ANALYSIS OF A PV POWERED CHARGING STATION FOR ELECTRIC VEHICLES

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ABSTRACT: The future developments in the automotive industry with electric drives with power from rechargeable batteries require a network of charging stations and loading facilities. In the last few years 1562 (as of 2012-01) charging stations have been built up in Germany. This Figure will considerably increase in the near future. Photovoltaic systems (PV) are a considerable energy source for electricity in Germany, especially in Bavaria. That is why E.ON Bayern, the largest local grid operator in Bavaria, has started studies together with Munich University of Applied Sciences to feed these charging stations with electricity coming from PV systems nearby.

Keywords: Battery Storage and Control, Simulation, Standalone System

1 OVERVIEW

In Figure 1, three types of charging stations are shown, as they are considered and investigated in following. All Systems are designed for charging the batteries of e-bikes i.e. bicycles with a lithium ion battery of approximately 10 Ah and 26 V. Other investigations [1] only consider grid connected systems. The systems are:

- System 1: The figure above shows a charging station powered purely by a photovoltaic system. It is a standalone system without any grid connection.
- System 2: In the middle, a charging station powered by a photovoltaic system with battery backup, but without grid connection, can be seen.
- System 3 is a charging station powered by a photovoltaic system with parallel grid connection.

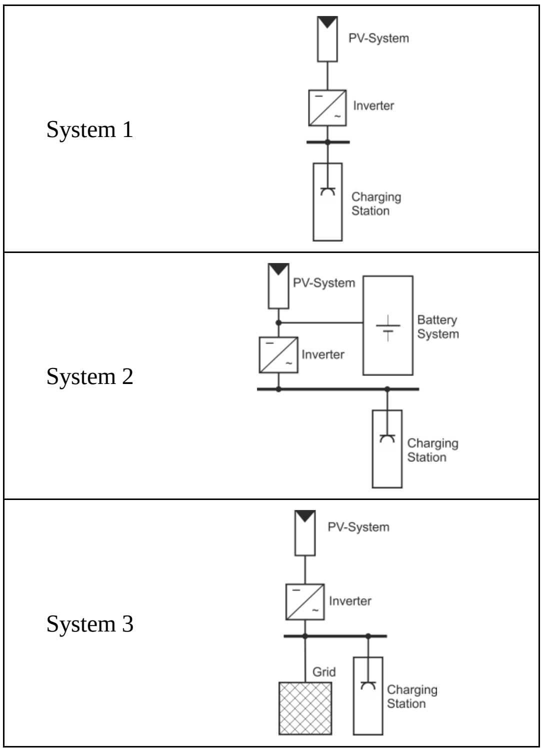

Figure 1: Three types of systems have been investigated.

2 INVESTIGATION OF CHARGING SYSTEMS

For the following investigations, a load profile (Figure 2) has been generated. For every time of the year, there is a specific load, depending on the different usage of the e-bikes in the various seasons. It has also be taken into account, that on the days in summer there are more hours in which it is bright.

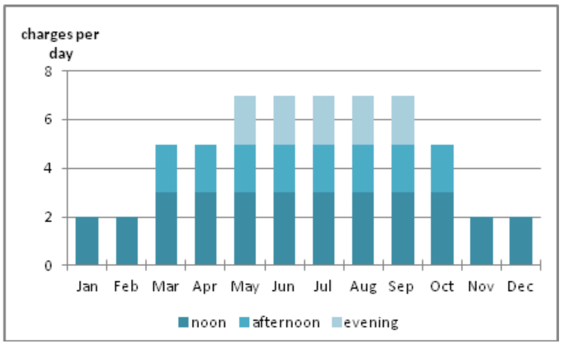

Figure 2: Load profile for simulations.

2.1 SYSTEM 1: STANDALONE SYSTEM

For this system, some simulations have been carried out. The simplest system, which has been investigated, is a standalone system without buffer battery and without grid connection. It has been built up as hardware and can in future be used for measurements, thus simulations can be validated.

