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

Deliverable D1.2 (Month 24)

Title: "Simulation model of the EV charging system and power flow algorithm"

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Executive summary

The deliverable includes the simulation results of the EV charging system model and the tested power flow algorithm. The team from Warsaw University of Technology performed it. The simulation which includes all of the assumed converters was prepared, after the initial simulation performed under the tasks WP3, WP4 and WP5. The power flow algorithm had all of the work modes described in the deliverable D1.1.

Table of Contents

1. Simulation study ***3***

1.2 Exceeding the maximal grid capability ***4***

1.2 Managing the power flow to reduce operation cost ***5***

2. The simulation model of EV charging system ***8***

3. Summary .... *Błąd! Nie zdefiniowano zakładki.*

1. Power electronics-oriented simulation study

The complete system was simulated in PLECS software using the parameters depicted in Table I. The nominal power values of each of the converter experimental model designed in the project was multiplied by a factor of 5. It was done, in order to test the system for real-life conditions for ultrafast charging station, considering the project scalability. The scheme of the system in PLECS is depicted in Fig. 1.

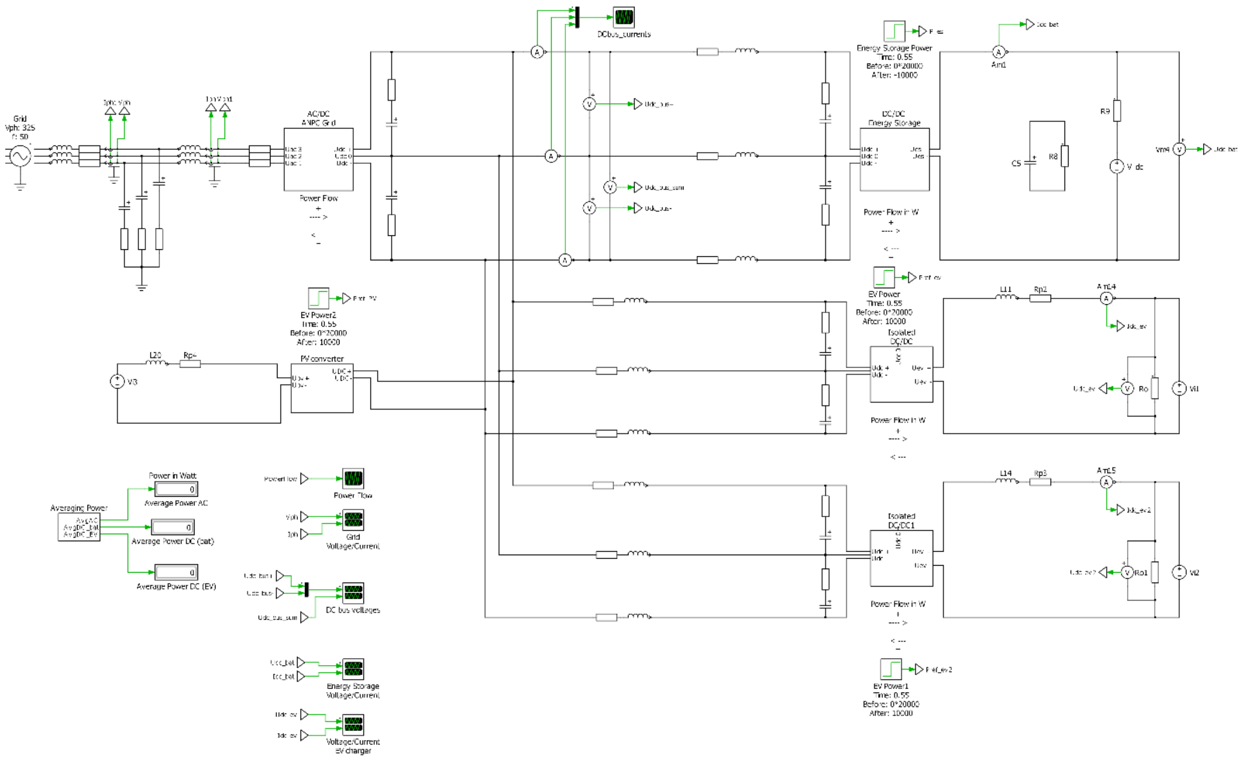

Fig. 1 Scheme of the system in PLECS software.

