# DEVELOPMENT OF THE COMPACT ENERGY BOX (CEB) AS A "PLUG AND PLAY" HYBRID UNIT FOR OFF-GRID POWER SUPPLY IN MINI GRIDS

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## 1. Introduction and Motivation

About 1.5 billion people worldwide still don't have access to electricity. Even in Germany and Central Europe, there are countless small forest and alpine huts, holiday and garden houses, that cannot be connected to the public grid. Gasoline- or diesel-operated generators usually cover their power demand. The consequences are high emissions (CO2, noise, exhaust gas pollution), high risks during transportation and storage of fuel, high operating costs and unreliable supply.

Although the technical equipment for off-grid power supply systems is nowadays available in very good quality, problems in running systems occur relatively often. The project "Integral Evaluation of Supply and Disposal Systems at Mountain Refuges" (www.ievebs.eu) initiated by the German Alpine Association, also assess this problem en detail. One hundred datasets of selected mountain refuges situated in the project partners countries Germany, Austria, Italy, Switzerland, Slovenia and the Czech Republic were analyzed. The result was, most of the problems with the off-grid power supply systems are caused by inadequate planning and design, inadequate installation and lack of maintenance as to be seen in Fig.1 (Deubler et al. 2010).

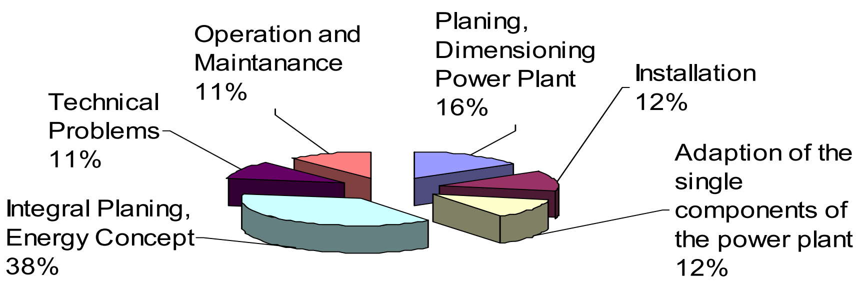


**Fig. 1: Problem areas causing failures of the energy-supply systems mentioned by the operators of the systems and the evaluation team (Deubler et al., 2010)**

Despite the positive development of the off-grid power supply systems in the last years, the lifetime of the batteries is still the weakest point in the system design. The main problems causing an early breakdown of the batteries are the following:

- High operating temperature of the batteries (a increase from 30 to 40 degrees Celsius of the operating temperature leads to a reduction of lifetime of 50%)
- Inadequate battery management (charge and discharge) due to excessive demand, lack of frequent full charge or frequent deep discharge

To resolve all the mentioned problems occurring in the customized systems formed the general motivation to think about the development of a standardized power supply unit. When Bergwacht Bayern (Bavarian Mountain Rescue Service) came up with the request to build up a compact off-grid power supply unit for a radio transmitter in the National park Berchtesgaden, a developing project was designed.

Up to now the location of radio transmitters mostly depends on availability of a public grid as necessary power source, leading to significant gaps in the network coverage. This leads to problems in emergency situations because reliable communication facilities are the basic requirement for their successful operations. And the basic requirement for radio communication (irrespective analog or digital) is an area-wide mobile radio network - as well in regions far away from a grid. Sometimes exactly these regions are most attractive to tourists, as for example the Alps near Königssee, Berchtesgaden (Germany). Therefore a compact, robust and maintenance free off-grid power supply unit is urgently needed. Thus the location of the transmission stations can be optimized in future regarding the network coverage. Due to the independency from the public grid, the stations can be located even faraway from populated areas avoiding the frequently occurring problem regarding the acceptance of the radio mast by the people.

For the execution of the project "Development and Field Test of the Compact Energy Box CEB as a Hybrid \`Plug and Function´ System for a Climate-Neutral, Off-Grid Power Supply for a Radio Transmitter at St. Bartholomä and for a Alpine Hut of the Mountain Rescue Service" a funding by the DBU (Deutsche Bundesstiftung Umwelt) could be achieved. In the following the objectives, methods, results and prospects of this project will be elucidated.