In Figure 3 the results of the simulations, made by means of the "Integrated Simulation Environment Language (INSEL)" are depicted. For these simulations, meteorological data from a "low irradiation week" in July (Location Nuremberg) have been applied, based on hourly mean values. Using this type of charging system, e-bike batteries can only be charged during daytime, when there is at least some (direct or diffuse) irradiation. In Figure 3 the behavior of the electric energy produced by the PV power plant is represented by the yellow color line. This power must feed the load, which follows the green curve. Depending on these two curves, the black curve shows the free power that is produced by the PV plant, but not used for charging. In times of small irradiation, the load cannot be fed by the PV power. Thus a curve of "missing power", in blue, is obtained.

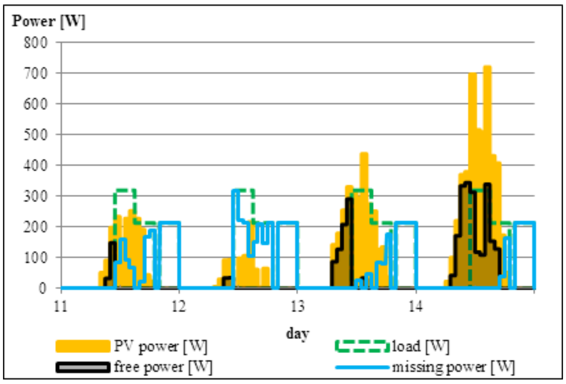

Figure 3: System 1 – power behavior over four days.

Summarizing, it can be stated that this system cannot reach a good utilization ratio in Germany because of the strong addiction to the global radiation. In southern countries, this value may be considerably higher.

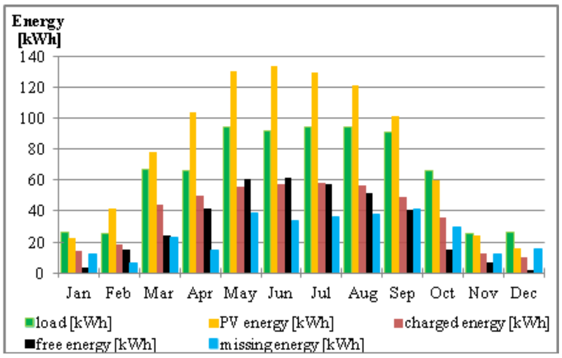

Figure 4: System 1 – energy behavior over one year.

In Figure 4 an annual overview of the mentioned energies is given. It can clearly be seen, that the missing energy has roughly the same size in all the months considered; in relation to the PV energy. That depends on the fact that the load increases with the irradiation, which is higher in summer.

2.2 SYSTEM 2: CHARGING SYSTEM WITH BUFFER BATTERY

For this system, simulations with INSEL have been performed as well. In contrary to System 1 System 2 is equipped with a buffer battery to store the energy, which could not charged into the batteries of electric vehicles. Thus, electric vehicles can also be charged without sunshine, a higher utilization time is possible. Figure 5 outlines the results of the simulation for the same time span with the same metrological data as in Figure 3. The system parameters were dimensioned that way, that the PV power plant has the same nominal power as in System 1. The colors show the same quantities (load, PV energy, …) as in System 1.

There is much less time when the load cannot be covered. This effect occurs although load is assumed in the night. There is only missing power in the shaded time span. It is the difference between the load and the power produced by the PV modules. The blue line state indicates the state of charge (SOC) of the buffer battery. For a lead acid battery, in this system, the SOC ranges between 40 and 100 %.

For an empty battery, SOC is nearly 40 %, because the minimum SOC is about 40 %. A fully charged battery has 100 %. The voltage of the battery is an indicator for the SOC. A battery with a rated voltage 24 V is being switched off by the controller at 24.0 V. Only when the voltage reaches the 25.2 V the controller switches on. The maximum voltage of this battery is 28.8 V. At day 12, the SOC is 40 %, but the switch off point at the beginning of the grey shaded area is on a higher SOC level. This happens because the voltage is lower wen the load (electric vehicle) is switched on.

It can also be seen in Figure 5 that the autonomy time of this system is one and a half days.

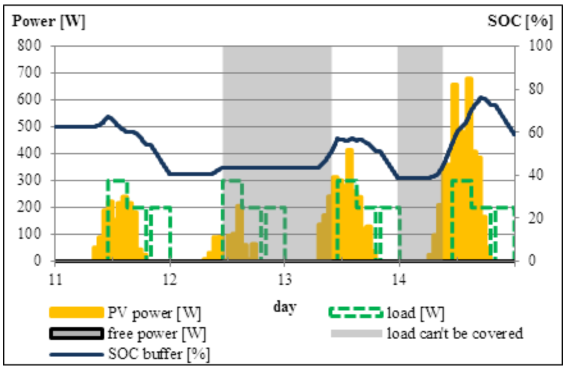

Figure 5: System 2 – power behavior over four days.

