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

Deliverable D6.2 (Month 42)

Title: "Report with complete experimental tests of the EV charging system in all operation modes"

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Executive summary

The deliverable includes the description of complete experimental tests of the advanced EV charging system in all considered operation modes without the addition of the PV converter. Thus, the deliverable includes basic scenarios with the grid converter, EV isolated dc-dc converters, and the non-isolated dc-dc converter for the battery energy storage interfacing. The considered operation modes include slow charging of EVs via the grid (mode A), slow charging of EVs via the grid and the battery energy storage (mode B), fast charging of an EV from the grid with several converters in parallel (mode C), grid support with the power drawn from the energy storage (mode D), grid support from the EVs (mode E), island operation with the power flowing from the energy storage to the EVs (mode F). In summary, all initially considered modes are performed in experiments, validating the concept and experimental models of the advanced charging station.

This deliverable has been naturally expanded with the addition of the EV converter after the project annex inclusion. Thus, it is recommended to look at Deliverable D6.3 which basically replaces this Deliverable D6.2, as it contains the very same data shown here, plus the additional results including the PV converter.

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1. The advanced EV charging station

The whole advanced electric vehicle (EV) charging system consists of four types of bidirectional power electronics converters: a three-level active rectifier with a three-port DC output to interface with a 3-phase grid, non-isolated three-level DC/DC converter interfacing energy storage (ES), isolated DC/DC converters interfacing EVs, and a unidirectional, three-level, non-isolated DC/DC converter. In this Deliverable, the PV is not included, as it showcases the basic modes, from the initial project draft. For full experimental study please refer to Deliverable D6.3.

The block diagram of the full advanced EV charging system is presented in Figure 1. The system is explained in detail in D6.1 and shown here only for a quick reference for the experiments for each operation mode.

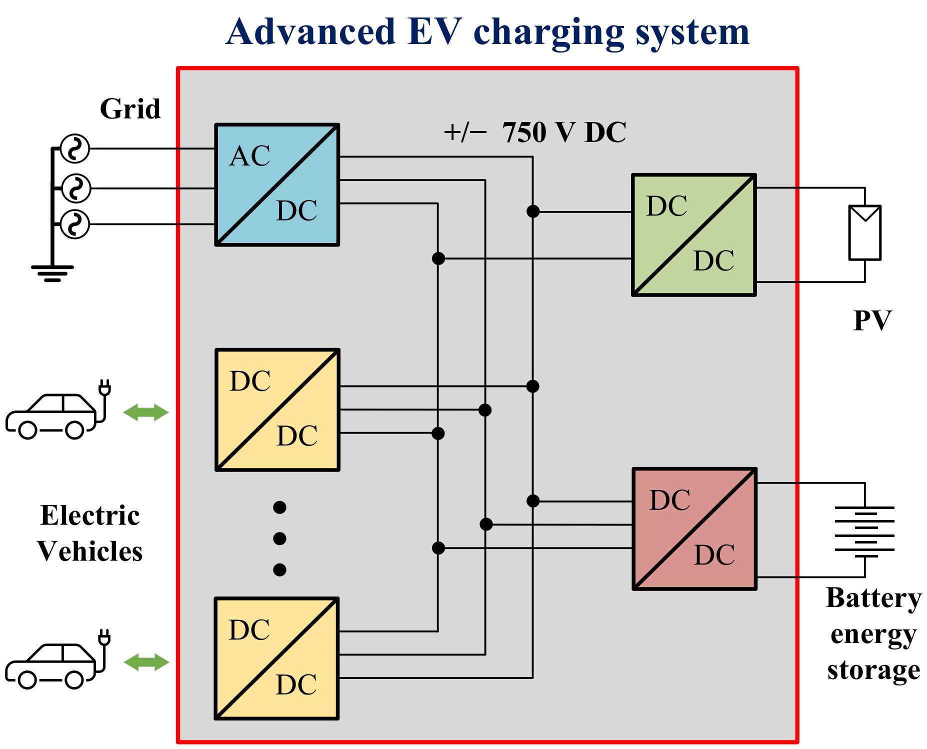

Fig. 1 Scheme of the advanced EV charging system.

2. Operation modes

In this section, experimental results will be shown for each operation mode and discussed on, exhibiting the possibilities of the station and validating the experimental model of the system.

a) <u>Mode A: slow EV charging from the grid</u>

In this mode, two converters are employed, the grid converter and EV converters (one or two). An exemplary result is depicted in Fig. 2, where a single EV converter is charged with up to 10 kW of power. Here, a common battery charging CC (constant current)-CV (constant voltage) characteristic is emulated. As can be seen, the power is slowly rising, until it reaches a maximum value of 10 kW, then, for a certain amount of time, constant current is delivered. Later, after the battery SOC (state of charge) reports higher values, the mode shifts to CV, and thus, the power is slowly lowered.