## 2. Objectives

The objective of the development of the standardized power supply unit ("CEB") was in general, to provide a compact, economical and easy to handle system for off-grid power supply as a flexible "plug and play" unit which ensures a long-lasting, safe and high quality power supply, even under extreme climatic conditions from the alps to the tropics.

For the power supply of the radio transmitters, the Bavarian Mountain Rescue Service requires some specific features:

- Remote control and administration
- Little maintenance effort
- High operational reliability
- Two different power supply units with a DC output power of around 200 W for the analog radio transmitter and with a AC output power of around 2 kW for their alpine huts and the future digital radio stations

Following specific features are required by the German Alpine Association (DAV) for their self supply refuges:

- Easy system design in corporation with the future user
- Automatic and reliable operation
- Automatic prevention of miss- or over-use
- Easy to use operator panel and display with relevant information for optimized usage
- Highly flexible and easy connection to different power generators as well as easy plug in of consumers
- Different AC output power classes – units providing about 2 kW for small self supplied refuges and units providing about 5 kW for small or medium DAV-refuges with AC coupled power generation
- Modular expandable – extending the AC output by connencting several units in series or even three units connected in parallel in order to deliver a three phase current grid 230 / 400 V
- Good cost effectiveness, environmentally friendly and a long operating life

## 3. Material and Methods

For the realization of these ambitious objectives an interdisciplinary team was created, combining the expertise of scientific specialists in the relevant research areas, specialists in the practical fields, technicians, manufacturers and last but not least, the further users of the power supply unit. In particular the group is composed as follows:

- Company Elektro-Mechanik Meisl GmbH, Berchtesgaden with over 15 years practical experience in off-grid power systems from a few watts to over 100 kW as customized PV-Hybrid Systems combined with wind and water power, CHP, fuel cells and diesel generators
- Leading manufacturer of control boxes
- Leading battery-experts
- Consultant MSc in renewable energy and energy efficiency with more than 15 years experience in development cooperation and off-grid power supply systems
- Leading manufacturer of radio transmission technology
- Experts from the future users: Bergwacht Bayern (Bavarian Mountain Rescue Service) and DAV (German Alpine Association)
- Company SMA AG as the leading manufacturer of inverters, especially island-systems of the highest quality
- Research institutes Fraunhofer ISE, Freiburg, and Fraunhofer IWES, Kassel, with their respective scientist for continuous discussions and feedback

Since the 4th of July 2011 the first prototype of the Compact Energy Box CEB6548-5 is providing the electrical energy for a one family house in south east Germany (see Fig. 2).

**Fig. 2: PV-hybrid-CEB system supplying power for the one family house that is seen in the background**

A PV generator with a nominal power of 2.76 kWp is the main power source. If there is a deficiency of PV-power due to bad weather conditions about two days after, the batteries can be recharged by a gasoline driven emergency motor generator. On the consumer side, a common, ordinary residential house is connected. Prior to that, the house had been supplied by public grid. No further changes in indoor installation had to be done. Due to the island grid, the residents are now much more aware of their behaviour regarding electricity consumption, trying to use the strongest consumers as e.g. the washing machine only when the sun is shining and not at the same time with the electrical cooker. The displays at the box permit a continuous control of the power supply unit. Thus, the residents do not have to accept any changes towards a lack of comfort but count on a power supply quality, which is equal to the public grid. Since the commissioning of the system no failure was reported. The technical data of the CEB6548-5 is shown in Tab. 1 in chapter 4.

Operation of the prototype facilitated the execution of different series of field tests under realistic and practical conditions. Besides the overall function checks, emphasis was put in the test of the passive cooling system of the box. As already mentioned in the introduction, the crucial point for the lifetime and therefore of the system's economic viability are the batteries. In the Compact Energy Box an optimized passive cooling system is applied. The aim is to avoid the application of an active cooling system (ventilation or air conditioning), even during warmer climatic conditions for examples in the tropics. Thereby additional power demand and possible system failures can be prevented.

The passive cooling system of the CEB is based on the generation of a continuous air flow through the box, caused by the specific thermal conditions in the box. The main sources of heat emission are the inverters, installed in the upper section of the box. The ventilation slots on the upper side of the box are designed to allow hot air to stream out easily, avoiding heat accumulation beneath the roof. As the box is airtight besides the ventilation slots on the upper and the lower side, the out streaming hot air is hauling in fresh air from underneath the box. Air that is flowing in has to pass the ground underneath the box, where it will be cooled down, compared with the outside air temperature. By ascending into the box the relatively cold air is cooling down the batteries, which are located on a steel grating in the lower part of the box.