The simulations are separated in two. At first, the problem of maximal available power from the grid is considered, when the power is raised with the support of the energy storage, as shown in Section 1.2 (Fig.). The second figure shows the managing of the power in case of different energy prices to reduce operating cost of the infrastructure, which is exhibited in Section 1.3 (Fig.). Each converter is simulated with discrete elements and in a closed-loop system. Moreover, the ANPC control system consists of an algorithm to maintain the DC-link voltage level at its nominal value and keep the voltage balanced on the DC-link capacitors. These simulations were presented at a conference and then published in the conference proceedings: J. Rąbkowski *et al.*, “Advanced charging system with bipolar DC-link and energy storage,” in *2022 Progress in Applied Electrical Engineering (PAEE)*, Jun. 2022, pp. 1–6, doi: 10.1109/PAEE56795.2022.9966572.

TABLE I CONVERTER PARAMETERS FOR THE EXPERIMENTAL MODEL

	Topology	**Nominal power**	**Input voltage**	**Output voltage**	**Switching frequency**
AC/DC	Three level ALL-SiC ANPC (grid connected)	20 kW	3 x 400 VAC	1500 VDC	62,5 kHz
Isolated DC/DC	4 x Three level DAB (char./dis. energy storage)	10 kW	1500 VDC	800 VDC	65 – 100 kHz
Non-isolated DC/DC	Interleaved three level buck-boost (char./dis. EV)	20 kW	1500 VDC	800 VDC	100 kHz

Note that the presented results are shown at a fraction of the time considering normal operation of the charger which would in reality take minutes or even hours. However, the process has been sped up in order to avoid very high computational burden of the simulations.

1.2 Scenario 1 - exceeding the maximal grid capability

Here, the first scenario, with the simulation results depicted in Fig. 2, is analyzed in detail step-by-step.

In the interval $t_{1A} – t_{2A}$, one electrical vehicle is connected to the system – fast charging battery at 100 kW, thus the energy is transferred from the grid via ANPC converter and isolated DAB converter to EV.

In the interval $t_{2A} – t_{3A}$, the second EV is connected to the system with fast charging request from second isolated DC/DC converter, power transferred from the grid is increased to 200 kW.

In the interval $t_{3A} – t_{4A}$, the third EV is connected via a third isolated DC/DC converter. In this case, the required power (300 kW) exceeds the nominal power of the grid (200 kW). Thus, the remaining power (100 kW) is delivered from the energy storage via the non-isolated converter.

In the interval $t_{4A} – t_{5A}$, the first EV is disconnected from the charging station. Hence the energy storage does not have to provide additional power.

In the interval $t_{5A} – t_{6A}$, second EV is also disconnected and charging storage utilizes the rest of grid converter maximal power to charge the storage.