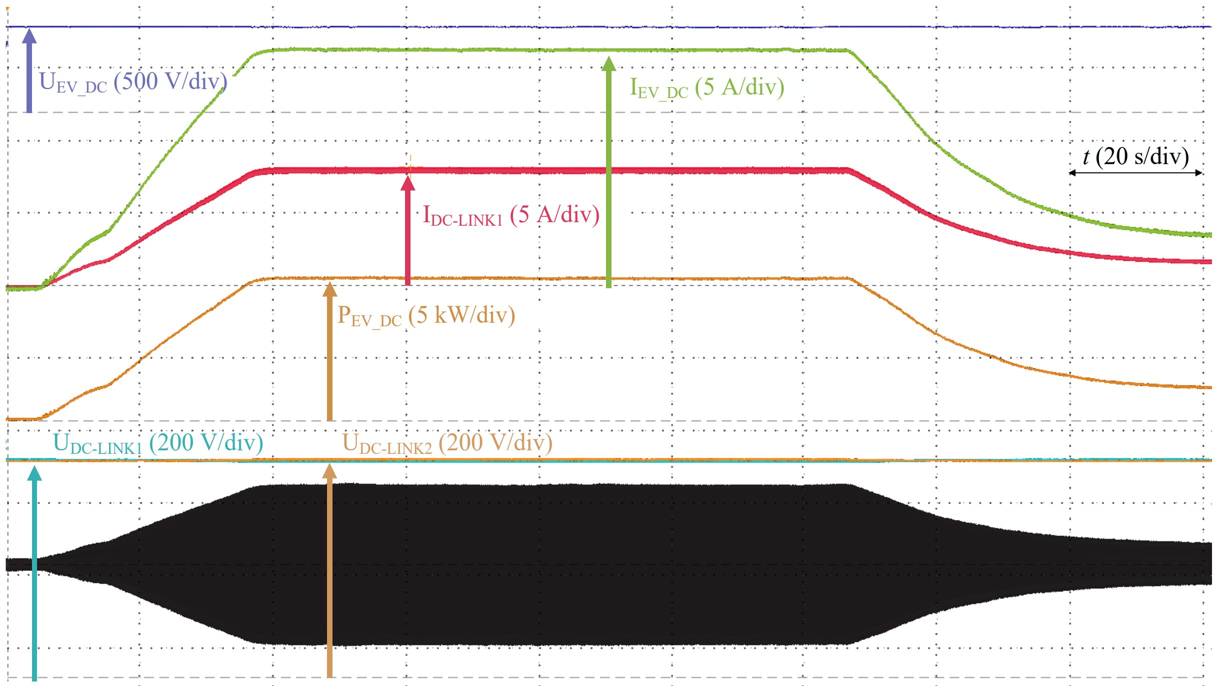

Fig. 2 An emulation of CC-CV charging of a single EV with one EV converter with the power drawn from the grid (up to 10 kW).

The efficiency characteristics in this scenario, for two different DC-link voltages of 1500 and 1200 V, are depicted in Fig. 3. As can be observed, higher voltage becomes more efficient at higher power ratings. All in all, given that this is two-stage conversion, the efficiency is a satisfactory level. Furthermore, it is worth noting that the experimental model is scaled, and in actual application with several hundred of kWs the efficiency would be higher.

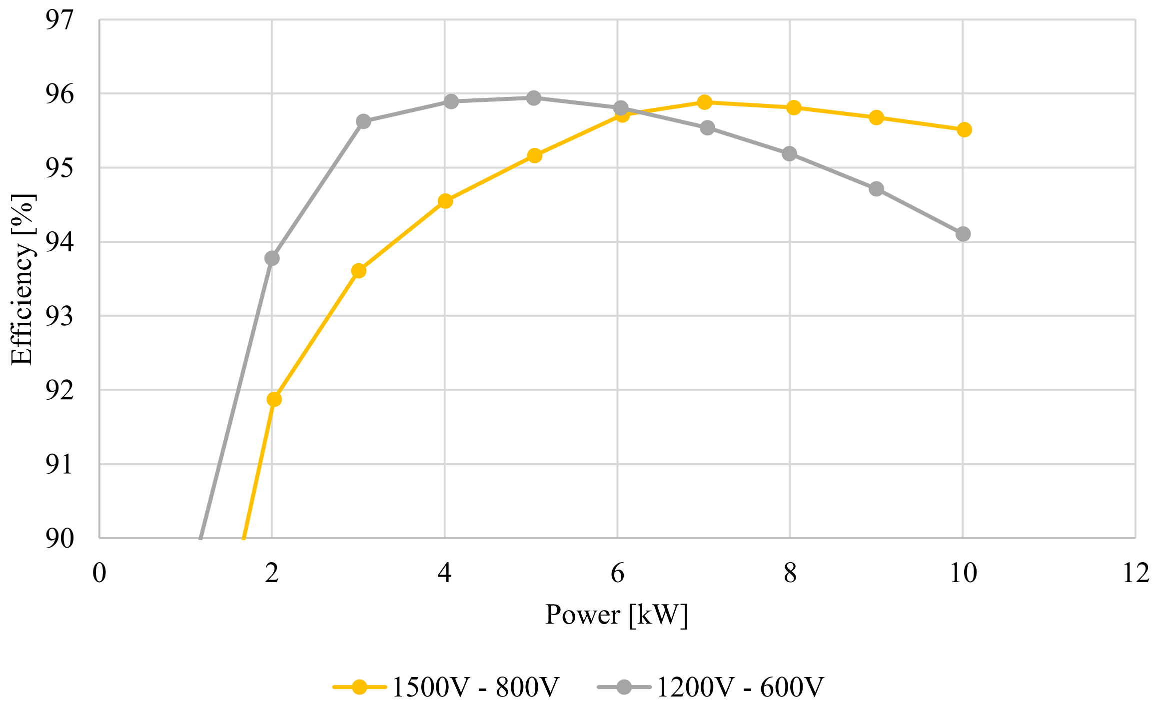

Fig. 3 Efficiency characteristics of single EV charging the power drawn from the grid (up to 10 kW).

Another possible scenario within this mode is depicted in Fig. 4. Here, the employed converters stay the same. However, another EV converter is employed to maximize the possible power drawn from the grid (up to 20 kW). Thus, according to the results in Fig. 4, the CC-CV charging processes are emulated for each EV separately. Therefore, at an overlap area, the momentary power reaches 20 kW.