The effect of this passive cooling system was analyzed in detail, using temperature data loggers attached on different levels in the box and outside in the shadow. Additionally, themographic images of both the open and the closed box were taken in order to reveal the temperature distribution in the box.

## 4. Results

### *4.1. Optimization of the passive cooling system*

From 5$^{th}$ of August starting at 07.12 am to the 7$^{th}$ of August 2011, ending at 12.00 pm the temperature distribution in the Compact Energy Box was measured and recorded. During these relatively sunny days the potential power production by the PV generator was higher than the power demand of the residents. Fig. 6 shows the dynamics of the power supply system, dispatching the state of charge of the batteries and the inverter power.

On the 5$^{th}$ of august at 11.00 am a thermal image of the box was taken. The reference picture on the right side in Fig. 3 shows the closed CEB. The ventilation slots on the lower and upper side are visible well. Even at the outside of the closed box the range of the temperature from the bottom to the top is clearly visible with a difference of 16 K. The vents at the bottom are slightly cooler than the surrounding material of the box, due to the in streaming air. Although the batteries were strongly charged at that moment and therefore heating themselves due to the internal resistance, the lower part of the box, where the batteries are installed, remained relatively cool.

The picture of the open box in Fig. 4 shows clearly that the batteries in the bottom part of the box remain cool. In contrast, the inverters installed in the upper part of the box were already heated up to more than 32 degrees Celsius. Directly beneath the roof of the box the temperature is again lower than the inverter temperature. That indicates that the hot air can sufficiently stream out through the ventilation slots.

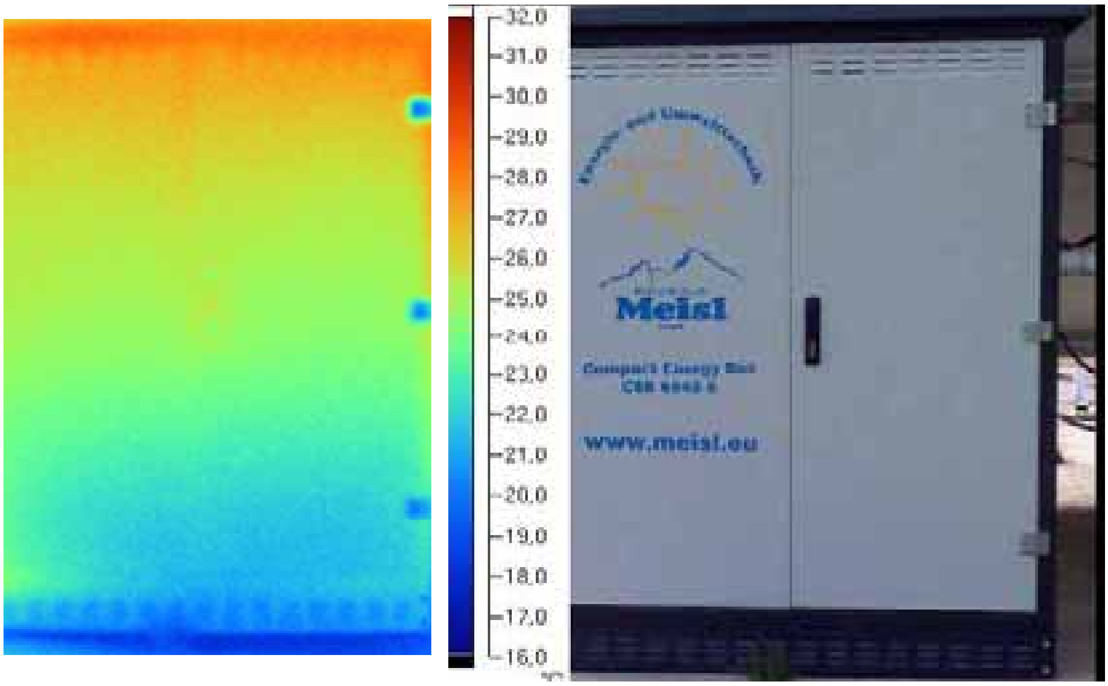


**Fig. 3: Thermo graphical picture of the CEB(left), temperature spectrum and reference picture (right); time of recording 05.08.2011 11:00**