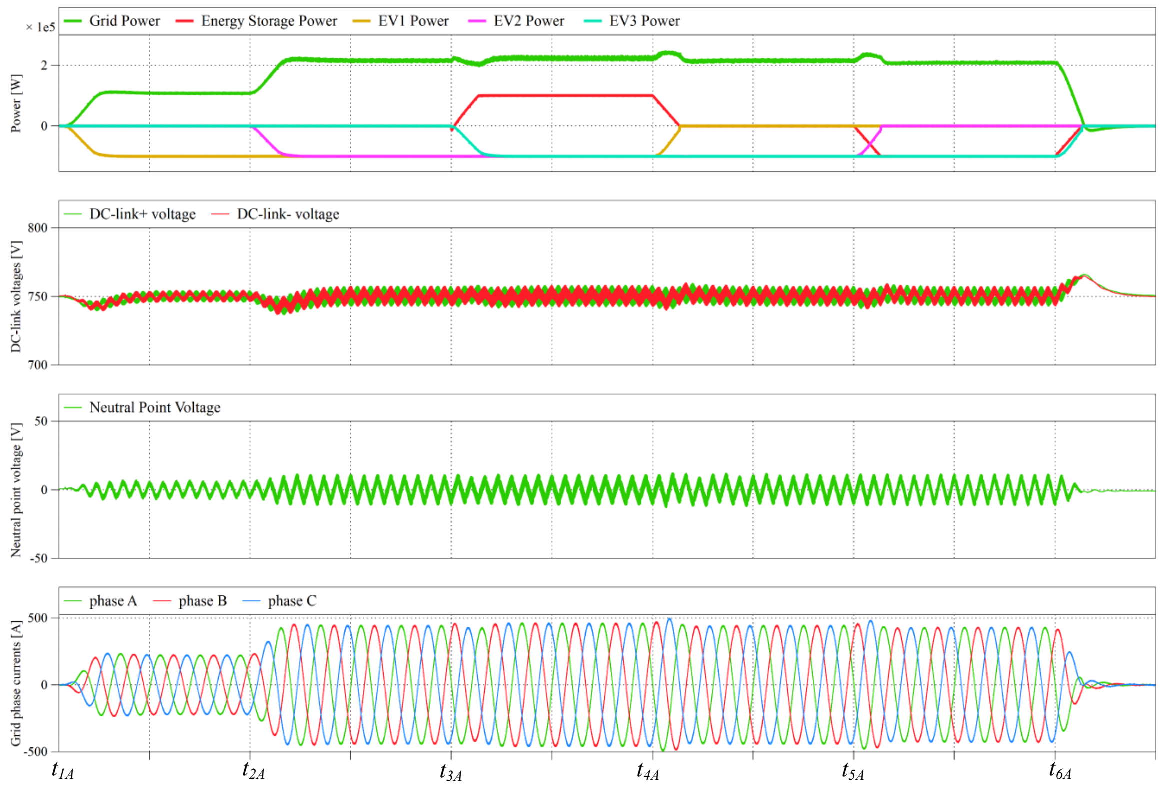

Fig. 2 Simulation results of the power flow in a scenario where the maximal power available from the grid is exceeded with the employment of the energy storage.

1.3 Scenario 2 - managing the power flow to reduce operation cost

In this sub-section, the second scenario, with the simulation results depicted in Fig. 3, is analyzed.

In the interval $t_{1B} – t_{2B}$, two EVs are charging each one with 50 kW power together with charging the energy storage (100 kW).

In the interval $t_{2B} – t_{3B}$, for the main controller, the information about step decrease of grid energy price appeared, thus the EVs charging is stopped and the energy storage supplies the grid.

In the interval $t_{3B} – t_{4B}$, the grid energy price is high enough for V2G operation; thus, each of the connected vehicles supplies (25 kW) power to the grid.

In the interval $t_{4B} – t_{5B}$, the energy stored in energy storage is cheaper than the energy from the grid; thus, the EVs are charged from the energy storage as well as supplying the grid.

In the interval $t_{5B} – t_{6B}$, the EVs demand full available power and the charging infrastructure supplies the power from the energy storage.

In the interval $t_{6B} – t_{7B}$, after disconnecting the EVs and energy price drop, the energy storage is charged from the grid.

