



Project 019883 (SeS6)

SoS-PV

Security of Supply Photo Voltaic Inverter:
combined UPS, power quality and grid support functions in a photovoltaic inverter for weak
low voltage grids

STREP

**Sustainable energy systems,
New technologies for energy carriers/transport and storage**

Deliverable 9.5: Publishable final report

Period covered: 1st October 2005 to 31st December 2008

Due date of deliverable: 31st December 2008
Actual submission date: 31st March 2009

Start date of the project: 1st October 2005

Duration: 39 months

Lead contractor for this deliverable: CEA

Revision 1

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contract no. 019883 (SeS6)

SoS-PVi

Security of Supply Photo Voltaic Inverter: combined UPS, power quality and grid support functions in a photovoltaic inverter for weak low voltage grids

STREP

WP9 : Management of the project

Deliverable 9.5: Publishable summary of final activity report

Hervé COLIN
Herve.colin@cea.fr



Content

Content	3
1 Project execution	4
1.1 Project objectives:	4
1.2 Contractors involved:	4
1.3 Coordinator contact details:	5
1.4 Work performed and achieved results:.....	5
2 Dissemination and use.....	11

Publishable summary of final activity report



1 Project execution

1.1 Project objectives:

SoS-PV (Security of Supply with PV inverter) project intended to:

- Minimise the impact of PV systems on the grid operation and planning,
- Insure security and quality of electricity supply to houses and buildings with PV installations,
- Increase performance ratio of PV systems,
- Increase penetration of PV in the networks.

In order to meet these global objectives, the target of the project is the production of a PV inverter with UPS functionalities basing on two different technologies for the storage system:






- A system based on a lithium-ion battery bank,
- A hybrid storage system, including a lead-acid battery bank, a supercapacitor and the electronic device to manage them.

In addition detailed objectives are listed:

- The **SoS-PV inverter** including storage function will be **validated on 4 prototypes**, which will then be available for demonstration systems,
- The SoS-PV inverter will prove to be **less than 30% more expensive than conventional PV inverters** (excepting storage components), to have a **low environmental impact, high energy efficiency and to maximise the PV production** in comparison to conventional PV inverters,
- The feasibility of **additional functionalities** will be studied, e.g. for **integration in virtual power plants**,
- **Barriers to the exploitation** of the full benefits of the SoS-PV inverter will be identified.

1.2 Contractors involved:

CEA/INES-RDI (FR)	The logo for INES (Institut National de l'Énergie Solaire) features a stylized sun icon to the left of the text 'ines' in a bold, lowercase font. Below 'ines' is the text 'INSTITUT NATIONAL DE L'ÉNERGIE SOLAIRE' in a smaller, uppercase font.
Skytron-Energy (DE)	The logo for skytronenergy features the text 'skytronenergy' in a blue, lowercase font. The 'skytron' part is in a bolder font weight than 'energy'.

SAFT (FR)	
Maxwell (CH)	
EnerSys (PL)	
Trama Tecno Ambiental (ES)	
Hawker (FR)	

1.3 Coordinator contact details:

Hervé COLIN
 INES-RDI/CEA
 Department of solar technologies Tel: +33 479444548
 Laboratory of solar systems Fax: +33 479688049
 50 avenue du lac Léman BP 332
 F-73377 LE BOURGET DU LAC
 FRANCE

1.4 Work performed and achieved results:

A market study was performed with collection of data on weak grids in Europe (load profiles, grid quality), estimation of market potential for small scale distributed generation and grid stabilization systems in Europe, especially considering power and storage capacity provided.

From the study of the national load profiles on the electricity network and of the irradiation curves, it was clear that for reaching a high penetration of PV energy, it will be necessary to delay the injection to peak load periods. The next figure shows the profile of a real consumption (data presented as 0/00 of simultaneity of the MV-LV transformer) as well as the simulation of the consumption with 10, 20 and 30% PV penetration and the average value of the daily consumption in the 3 scenarios. The load profile is representative of a mixed urban area with households and small businesses, during a winter day, in Spain.