In Figure 6 an annual overview of the energies is given. The colors are the same as in Figure 4. There is a little difference between the produced energy of the PV modules in system 1 and 2, caused by the fact, that in system 2 the system voltage is addicted to the voltage of the buffer battery. This voltage depends on the SOC. The charged energy is nearly the same as the load, because less energy is missing. In the summertime, the free energy reaches a top. That depends on a little load in proportion to the PV energy. A good availability is the result.

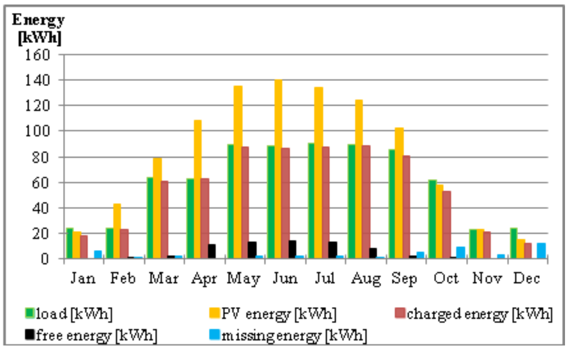

Figure 6: System 2 – energy behavior over one year.

A Sankey diagram, see Figure 7**,** shows the energy flows within the system in a year very clearly. The energy of the PV modules is separated into three parts. Roughly a half goes directly into the inverter. About 44 % flow into the buffer battery and 7 % are unused. From the inverter and from the buffer battery 70 % used to charge the vehicles battery, 5 % are inverter losses and 18 % battery losses. The battery losses depend on the SOC level. The higher the SOC level is, the more important the battery efficiency becomes...

Concluding this system has a much better availability than System 1. This fact depends on the battery, which – on the other hand – is costly.

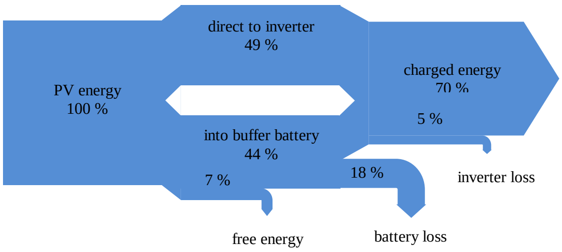

Figure 7: System 2 - Sankey diagram.

2.3 SYSTEM 3: CHARGING SYSTEM, CONNECTED TO THE GRID

Theoretical investigations and practical measurements have been made for system 3. However, the measurements cannot be used for the validation of the simulations, depending on the design of the system. In this case, the PV system is extremely over dimensioned; because it was designed for the (large) roof of a public building.

In this system the PV power plant is connected to the grid. This system is located in Sengenthal (Bavaria, Germany); Figure 8 illustrates the basic components. It consists of a PV power plant on the top of a public building, an inverter and a charging station. Measurements were made during a charge of an e-bike. The locations where the measurements took place are marked in the figure below.

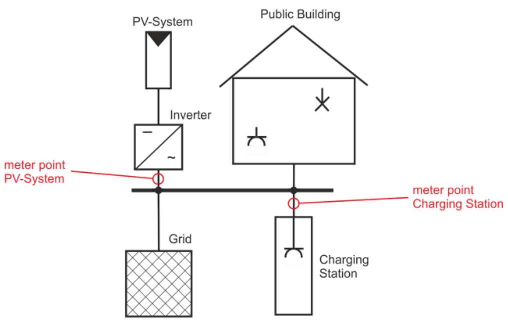

Figure 8: Basic structure of the real system. The inverter consists of two sub inverters.

Figure 9 shows a short time of the measurements. The total power of the three phases is presented by the purple line. The power of the wires 1, 2 and 3 (3~) are shown in red, green and blue. The e-bike was connected to wire 2. At 14:10, charging was finished; the e-bike was removed from the station. There is a high base consumption of the charging station with 200 W.