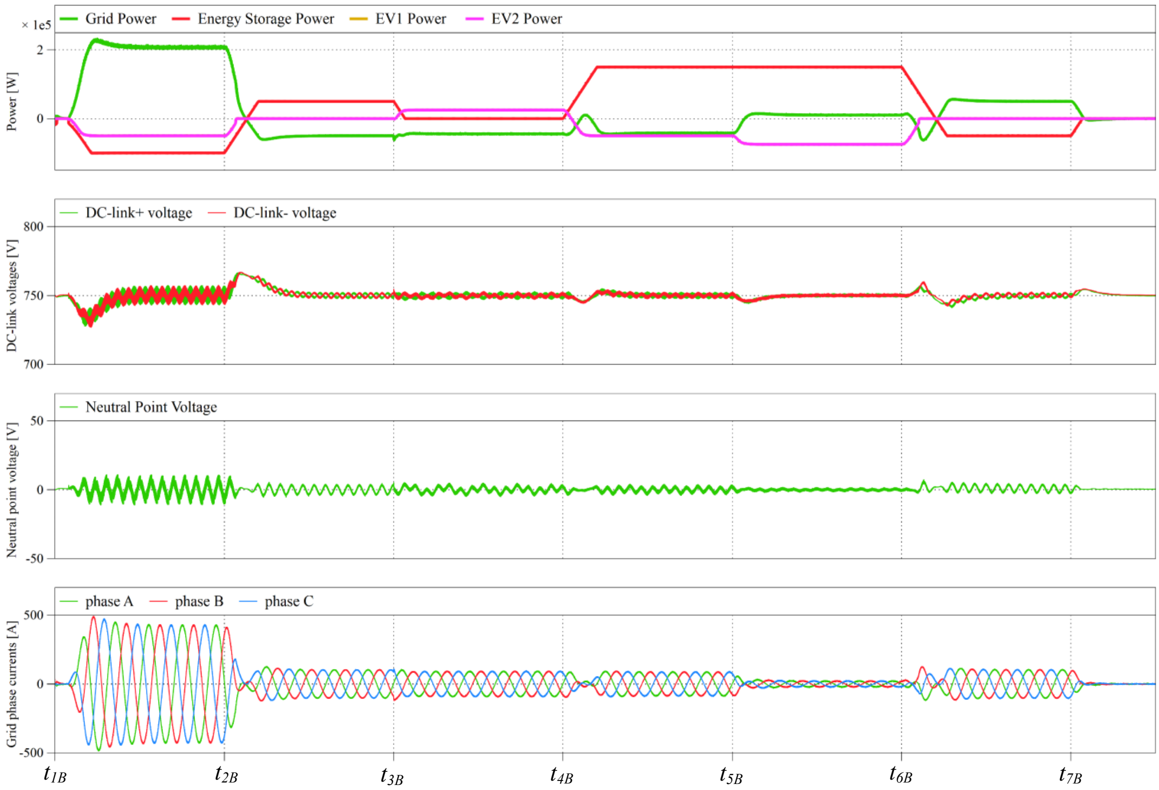

Fig. 3 Simulation results of the power flow in a scenario where the energy price dynamically changes throughout the operation.

2. Exemplary simulation results for the extended advanced charging station with PV inclusion

Simulation results for the system extended with photovoltaics were carried out for the rated powers of the laboratory model. The tested system worked as expected. The report below presents two waveforms shown in Figures 4 and 5. They assume the operation of individual converters in different directions with the integration of the photovoltaic converter.

Figure 4 shows the operation of the system in the D+ operating mode (energy return to the grid supported by photovoltaics). At time t1, the system starts returning energy to the grid with a power of 10 kW. During time t2, the converter responsible for transferring energy from the photovoltaics to the grid is additionally turned on with the power of 10kW – in total 20kW is transferred to the grid.