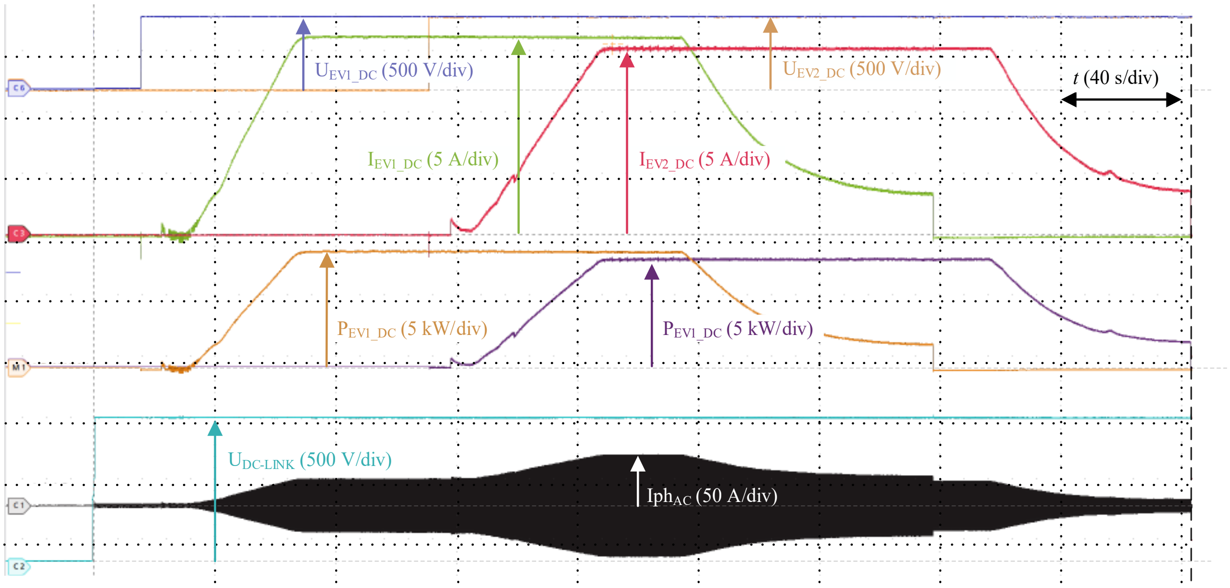

Fig. 4 An emulation of CC-CV charging of a two separate EV with two independent EV converters with the power drawn from the grid (up to 20 kW).

Finally, Fig. 5 depicts the THD of the grid current at different power levels. As can be seen, the minimum value is less than 4%, whereas it stays below 5% for roughly the upper half of the power characterstics. The higher THD at low powers appear because of the relatively low power of the scaled experimental model. For a full-scale converter to be applied in a real charging station with the power of hundreds of kWs, the THD would easily stay at very low levels for the majority of the power range, and thus, this would not be an issue. Nevertheless, the THD is already decent for the scaled model for most of the operating range.

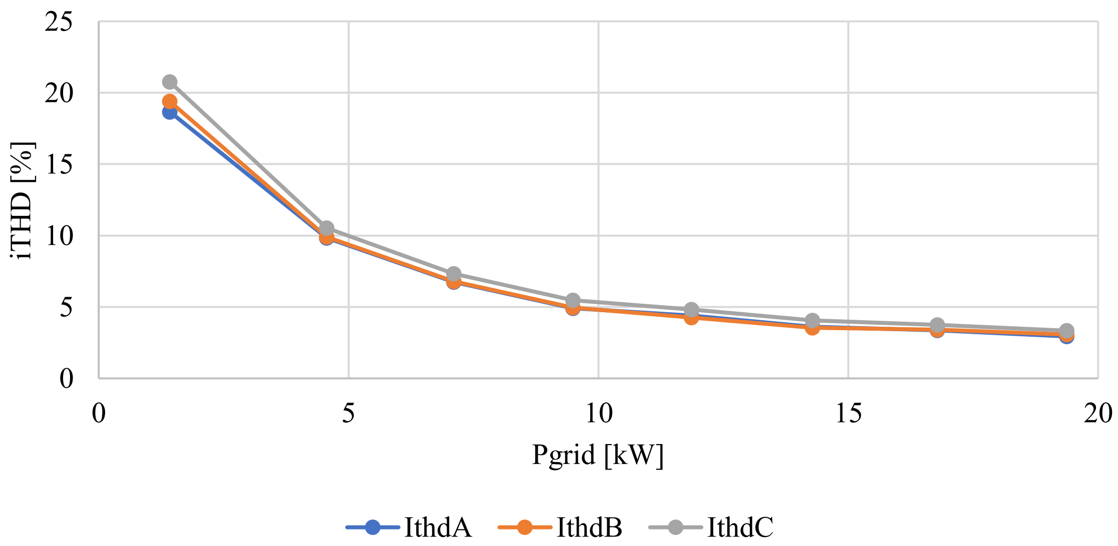

Fig. 5 THD of the grid current for various power levels.

b) Mode B charging the energy storage

In this mode, the system is configured as follows. The power is delivered from the grid to the energy storage up to the converter's capability of 20 kW. The grid converter is set to balance the DC-link voltages if needed. The results from this mode are shown in Fig. 6 and 7.

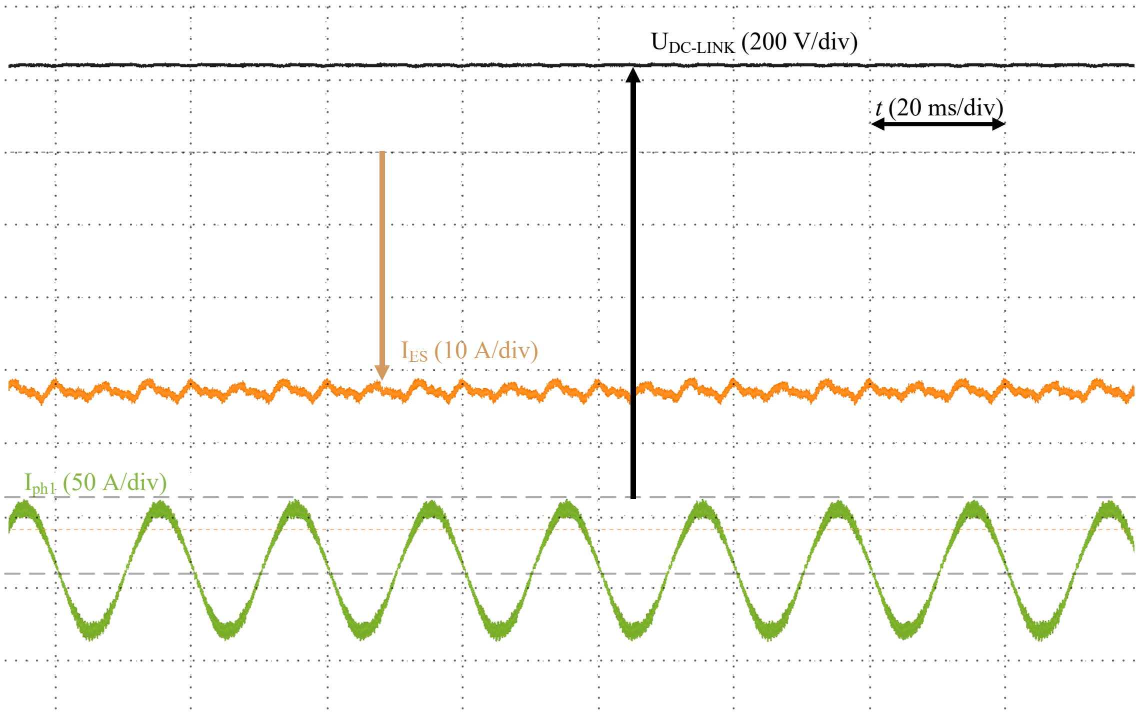

Fig. 6. Exemplary results from mode B, with the power delivered from the grid (20 kW) to the ES (20 kW).