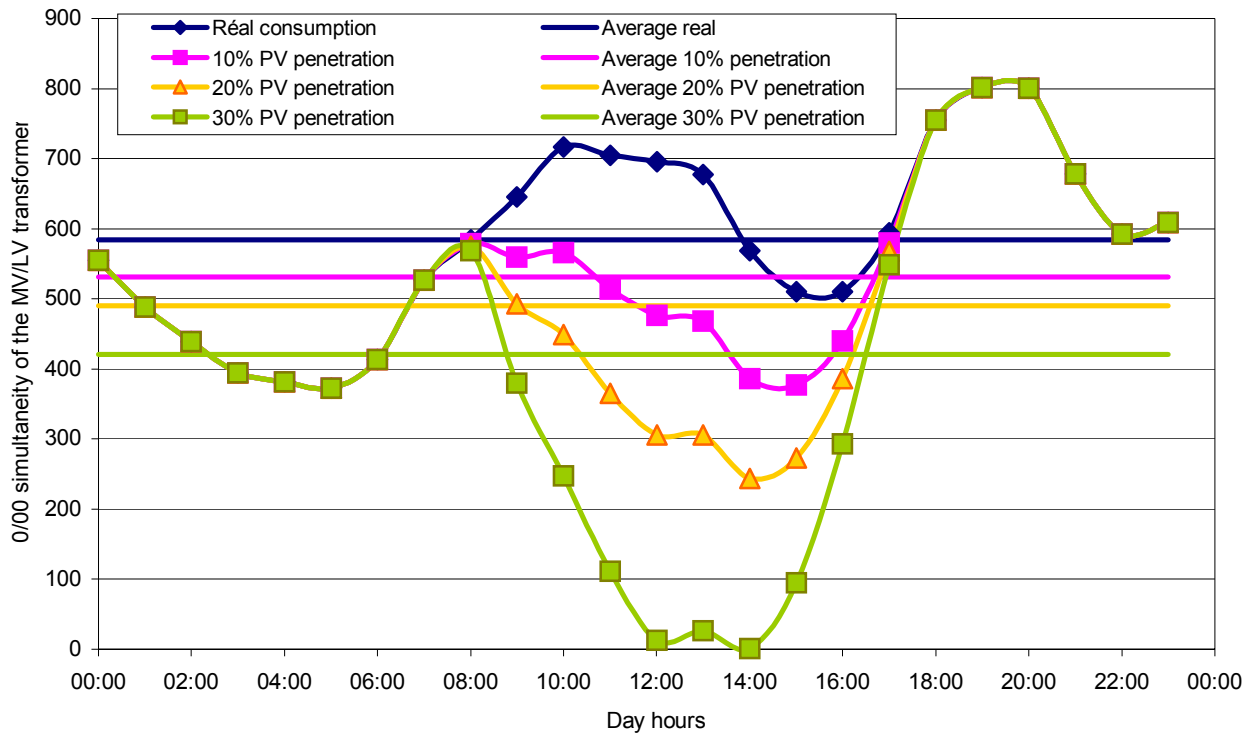


Figure 1- Load curve in an urban area in Spain:
real, with 10 to 30% PV penetration and average on the day

Clearly, direct PV injection does not help reducing the power factor of the line and does not allow taking benefit of the distributed generation. In addition, over 30% of penetration, it will induce a reverse flow of the energy at the transformer.

In the market study, three different scenarios were taken into account:

- A short term scenario in which a single feed-in tariff is applied and where the storage will be used for UPS purposes and for storing the PV energy in case of disconnection from the inverter. In this case the size of the array should supply energy at the low end of the annual consumption and the inverter should be able to feed the totality of the PV power to the grid
- A long term scenario in which the system is designed for grid support purpose and for securing the house. In this case, the inverter does not need to be of the size of the PV array since injection will happen only when the grids requires support. The storage system should have a larger size in order to store the PV energy for later feeding.
- A long term scenario with real time pricing in which it is of interest either to feed as much energy as possible during the peak times or to shed from the network.

The respective size of PV array, inverter and storage system in the three scenarios is presented in the following table.

Scenario	Short term	Long term: grid support	Long term: real time pricing
PV array size (kWp)	3	4 - 6	4 - 6
Inverter size (kW)	3	1.5	2 - 6
Storage size (kWh)	9	15	8.5

It was decided to focus on the long term scenario and to build a system for which the flexibility of installing two inverters in parallel is possible without exceeding one phase standards. Thus *the system will have an inverter of 2400 VA and a storage system with 4.5 kWh reserve energy for emergency and 10 kWh energy for daily cycling*. For the sizing stated here, detailed specification of the inverter and of the storage system were performed in term of sizing, system file, interfaces etc... In addition, tests to be performed on the inverter block on the storage system and on the global SoS-PV systems were defined.