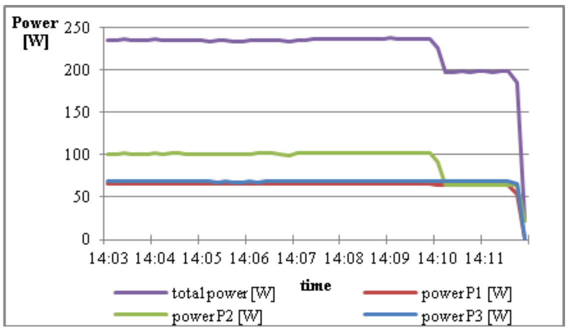

Figure 9: Real system – power values during the charge of an e-bike.

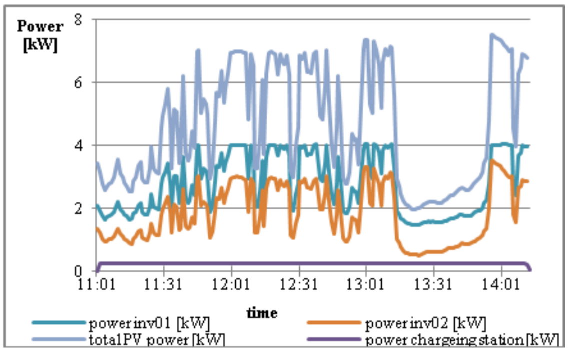

Figure 10: Real system - power values in Sengenthal during charging an e-bike.

The PV power has also been measured, see Figure 10. The power of the charging is very small in the opposite of the total PV power. The PV power is split into sub inverter 1 and 2. At the last maximum (at 14:00), one can see that inverter 1 is working at its limit. No higher power than 4 kW is possible, which is coming from wrong dimensioning.

In the following simulation for System 3 the same time span as before has been applied. Figure 11 illustrates the results. The PV power is shown in yellow color. The load is green and the power fed into the grid is black. With a grid connection there is no unused energy. The energy, which cannot be used (for the load), is being feed into the grid. If the load is higher than the PV power, the difference has to be balanced by the grid. In the other systems, this power is called the missing power.

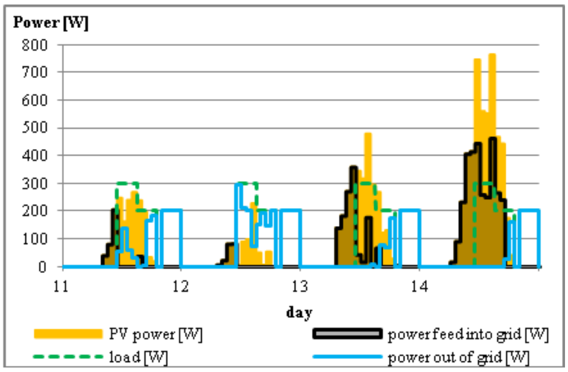

Figure 11: System 3 – power behavior over four days.

In Figure 12 an annual overview of the mentioned energies is given. The colors of the load and the PV energy are the same as in Figure 3. There is although a little difference between the produced energy of the PV modules from system 3 to the others, caused by the fact, that in system 3 Maximum Power Point Tracking (MPPT) is applied. The charged energy is the same as the load, because there is no missing energy. The grid provides the energy difference between the load and the PV energy if there is not enough energy produced by the PV power plant. If the PV energy is higher than the load, the difference will be fed into the grid. Thus, there is no energy unused. With the purple color, the energy charged direct from the PV modules without the grid is shown. If there would be no grid connection this would be the charged energy.

This system does not have any missing energy because of the grid connection.

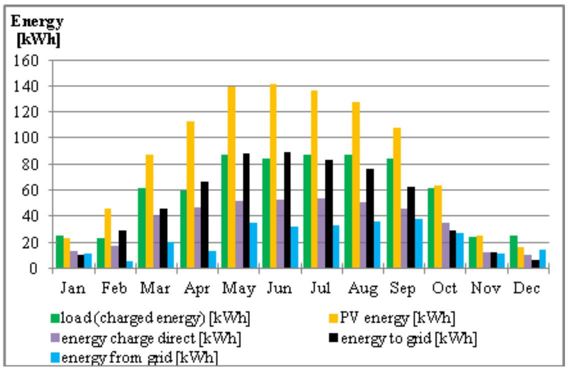

Figure 12: System 3 – energy behavior over one year.