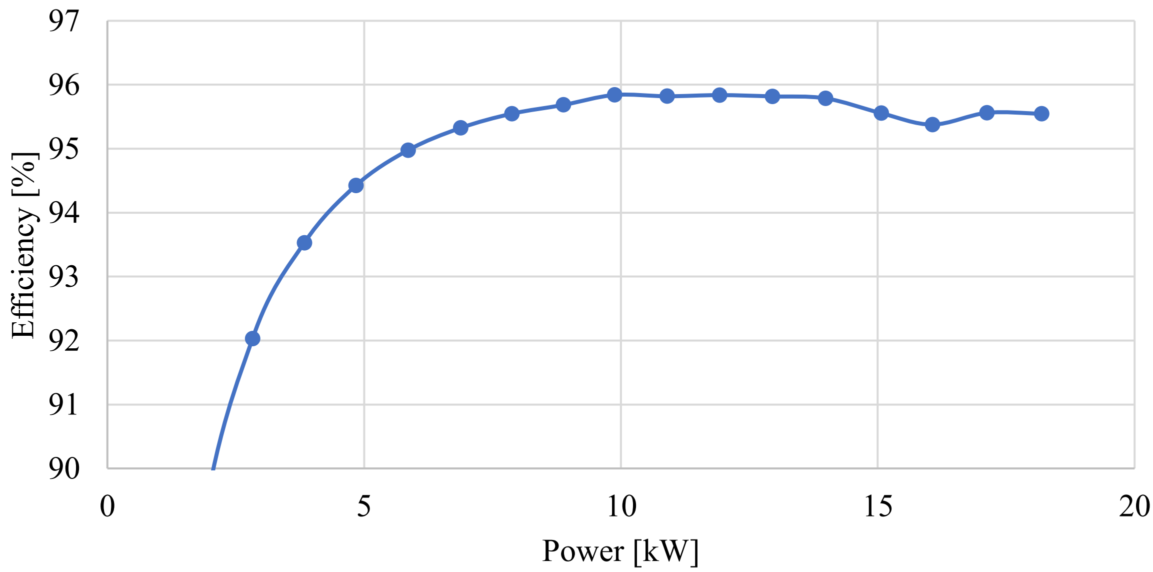

Fig. 7. Efficiency vs. power for mode B (power delivered from the grid to the ES).

c) Mode C – fast charging from the grid from the ES and grid and paralleled EV converters

In this mode family, the idea is that the EV converters are connected in parallel and the power can be drawn from various sources. This is the most complicated scenario group, with several converters from the experimental model possibly cooperating. Therefore, given the limitation of measurement channels, the full efficiency measurement was not possible. Nevertheless, the system has been succesfully tested in the experiments, according to the operating points depicted in Table I.

Fig. 8 depicts an exemplary results from mode C, with the power delivered from the ES (10 kW) and grid (10 kW) to the EV via parallel connected EV converters (20 kW). As can be seen, the system operation is validated successfully. Furthermore, the efficiency plot for this mode is shown in Fig. 9.

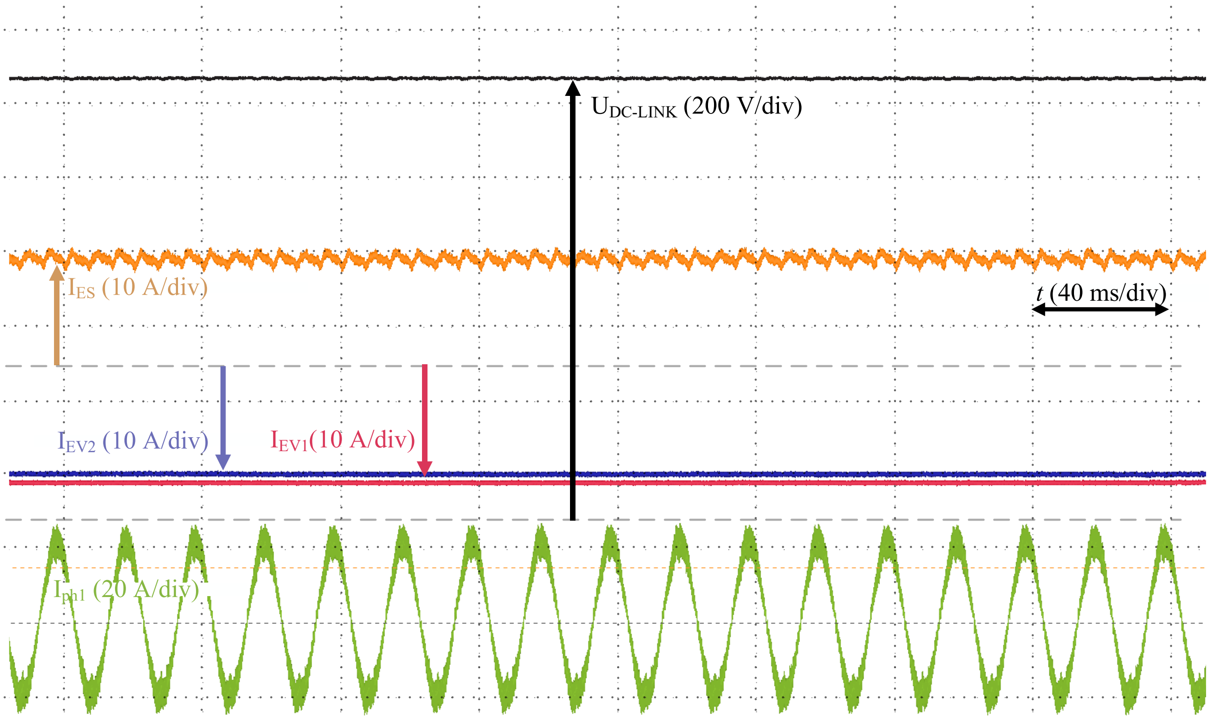

Fig. 8. Exemplary results from mode C, with the power delivered from the ES (10 kW) and grid (10 kW) to the EV via parallel connected EV converters (20 kW).