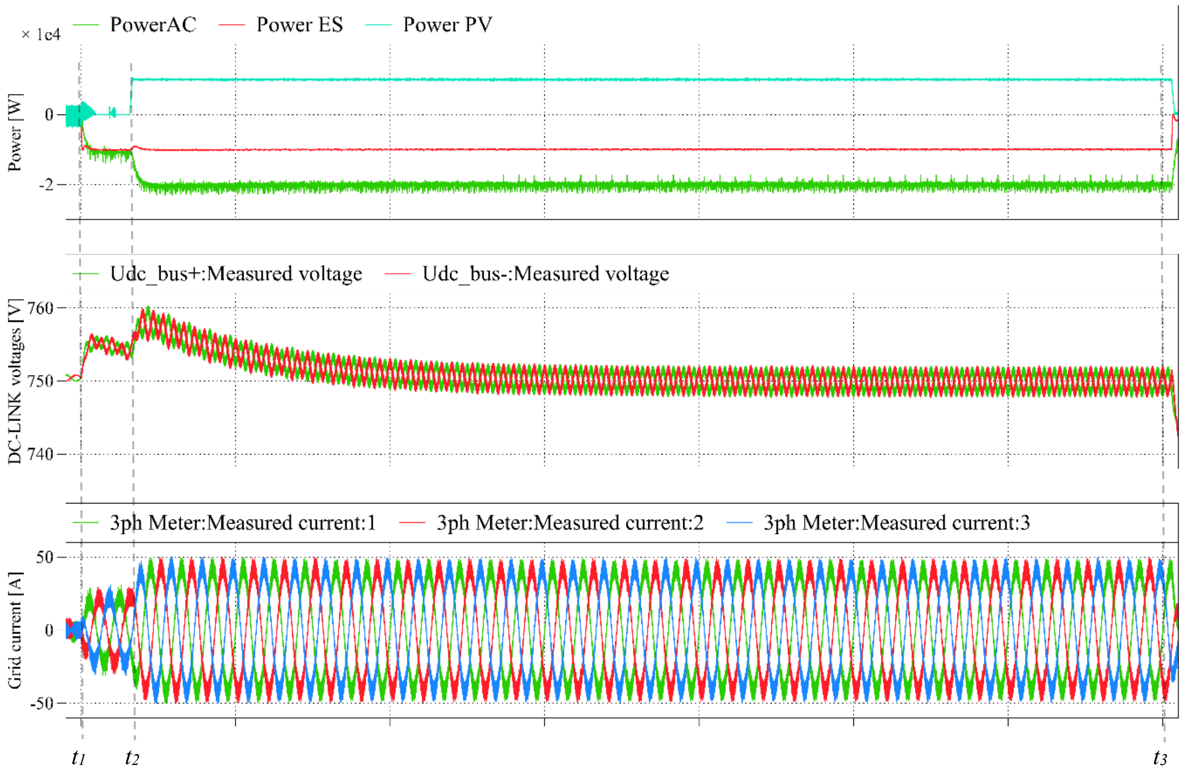

Fig. 4 Simulation results of the power flow in mode D+, where the energy is transferred from energy storage and photovoltaics to the grid.

Figure 5 shows the system operation in C+ mode (Fast EV charging supported by photovoltaics). This mode is particularly interesting because all converters in the system are active, and thus the whole system is validated in simulations. At time t1, energy demand (20 kW) is reported by two converters responsible for EV charging connected together. At the same time, the energy storage converter together with the grid converter start transmitting energy (grid 10kW, energy storage 10kW). This is operating mode C without photovoltaic support. At time t2, the photovoltaic converter starts working at full power and thus takes over generating power from the grid (10 kW). The system stops drawing energy from the grid, but the grid converter still stabilizes the DC-link.