3 ECONOMIC EFFICIENCY ANALYSES OF THE THREE SYSTEMS

The economic efficiency of these systems depends on the location, where they are installed. Here, the factors like an existing grid connection or the global radiation in this area are great issues. An "Economic Efficiency Analyses Matrix" has been built up, in which all variables can easily be changed and adjusted.

For a simple comparison, the costs for grid connection are not being taken into account. The costs for the systems can be seen in Figure 13. The capital value method was applied. The cheapest systems are System 1 and System 3, depending on the fact that there are only few components required. System 2 with a battery causes the highest costs.

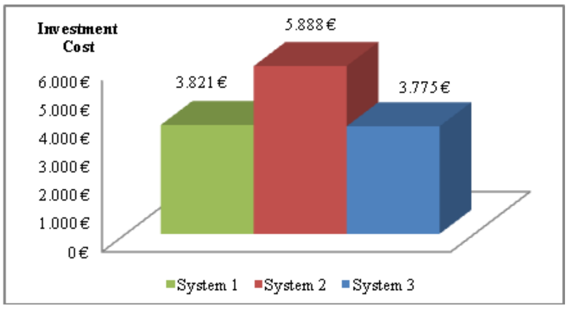

Figure 13: Comparison of the investment costs.

The location where the systems are – theoretically - installed, is Munich, i.e. a global irradiation of 1000 kWh/m² (on a horizontal plane) can be expected in a year. The appropriate electricity production costs as illustrated in Figure 14. Here, a total use of the produced energy is assumed. If there is no total use, the costs per kWh will increase, see Figure 15.

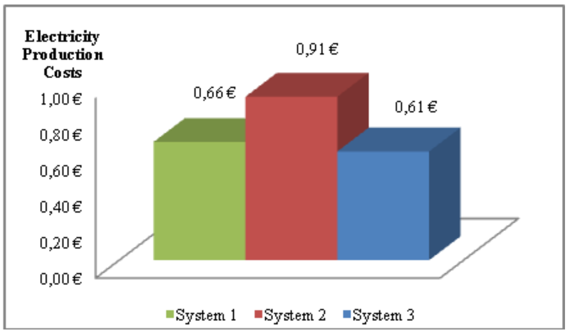

Figure 14: Comparison of the electricity production costs of all three systems.

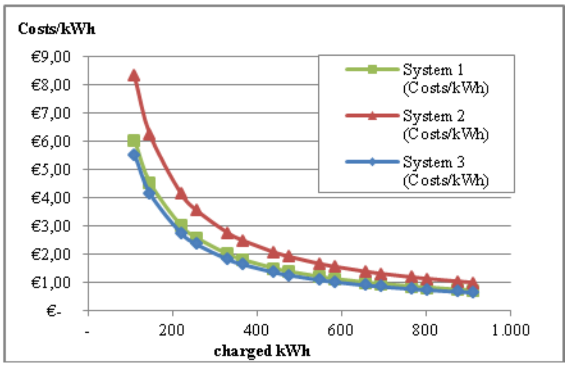

Figure 15: Comparison of the electricity production costs of all three systems, depending on the charged energy.

4 CONCLUSION

Finally, it can be concluded, that the standalone systems 1 and 2 are not able to compete economically at this time. However, this statement is not applicable for the system with grid connection (System 3). There is a special situation in Germany, if the owner or operator receives a "Renewable Energy Sources Act (EEG)" benefit for the PV power plant. High costs for battery systems and a low utilization time for these systems are responsible for high costs. It should also be considered that the overall availability is not given.

In System 1, an electric vehicle can only be charged when there is enough irradiation. Because of this fact, this system makes only sense for e-bikes. If there is rainy weather, less people are driving with their e-bikes. On the other hand, there would be more e-car drivers during bad weather times.

System 2 has an availability of 95 %. It is although better to use it for e-bikes and not for e-cars. The buffer battery would be too expensive for e-cars. System 3 is the easiest to handle. No buffer battery has to be dimensioned and the size of the PV power plant is not as important as in the other systems, because there is the grid to balance the necessary energy.

System 2 is more expensive than system 1, however it shows a better availability; more energy from the PV power plant can be used. With the future prospect, that battery costs will drop in the next few years, System 2 will become interesting for areas without a possibility for grid connection.

5 REFERENCES

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