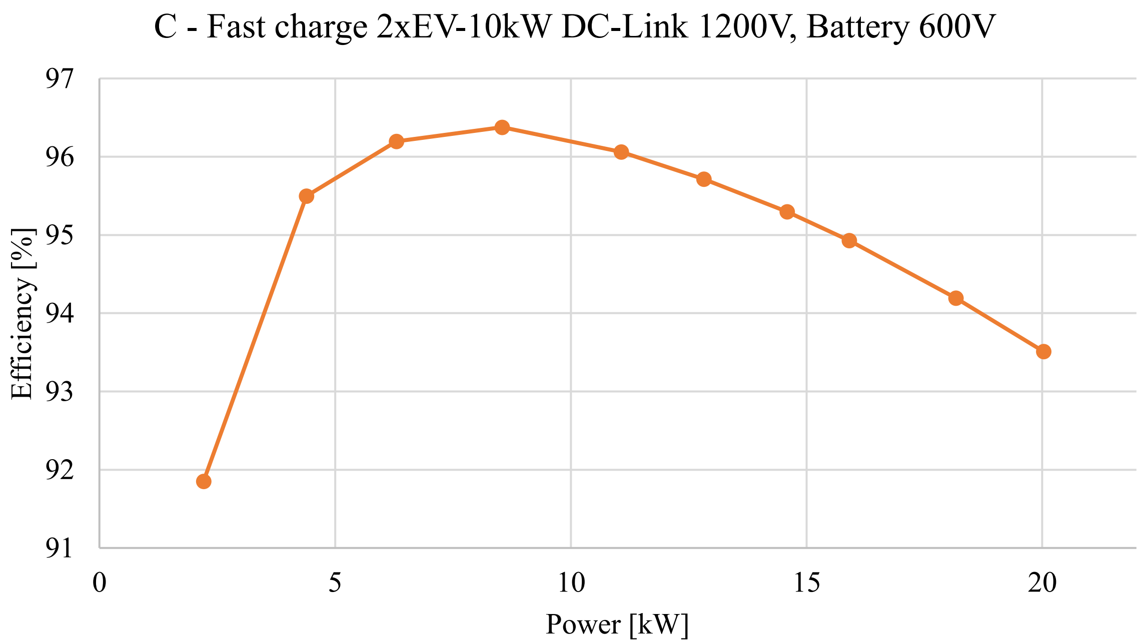

Fig. 9. Efficiency vs. power for mode C (Fast Charge - power delivered from the ES and grid to the EV via parallel connected EV converters).

d) <u>Mode D grid support from the ES</u>

In this mode, the station is oriented at grid support. More specifically, ES is supporting the mains. An exemplary oscillogram from mode D, with the power delivered from the ES to the grid at the level of 18 kW, is depicted in Fig. 10. As can be observed, the system behaves as anticipated. Furthermore, efficiency graph is plotted in Fig. 11, for a varying power of up to roughly 18 kW. As earlier, the efficiency is good, reach nearly 96% for a decent amount of operating range.

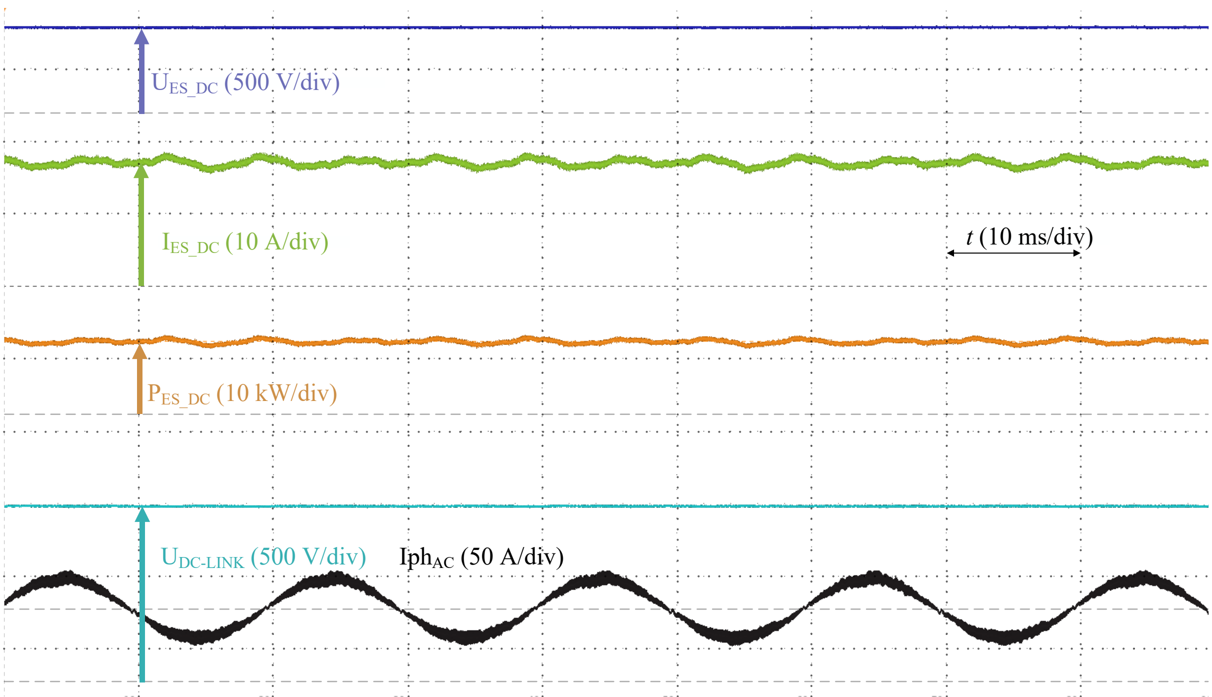

Fig. 10. Exemplary results from mode D, with the power delivered from the ES to the grid (10 kW).