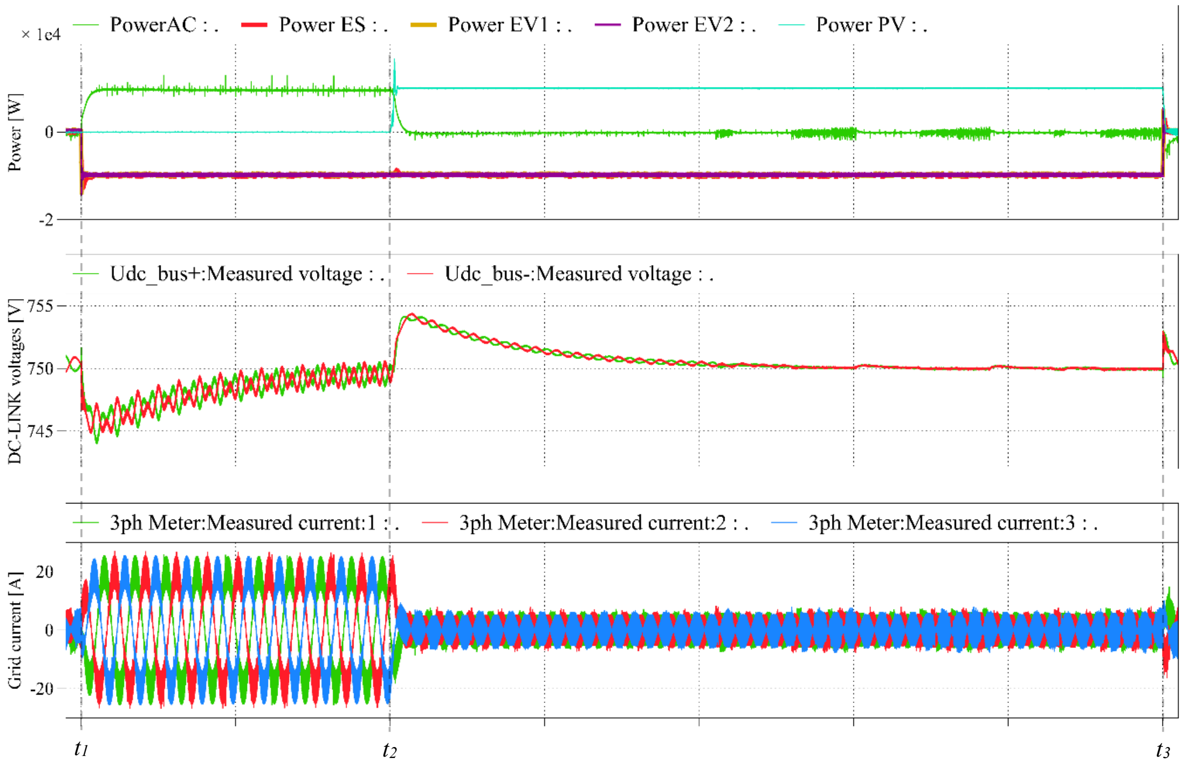

Fig. 5 Simulation results of the power flow in mode C+, where the energy is transferred from energy storage and grid with photovoltaics support to the parallel connected EV power converters.

3. Power flow simulation model of the EV charging system

After the simulation was conducted in PLECS software, an additional simulation was conducted. In this case, the Python program was designed to verify and create a basis for the experimental setup, which will be designed in the next step of workpackage 1. The simulation was made to test the basic functionality of the infrastructure, emulating a real behaviour by setting the reference power values for the converters, focusing on the energy flow in the station. This value was put into the graphical view in the timeline.

In this simulation study, there was a possibility to apply the price curve which dictates the change in the energy storage usage. When the price from the grid was low, the EV should charge directly from the grid. When the price goes up, the energy stored in the energy storage is transferred to the EV. In that case, the overall operation cost of the station should be minimized.

The first conducted simulation was prepared as follows:

1. The hour was set for 12:00, which indicated the 614,54 zl/MWh price of the energy.
2. Capacity was set for 1000kWh with the SOC equal to 50% and the 1000 zl/MWh estimated price of the energy storage.
3. After the initial set of data was set the simulation was started.
4. Immediately the energy storage started to charge with the power of 13,52 kW
5. In time t2 the EV1 was connected with the 1 kWh energy demand, it was forced to set the energy storage power to 10kW and Grid power to 20 kW to charge EV1 and the energy storage simultaneously.

6. At t3, the EV2 was connected with 1 kWh energy demand, the energy storage was no longer charged, and the whole energy which goes to the electric vehicles comes from the grid.
7. T4 was the time when the EV3 was connected with 1 kWh energy demand. Because the limit of the maximal power from the grid was used, the additional demand for charging the EV3 was needed, and the energy storage started to discharge.
8. At t5, the EV4 was connected with 1 kWh energy demand, this was the maximal power of the whole station, which can be delivered. 20 kW from the grid and 20 kW from energy storage.
9. At t6, the EV1 charged fully, and the power from the energy storage was minimized for 10 kW.
10. At t7, EV2 charged fully. The remaining power comes only from the grid.
11. At t8, the EV3 charged fully. Due to low energy prices, the energy storage started charging with the maximum possible energy from the grid 10 kW.
12. At t9, the EV4 disconnected, and the energy storage started to charge with the power of 13,52 kW
13. At t10, the hour was changed, which changed the market price to 1252,73 zł/MWh, which was very high. That causes stopping the charging of the energy storage.

