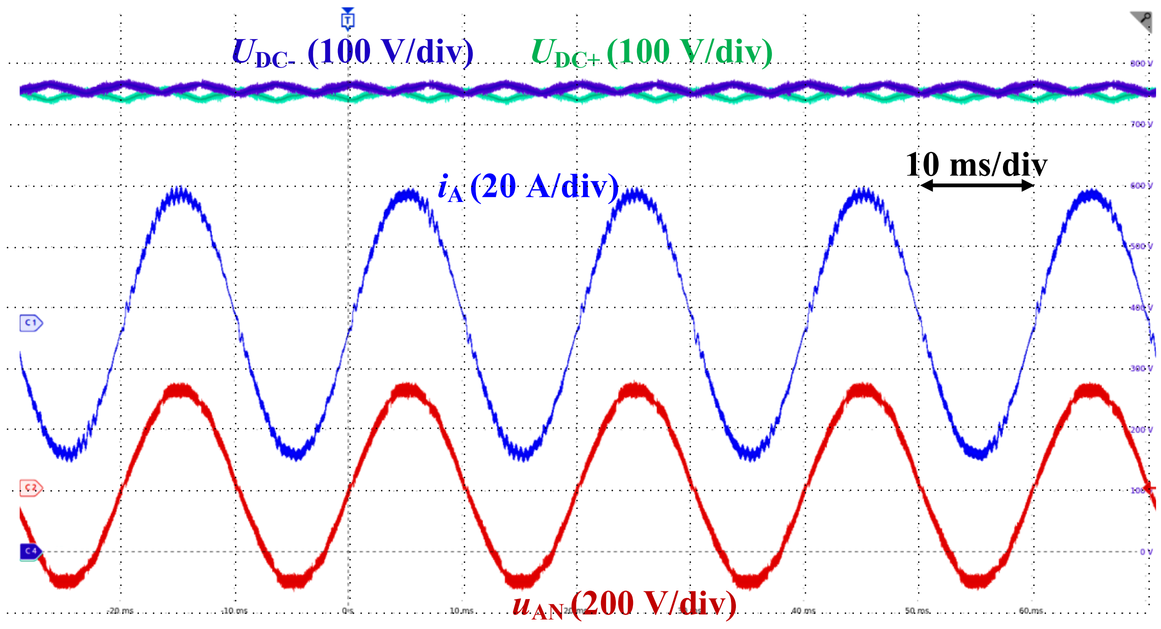


Fig. 5 Photograph of the experimental model of the isolated DC-DC converter.

First, the correct operation of the ANPC converter was tested in the rectifier mode at rated power and a DC-link voltage of 1200 V, which corresponds to operation with the lowest possible DC-link voltage with the assumed charging profiles and battery parameters. Then, for the same power, the operation of the system was verified at a DC-link voltage of 1500 V. The results from the tests are presented in Fig. 6. In both cases, the grid converter works correctly - the grid current and voltage are in phase. Moreover, both tests are characterized by low values of THD coefficient below 2%, equivalent to high-quality grid waveforms. Furthermore, in both cases, the DC-link voltage value ripple does not exceed 2.8%.



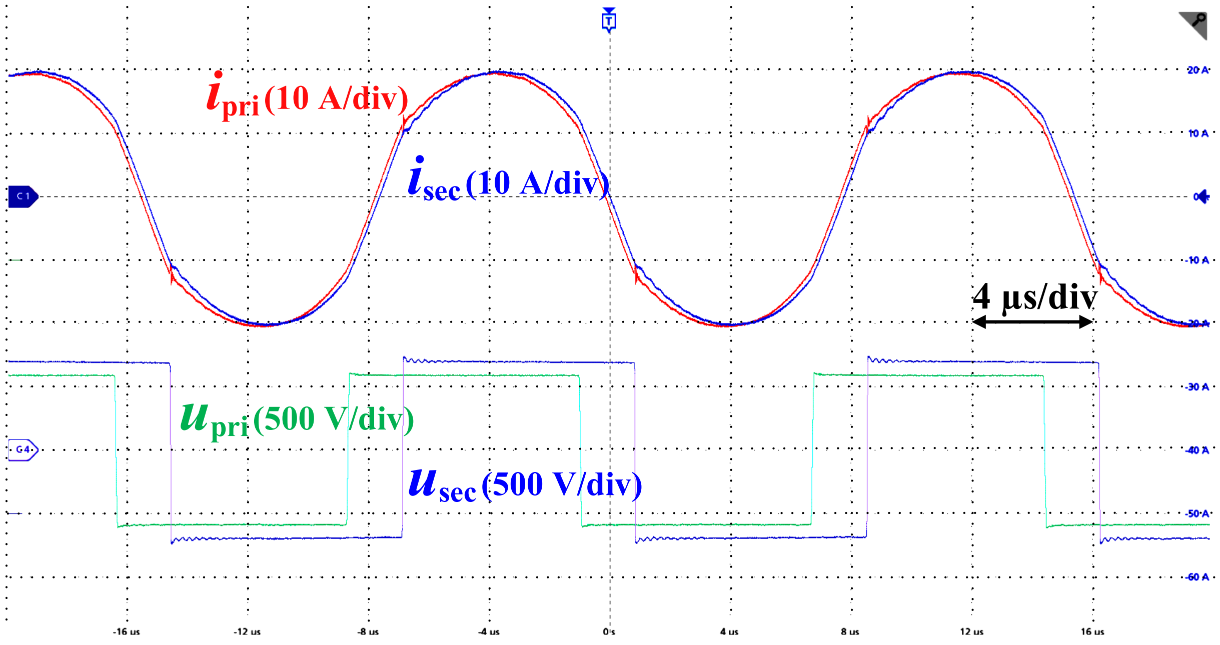
a)