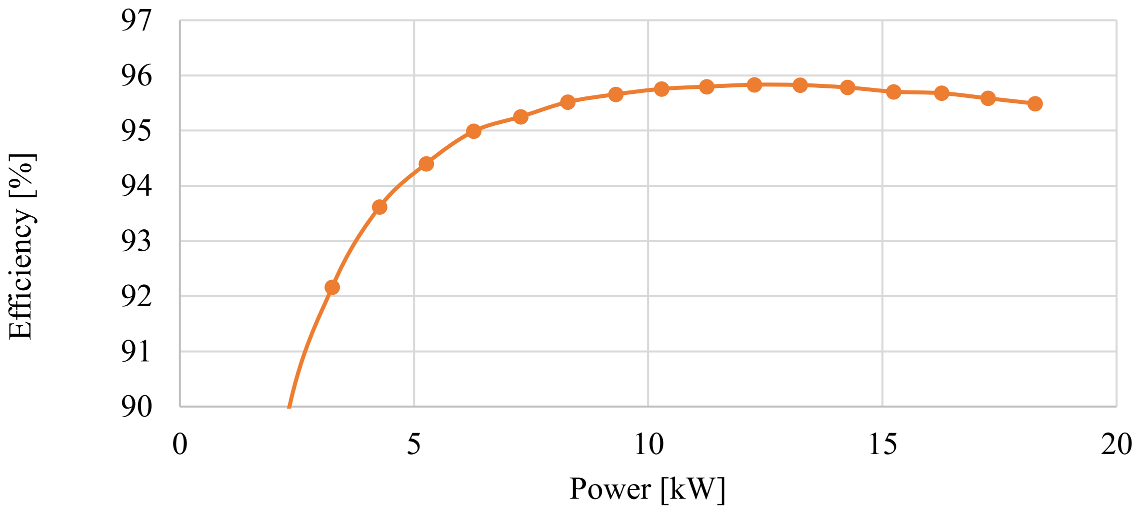

Fig. 11. Efficiency vs. power for mode D (power delivered from the ES to the grid).

e) <u>Mode E grid support from the EVs</u>

The next mode E is also focused on grid support. However, in this case, the EVs are source of power. This mode is also commonly referred to as vehicle-to-grid (V2G). Exemplary results from mode E, with the power delivered from the EVs to the grid, at up to 20 kW, are depicted in Fig. 12, while the efficiency plot for this mode is shown in Fig. 13. Furthermore, the power characteristic in time is depicted in Fig. 14, which explains the dynamics of the system in case of the emulation of EV battery discharging. All in all, this mode is also successfully validated.

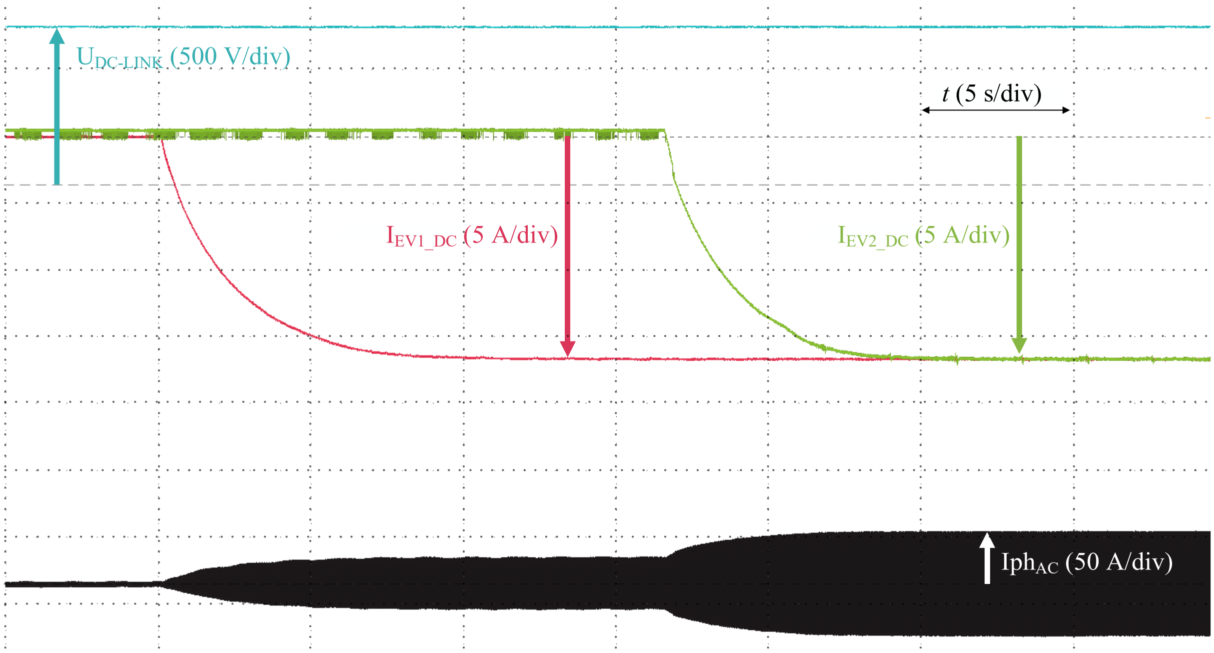

Fig. 12 Exemplary results from mode E, with the power delivered from the EVs to the grid (up to 20 kW).