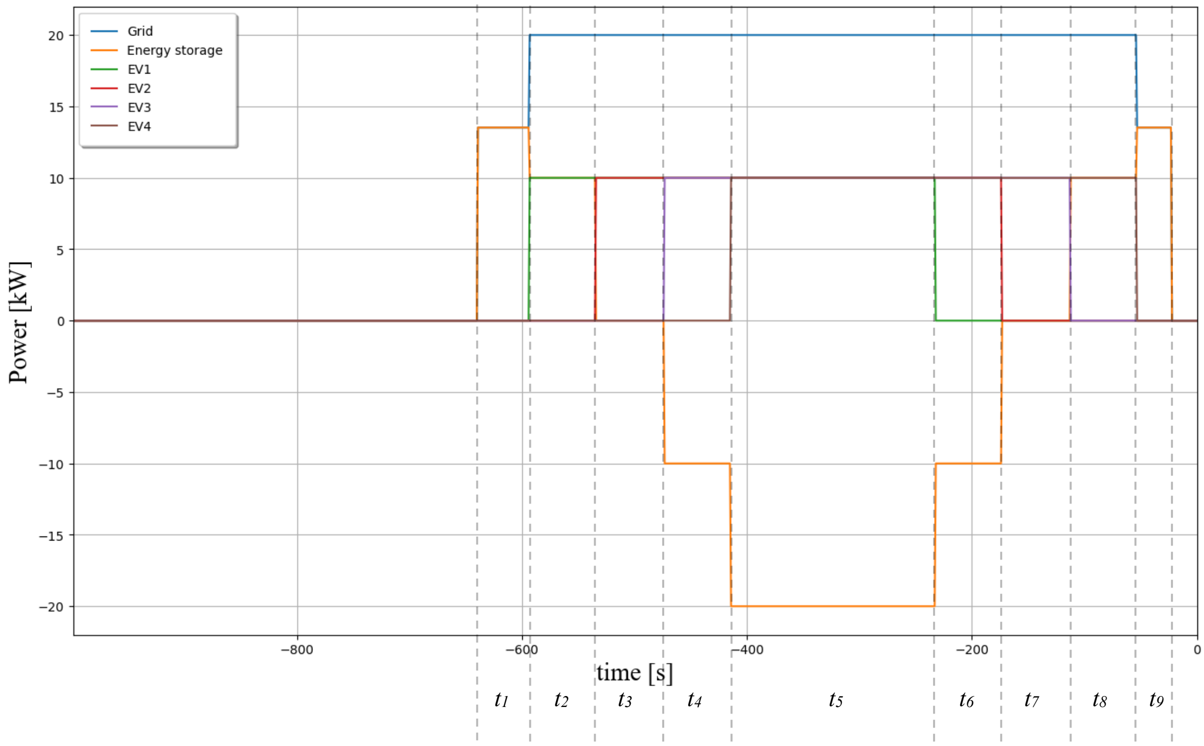

Fig. 6 The first simulation scenario – extension of grid maximal power.

In the second simulation, the operation of fast charging capability was proven. The simulated steps go as follows:

1. The hour was set to 12:00, indicating the energy price at 614,54 zl/MWh.
2. Capacity was set to 1000 kWh with the SOC equal to 50% and the 1000 zl/MWh estimated price of the energy from the energy storage.
3. After the initial set of data was set, the simulation has been started.
4. Immediately, the energy storage started to charge with the power of 13,52 kW.
5. At t2, the EV1 was connected with 1 kWh energy demand and fast charging was chosen. The reconfiguration of output relays was done to combine the output power of four power converters. The power from the grid and the energy storage was maximal and equal to 20 kW,

which added to each other, leading to 40 kW of power. Meanwhile, the fast charging operation of the two EVs arrived with 1 kWh demand. Each was queued because of the fast charging operation.