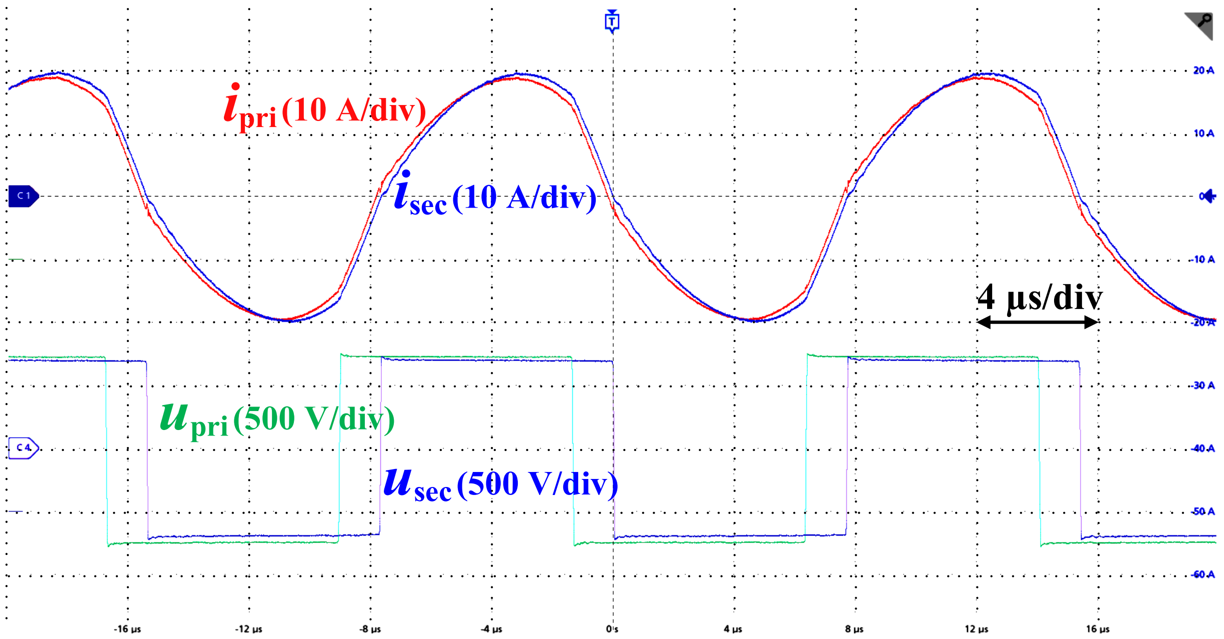
b)

Fig. 6 Experimental results of the grid converter at a power of 20 kW and DC-link voltage at (a) 1200 V and (b) 1500 V.

Then, the operation of the SRDAB converter was tested at a power of 10 kW, a battery voltage of 700 V, and DC-link voltages of 1200 V and 1500 V. The results of these tests are shown in Fig. 7. For both values of the DC-link voltage, the current flowing through the primary and secondary windings of the transformer are sinusoidal, which has a positive effect on the operating conditions of the resonant circuit elements and the transformer itself and allows for soft-switching of the transistors. The voltages on the primary and secondary sides have a rectangular shape and are shifted relative to each other by an angle that ensures the appropriate power at the output of the system.