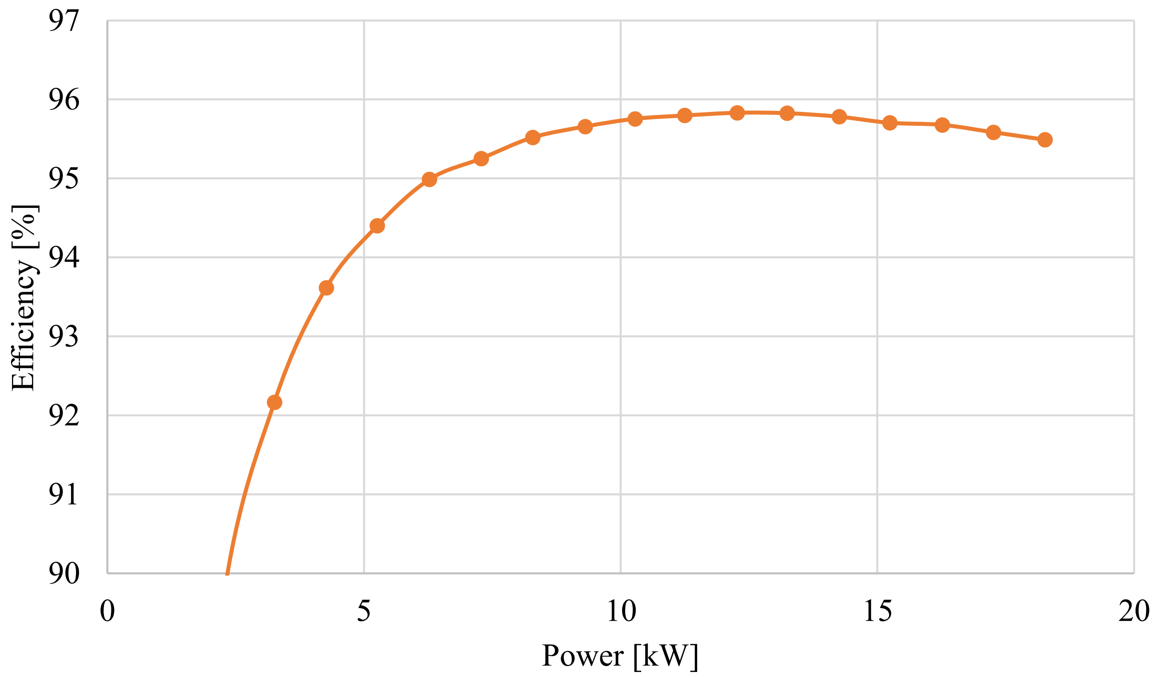

Fig. 13. Efficiency vs. power for mode E (power delivered from the EVs to the grid).

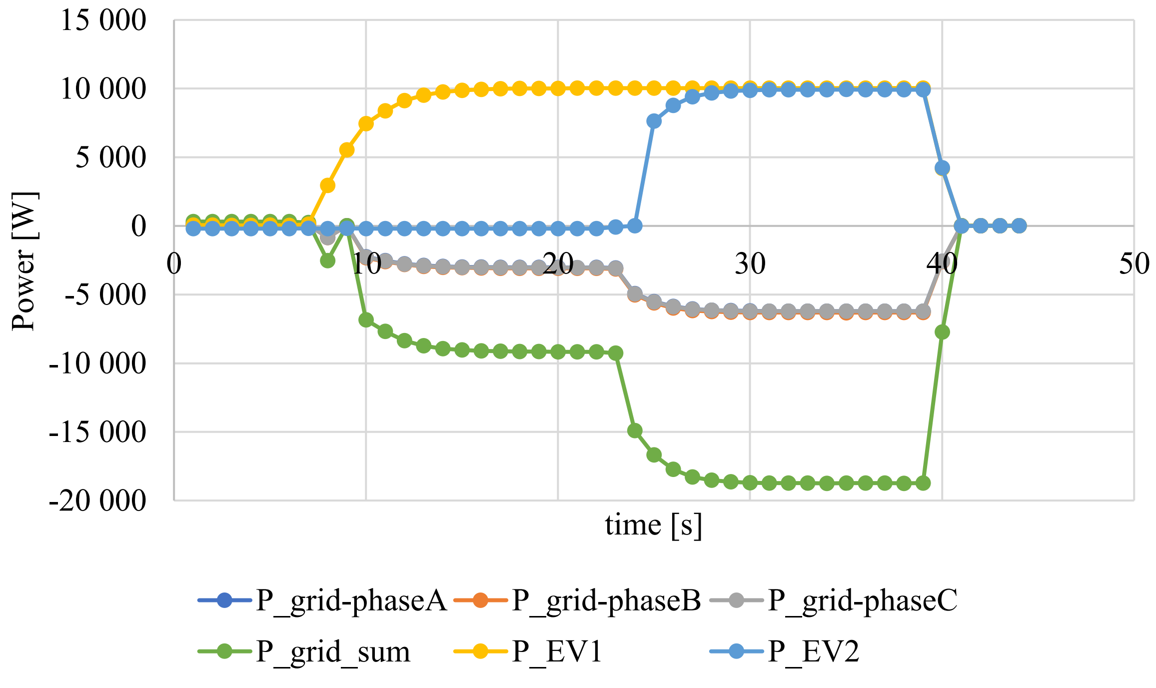

Fig. 14. Power characteristic in mode E, with the power delivered from the EVs to the grid (up to 20 kW).

f) Mode F island operation; EVs charged from the energy storage

In this mode, the assumption is that grid converter is off, e.g., because of a grid fault. Therefore, when there is a demand for EV charging, the power has to be delivered from the ES. Exemplary result from mode F, with the power delivered from the ES to the EVs at up to 20 kW, is exhibited in Fig. 15, whereas the efficiency plots for one and two EVs connected in parallel are depicted in Fig. 16 and 17, respectively. Once more, the system is positively verified.