6. At t3, the EV1 was charged fully, and the EV2 and EV3 started to charge with 20 kW power. All of the power comes from the grid because of the low market price.
7. At t4, the hour was set to 18:00, which indicated the grid energy's market price changed to 1049,99 zł/MWh. This energy rise changes the power distribution for 9,24 kW from the grid and 10,76kW from energy storage.
8. At t5, the EV2 and EV3 charged fully and disconnected.

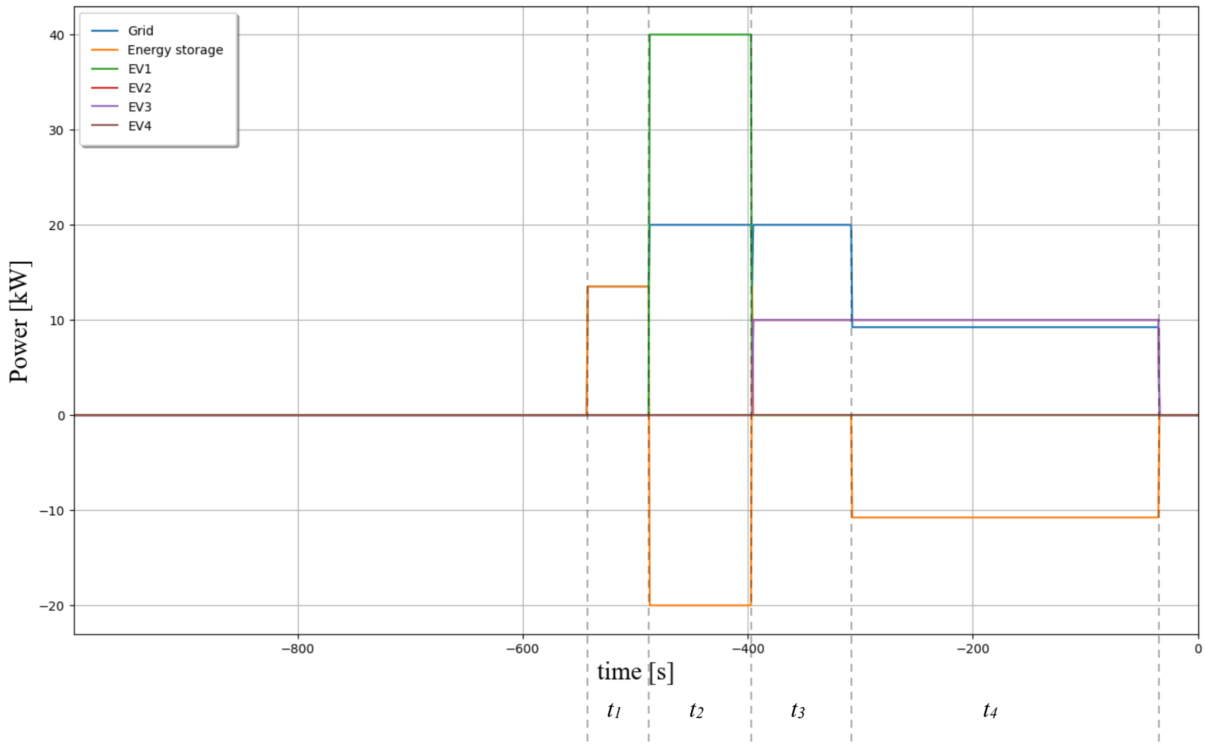

Fig. 7 The second simulation scenario – fast charging.

3. Summary

In the presented report, all of the assumed work was done. Based on the simulation models of the converters together with the control methods made in the program from the tasks WP3, WP4, WP5, a simulation model representing all operating states and the power flow calculation was developed. The results in the form of voltage and current waveforms of individual converters for a given time interval are presented in Chapter 2.

The results indicates stable operation for all of the modes of operations along with the transitions between them. The designed EV charging infrastructure in the project was designed to be scalable by a factor of 5. This simulations shows that this assumptions can be fulfilled and the station can operate successfully.

The Python simulation program was designed to be basis for the next task of controlling the charging infrastructure. The principle operation of was prepared, tested and successfully verified.

Moreover, there were additional studies including the PV plant, which also validated the system.