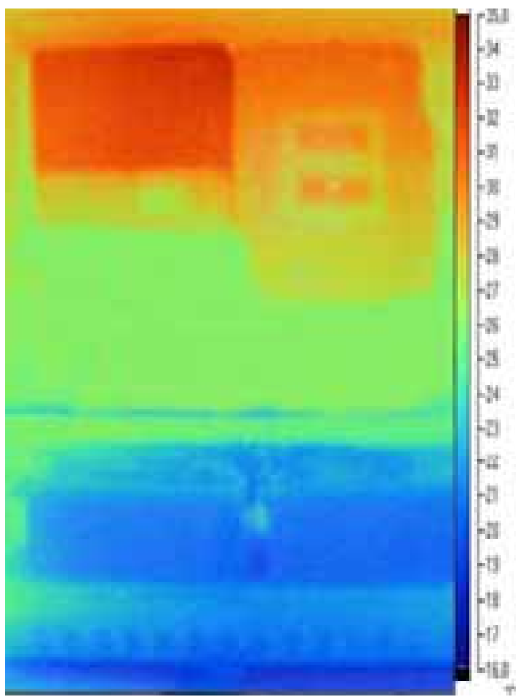

**Fig. 4: Thermo graphical picture of the internal view of the CEB in operation; time of recording 05.08.2011 11:05**

To provide more specific data, the temperature is measured and logged continuously at four different levels inside the CEB and for comparison also outside in the shadow above the PV generator. Fig. 5 shows an excerpt of the temperature development during the measurement time. It is clearly visible, that the battery temperature remains lower than the temperature bneath the roof of the box and even lower than the outside air temperature. It can be observed, that the hot air caused by the inverters can sufficiently stream out, so there is no occurrence of unacceptable heat accumulation.

These results show that the passive cooling concept applied on the Compact Energy Box is working efficient and satisfying. Therefore the batteries remain on a favourable operation temperature, even while installed in a closed box together with strong heat emitters like the inverters. It is for this reason, the CEB has proven to guarantee a long lifetime of the system and especially of the batteries.