In parallel to the sizing and specification of the different components of the SoS-PV system, a research was done in order to identify the barriers to the introduction of the SoS-PV system and to exploitation of its full benefits. **Barriers identified** so far for the full exploitation of the benefits of the SoS-PV system are:

- For the exploitation of the benefits by the PV owner
 - Possibility of injecting electricity to the network directly from a storage unit.
 - Retribution of the PV system owner via flexible feed-in tariff or an incentive from the utility to PV owners that install a SoS-PV system.
 - Need of a sensor for the reactive power at the integration point.
- For the exploitation of the benefits by the utility (Distribution system operator)
 - Standard for short-circuit should take into account the installed distributed generation (DG) when this DG can be controlled by the utility.
 - need of communication interfaces between the PV owner and the utility
 - In low quality grids, PV and especially a SoS-PV system have only a positive impact on the network stabilisation when injecting in the case of a low voltage. Therefore, the low voltage threshold should be decreased.
 - Have a deregulated market in order to be able to charge clients for higher power quality
 - The utility needs to be able to control the injection of the reactive power.

Finally, strategies for demand side management were developed in order to progressively shed the loads from the house grid when the network is weak.

The possible strategies that the final user could realize are the following:

- Energy Conservation and Efficiency programs, to decrease the energy consumption,
- Load response programme, to modify the programme of energy consumption through levelling of load,
- Load control,
- Rate schedules,
- Power Factor Charges,
- Real time pricing.

During the first working period, the general information and energy flow in the system was defined in order to implement DSM strategies in the SoS-PV system.

After this first step of definition of the system and components, the project entered an active phase of making of the prototypes:

The first item dealt with the storage system development, their making and testing:

- Lithium-Ion based storage system: the first prototype was constructed, controlled and submitted to preliminary testing by Saft,
- Supercapacitor bank: the supercapacitor bank was designed to fulfil the application requirements defined earlier. The development of a 165F module for 48V was performed by Maxwell, and the use of 2 such modules in series was fitting SoS-PVi

requirements. Maxwell sent 1 supercapacitor bank to CEA and another one to TTA for integration in the hybrid storage system and testing.

- Lead-acid batteries: Hawker and EnerSys designed a new cell, then did some first capacity tests, and developed a cabinet. Two valve-regulated lead-acid battery banks were then sent to INES and TTA for integration in the hybrid storage system and testing.



Figure 2- Lithium battery



Figure 3 – Lead acid battery



Figure 4 - Supercapacitor

In parallel inverters and algorithms were developed. The tasks are listed hereafter:

- Definition of the functional components of the inverter electronic design in terms of architecture to fulfil the requirements,
- Development of a Synchronisation & Fast Cut-off Switch device and construction of the prototype (grid supervisor),
- Development of two PV-input converters with MPPT control unit: one for the Hybrid Storage device and one for the Li-Ion battery device (due to different DC voltages, **two different types of converters had to be designed**), and construction of the prototypes,
- Development of two Multifunctional Inverter units: one for Hybrid Storage device and one for Li-Ion battery device (different DC voltage), construction of the prototypes.
- Algorithms of charge and discharge for both systems (with Li-Ion battery and with hybrid storage) were implemented,
- Development of an electronic Power-Inductor-Based device for the hybrid storage system, which is suitable for an easy management of the lead-acid and the supercapacitor, in order to protect the battery against the power peaks, and construction of the prototype.

Studies concerning the **Demand Side Management** (DSM) led to the development of several electric devices:

- Development of a demand signal generator device, which is able to inform the system about the grid status –normal, overcharge... and construction of the prototype,
- Development of an automated demand management device (to connect or disconnect individually the loads according to the grid status and their level of priority) and construction of the prototype,

- Development of a User demand management device (information about the system energy status, definition of energy status modes) and construction of the prototype.

Architecture of SoS-PVi inverters :