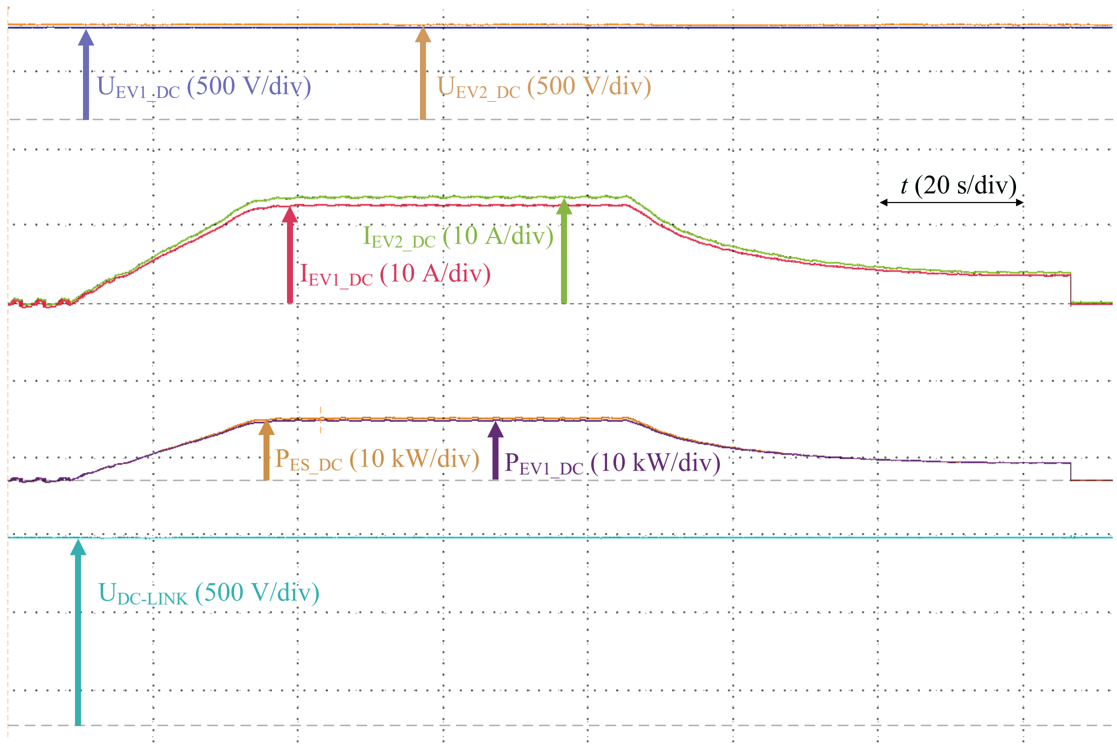

Fig. 15 Exemplary results from mode F, with the power delivered from the ES to the EVs (up to 20 kW).

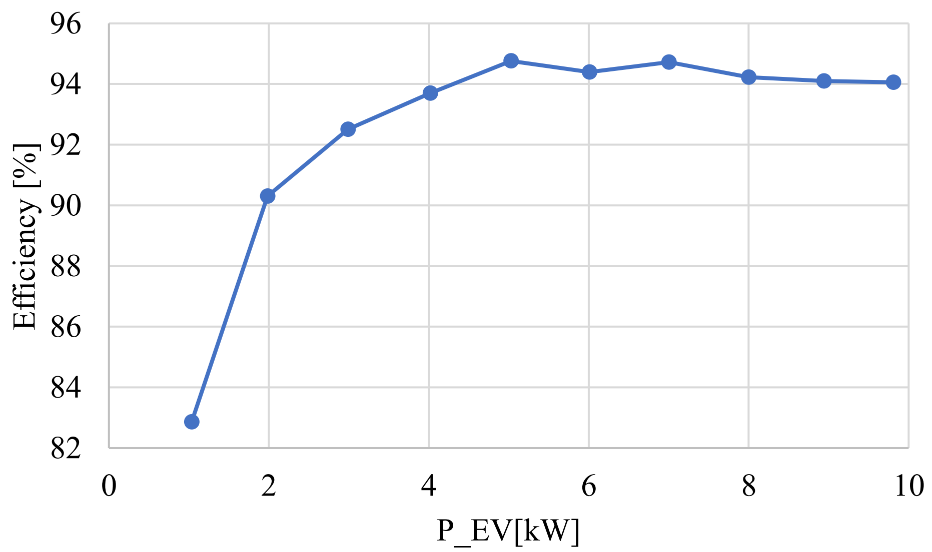

Fig. 16 Efficiency vs. power for mode F (power delivered from the ES to the EV).

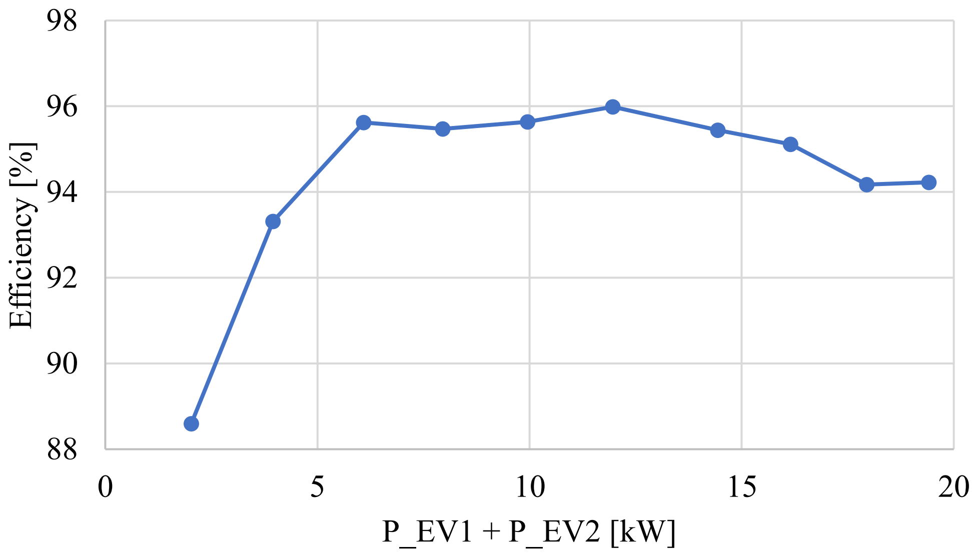

Fig. 17. Efficiency vs. power for mode F (power delivered from the ES to two EVs).

3. Conclusion

In the deliverable report, the experiments for the advanced EV charging system in its initial form (without the PV converter) were presented. The shown experimental results succesfully validate all considered operation modes. Thus, tasks T6.2 – T6.7 are completed, and so is milestone M6 (Completed experiments of the EV charging system).

The specific tasks in more detail:

- T6.2 Investigation of the operation when system is charging two vehicles from the grid in slow charging mode (A);
- T6.3 Verification of the mode B, when slow charging and recharging of the energy storage is considered;
- T6.4 Validation of the fast charging mode, also including the energy storage (mode C);
- T6.5 Testing of the grid support with the use of the storage (D);
- T6.6 Investigation of the vehicle-to-grid operation (E);
- T6.7 Verification of the stand-alone mode, a case with charging during the grid fault (F).