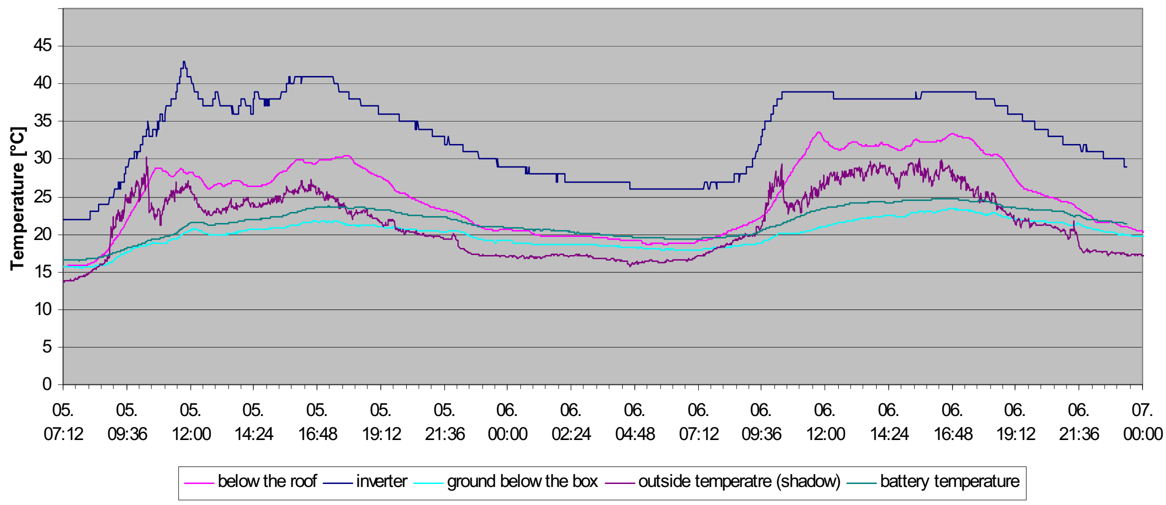


**Fig. 5: Temperature distribution profiles of the CEB during operation on two days in August 2011**

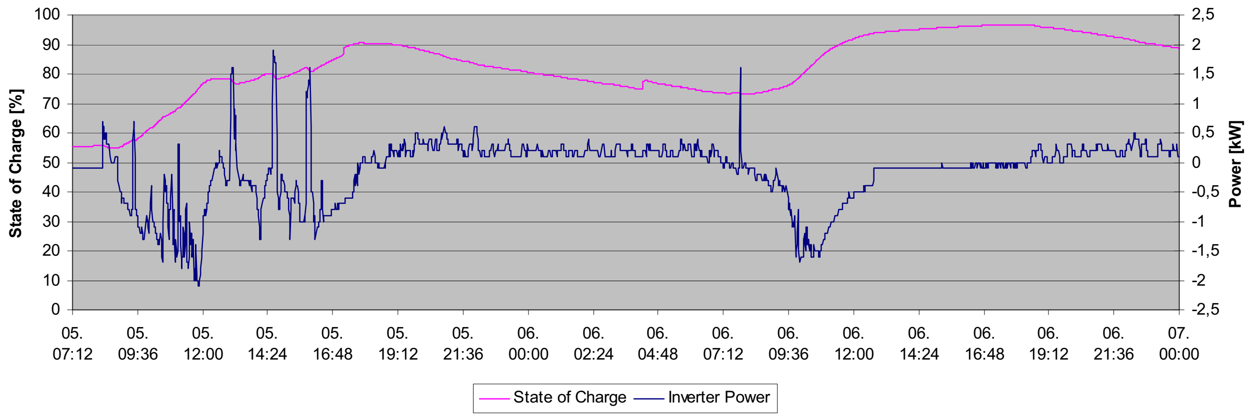


**Fig. 6: Gradient of State of Charge of the Batteries and AC Inverter Power[1] of the CEB during operation on two days in August 2011**

To implement the results of analysis of the passive cooling system, the ventilation slots have been optimized in dimension and location to achieve an even better passive cooling system in the new model line of the Compact Energy Box.

[1] Negative power reflects the charging of the battery, positive power shows the power demand by the resident

### *4.2. Description of the model line of the Compact Energy Box CEB*

Based on the results of the field tests undertaken with the prototype, the design of the box has been adapted and optimized. At the end of August 2011 the new model line of the CEB is available on the market at company Elektro Mechanik Meisl GmbH (www.meisl.eu).

The different CEB-models contain all components of necessary power electronics, inverters, protective devices, batteries and cabling. The control panel on the outside is equipped with all necessary socket outlets and plugs as well as LED displays, consumption data logger and fuses.

The new model line consists of three different models types, each combined with different battery options, to satisfy the various requirements of the future users in the best way. For the power supply of a mobile radio network and analog transmitters, which work with a relatively low DC output power of a few hundred watts up to 1000 W, the CEB 1024 is optimized. The CEB2524 offers an DC output as well as an AC output and is optimized for applications like digital radio transmitter or small refuges in the alps, holiday and garden houses, hunting lodges, small schools, hospitals and health stations or scientific or monitoring stations. And finally the CEB6548-3/5 with the most powerful AC output (nominal output power 6.5 kW) fits for all applications like the CEB2524 with a higher power demand e.g. medium size refuges and even residential houses or small villages or workshops in the rural electrification worldwide. The detailed technical information regarding the different model lines are summarized in Tab. 1.

**Tab. 1: Technical Data of the 3 standardized CEB models differentiated mainly by the system power and the battery capacity**

| | CEB1024 | CEB2524 | CEB6548-3/5 |
|---|---|---|---|
| **DC Output** | | | |
| Nominal Output Power max. [W] | 1000 | 1000 - 2000 | - |
| Nominal Battery Voltage [V] | 12 / 24 | 12 / 24 | 48 |
| **AC Output** | | | |
| Nominal Output Power [W] | - | 2500 | 6500 |
| Maximum Power (3s) [W] | - | 3900 | 12000 |
| AC Nominal Voltage [V] | - | 230 / 120 | 230 / 120 |
| **DC Input** | | | |
| PV Connection Power [Wp] | 630 / 1250 | 630 / 1250 | 3200 / 5200 |
| DC Input max. [V] | 140 | 140 | 550 |
| MPP optimal [V] | 25-60 / 40-80 | 25-60 / 40-80 | 175 / 188-440 |
| **AC Input** | | | |
| AC Input max. [A] | - | 16 | 32 |
| **General Data** | | | |
| Dimensions (W / D / H) [cm] | 120 / 62 / 150 | 120 / 62 / 150 | 120 / 62 / 150 |
| Ca. Weight (Basic Version) [kg] | 250 | 350 | 450 |