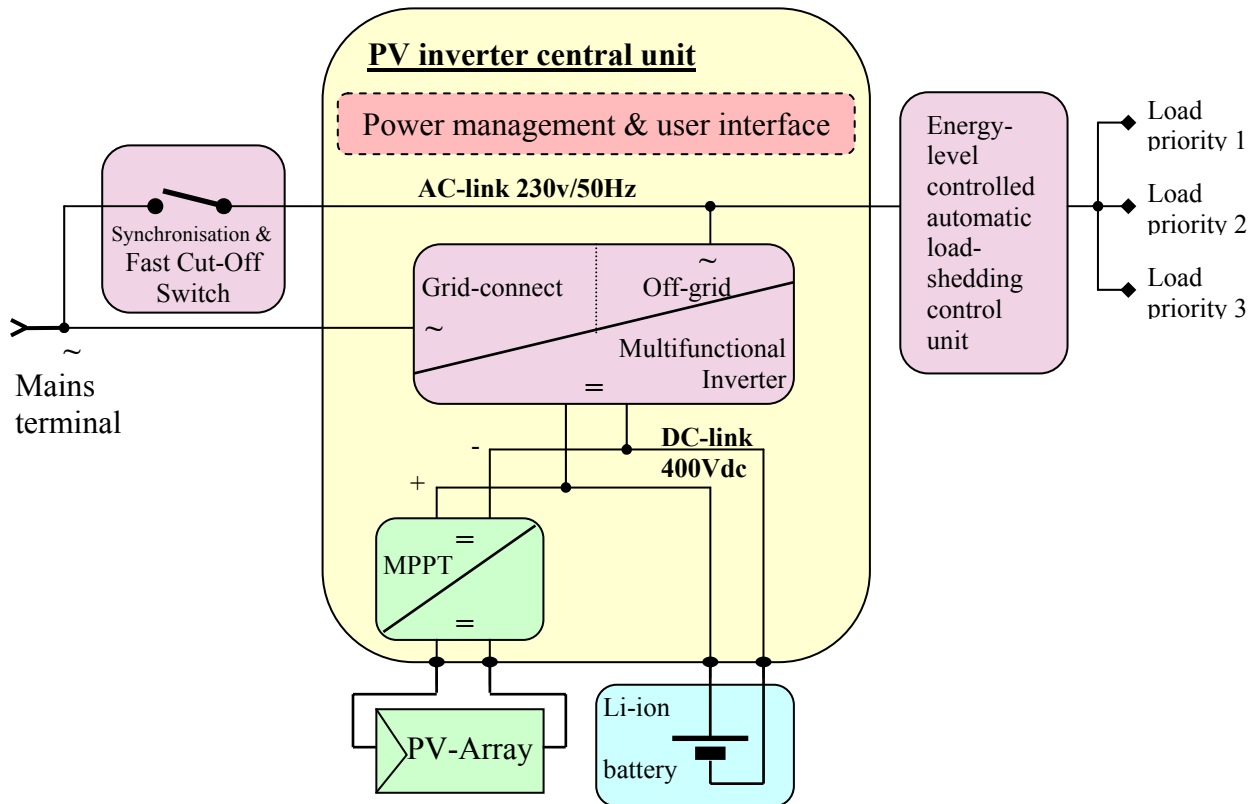


Figure 5- Architecture of SoS-PVi inverter for Li-Ion battery

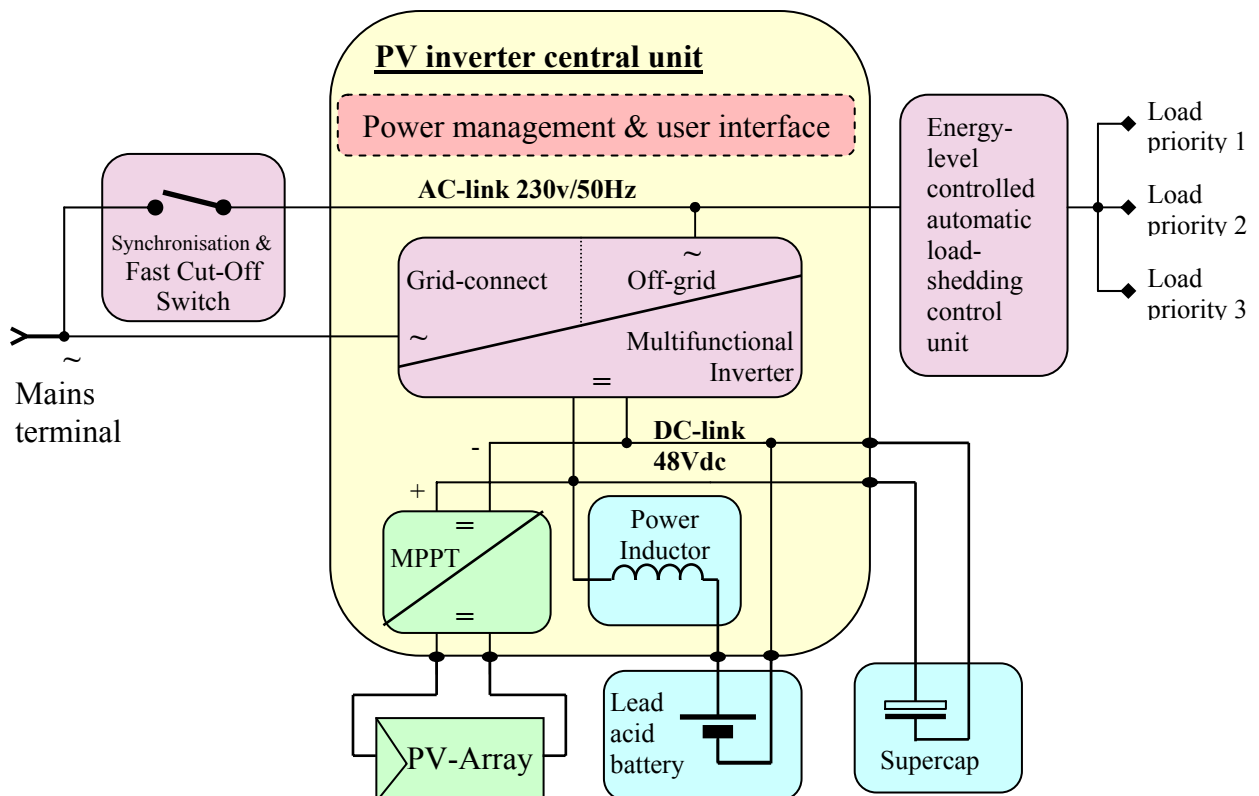


Figure 6 - Architecture of SoS-PVi inverter for Hybrid system

After the second step dedicated to the making of the prototypes, the third and last step of the project aimed at the final tests of the prototypes, the installation of the whole systems in the field (France and Spain) and the validation of operation.

Both complete storage systems have been tested according to charge/discharge profiles (including power peak pulses) that had been designed from real Spanish consumption patterns.

- Lithium-Ion based storage system: the prototype has been tested in Saft's facilities over a period of 15 months, which has shown ***no ageing effects and no loss of capacity and performance***,
- The hybrid system, made of a supercapacitor bank and lead-acid batteries, has also been tested according to the same charge/discharge profiles. Results show the good operation of the two components, and, in particular, the ***absorption of the power peak pulses by the supercapacitor***, thus protecting the battery.

In the meanwhile inverters were updated and tuned up (lithium based one and hybrid system one); they are in fact real systems consisting each of a Synchronisation & Fast Cut-off Switch device, a PV-input converter with MPPT control unit, a multifunctional inverter unit, components for the load management and components for the system monitoring.

Systems were then ready for field testing during the last months of the project:

- ***Installation of four prototypes in the field*** (two of each type in Spain and France),
- Installation of the monitoring equipment on all systems,
- Evaluation of the system operation: specific tests (voltage sags, grid interruptions ...) were done to check the operation with a weak grid, switch between grid-tied and autonomous modes ...) and ***validate the intended behaviour*** (grid support in case of shortage, improvement of solar electricity use, security of supply for the end-user ...),
- Identification of ways of optimisation.