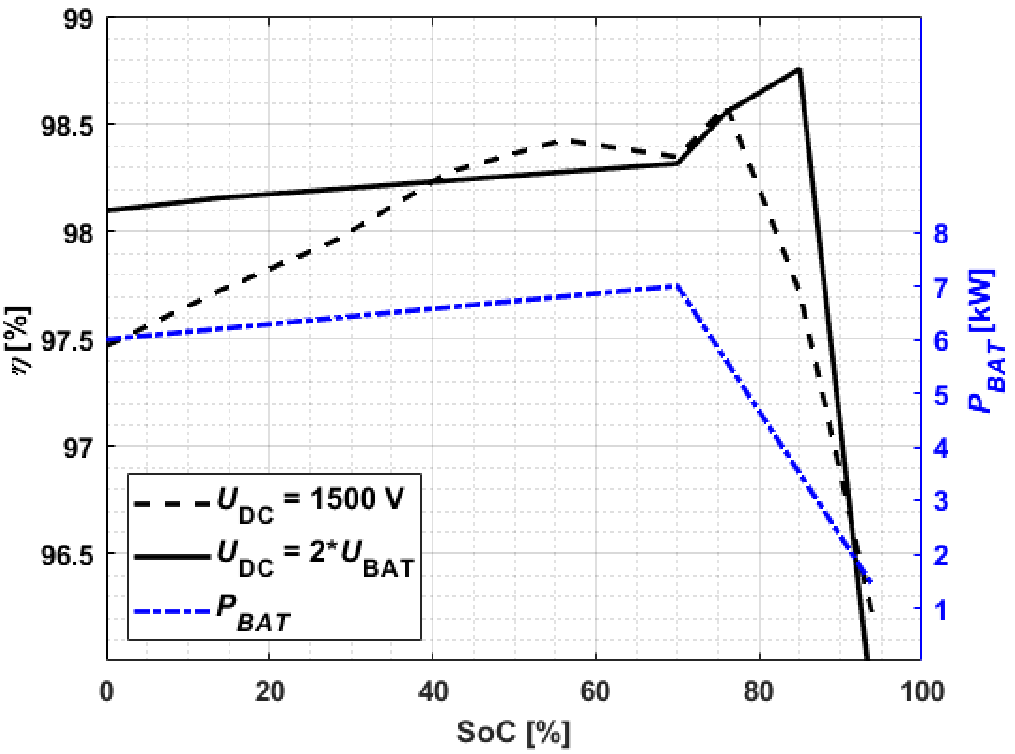
a)



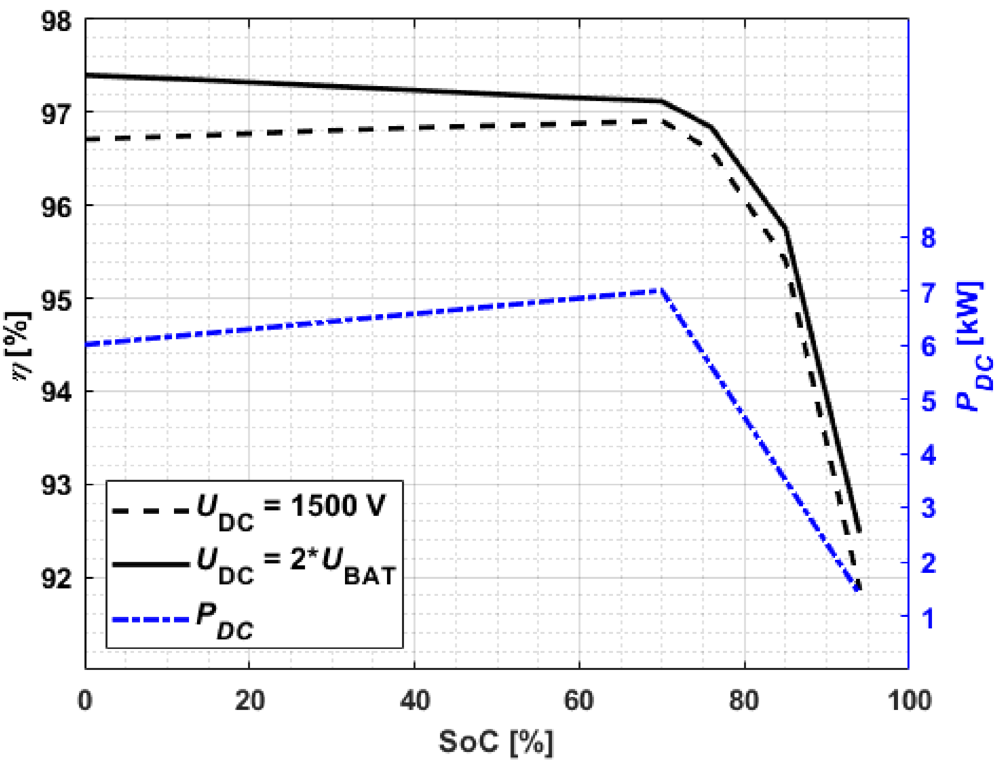
b)

Fig. 7 Experimental results of the SRDAB converter at a power of 10 kW and DC-link voltage at (a) 1200 V and (b) 1500 V.