All models are equipped with a complete protection and security package including e.g. DC Fuse, AC Short Circuit and Overload protection, and optimized battery management with protection against Over Temperature and Deep Discharge.

Lead-Acid Gel Batteries with a capacity of 300 Ah are standard equipment. 600 Ah are optionally available for CEB1024 and CEB2524. Alternatively, the CEB can also be equipped with Lithium Batteries to achieve at least a double capacity with the same volume of batteries.

Other optional features are also available e.g. Automatic Generator Start, External Control Display, Remote Monitoring, Load Management, ENS, Control Panel Cover and Protective Roof. Also Sets including PV generator, small wind turbine, fuel cell or CHP (Combined Heat and Power Plant) can be delivered.

All the requirements of the Bavarian Mountain Rescue Service and the German Alpine Association mentioned in the chapter 2 will be implemented in the two CEBs elaborated and installed in the context of the project funded by DBU. Besides these characteristics, the CEB also provides the following features:

- Easy handling and transport of the Compact Energy Box (compact dimension and low weight)
- Flexible location out- or indoor in various climatic regions (robust design)
- Maximized economic efficiency by minimized retail price
- Highly flexible connection of different power generators (PV, small wind- and hydro-power, fuel cells, CHP, motor generator, etc.) with the capacity to sum up the nominal power of each system component to the total system power
- User-friendly (plug and play), easy to handle and maintenance free
- Data monitoring function for control and fault detection (including alarm system e.g. in case of over-use)
- Modular expandable (single phase - three phase)
- Easy selection of the adequate CEB by the future users using an optimized data collection sheet in matrix form
- No specialized electrician needed for the on-site installation and commissioning

For the application in the area of rural electrification the CEB also satisfies the following criteria in addition to the aspects mentioned above

- Resisting a wide range of climatic conditions, even tropic conditions
- Easy adaptation to global grid types (frequency / voltage, TN-C / TN-S / TT)
- Possibility of subsequent integration into the public grid

The CEB can not only be used as an off-grid power supply system but also grid connected. Additional objectives for grid coupled applications are:

- Backup function in case of frequent break down of the public grid comparable in quality to an uninterrupted power supply unit (UPS) but even for a much larger time
- Stabilizing a public grid with strong fluctuation of frequency or voltage
- Increasing the self consumption portion of the own power production e.g. with the PV generator on the roof, compared with the feed into the public grid

## 5. Conclusions and Further Work

After having completed the field test cycle it can be determined that the tested prototype of the CEB mostly satisfies already the ambitious expectations which were defined at the beginning. Especially the passive cooling system operates very well, so that the main threat to lifetime of such a compact box is eliminated. The results of the executed field test are already transferred to optimize the production of the new model line.

At the end of August 2011, the new and enhanced model line will be available at international level. In the scope of the project “Development and Field Test of the Compact Energy Box CEB as a Hybrid `Plug and Function´ System for a Climate-Neutral, Off-Grid Power Supply for a Radio Transmitter at St. Bartholomä and for a Alpine Hut of the Mountain Rescue Service” the planed power supply units will be installed, starting in September.

To enhance the quality of the Compact Energy Box even more, a continuous observation and analyses of the installed unit will be implemented combined with a scientific thesis. The results will directly be integrated in the further production of the CEB.

## 6. Acknowledgement

The development of the Compact Energy Box is supported by the funding of the Project “Development and field test of the Compact Energy Box CEB as a hybrid `Plug and Function´ system for a climate-neutral, off-grid power supply for a radio transmitter at St. Bartholomä and a alpine hut of the mountain rescue service” by the DBU (Deutsche Bundesstiftung Umwelt).

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