After validating the correct operation of both converters at different DC-link voltage levels, the energy efficiency of the AC/DC and DC/DC converter was measured as a function of the SoC battery charge state. Energy efficiency characteristics illustrating the results of these tests are plotted in Figure 8.



a)



b)

Fig. 8 Efficiency of the converters and their power in the function battery SOC for different DC-link voltage levels: (a) for the ANPC grid converter, (B) for the DC-DC SRDAB converter.

Based on the characteristics presented in Fig. 8, the energy efficiency of the set of ANPC and SRDAB converters for two battery charging profiles was plotted and presented in Fig. 9. To compare the proposed efficiency-oriented algorithm with a conventional method, a test with constant 1500 V DC-link voltage was plotted as well. As can be seen, depending on the state of charge of the battery, the presented DC-link voltage regulation method allows for increased efficiency conversion to approximately 1.3 percentage points compared to the conventional method.

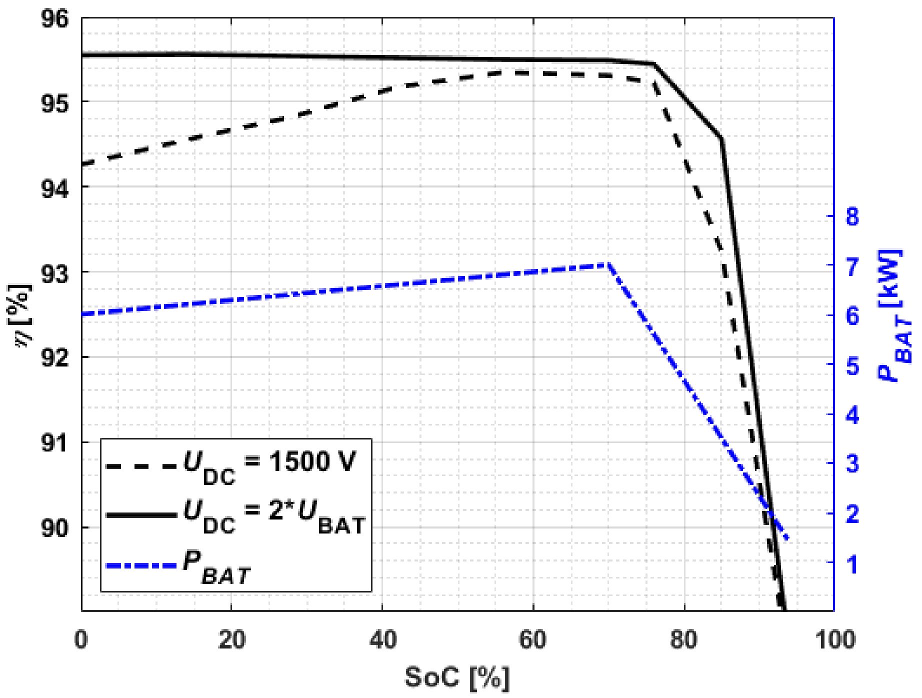


Fig. 9 Characteristics of the energy efficiency of a set of AC/DC and DC/DC converters for charging the battery with different voltages of the DC-link voltage as a function of the state of charge of the battery.

While the gain in energy efficiency employing the proposed method is visible, it is still quite low. Furthermore, to fully use the method with variable DC-link voltage with proper dynamics, the DC-link capacitance should be relatively low, which is in opposition to the conventional DC-link approach, as well as might induce some issues related to high DC-link fluctuation in a specific operating point. Thus, while efficiency improvement is definitely an advantage, the disadvantages may be highly debatable when using the proposed solution. Thus, a conventional approach to the DC-link voltage has been decided on for other tests in the project.

3. Conclusion

In the presented report, an efficiency-oriented algorithm is proposed. The developed control concept relies on actively altering the station DC-grid voltage, including the efficiency characteristics of the converters, to maximize energy efficiency. As validated in the experimental study, employing this approach yields lower power losses compared to conventional control with static DC-link voltage and thus enhances the operation of the advanced charging station, especially considering the aim to preserve energy and cost. However, the gain in efficiency is not immense, and the possible issues with the need to lower the DC-link capacitance to provide proper dynamics for variably controlling the DC-link voltage may deem the solution questionable in practice.