Figure 7 – PV array of Ines facility



Figure 8 – Complete lithium based inverter with instrumentation

During the last period of the project a life cycle analysis was done to check the fulfilment of two objectives concerning cost and environmental impact:

- A life cycle analysis has been conducted in order to quantify the energy needs to operate both system types over a 20 year life time (making, use, end of life), to assess their impact on the environment, to identify the energy consuming components and make a comparison between both technologies. *The impact of the hybrid system appears to be higher due to a bigger amount of material and mainly a shorter life time,*
- A life cycle cost analysis was realised in order to calculate all the costs of both systems over their lifetime (making, transport, installation, use, disassembly ...) to make a comparison between themselves and with conventional systems. *Costs regarding the lithium and hybrid systems are in the same range considering a 10 year life time today; in the long term (year 2020) and considering a 20 year life time, the lithium system is less expensive.*

During the whole duration of the project, networking activities were undertaken to promote the issue of grid-connected storage among the community of European project researchers, and in particular, assess the possibility of integration of SoS-PV systems in Virtual Power Plants (VPP), which are a centrally controlled aggregation of decentralised energy resources:

- Networking the project with activities on Decentralised Energy Resources within European projects, in particular the IRED cluster, identification of common issues (barriers to further penetration, need for the regulatory framework, communication needs ...), needs for the specific case of SOS-PV,
- Study of the possibility of SOS-PV system integration in a Virtual Power Plant to assess the interest of this configuration and identify the improvements to be realised on the prototypes.

2 Dissemination and use

Plan for using and disseminating the knowledge: Section 3 - Publishable results

- **Li-Ion battery for grid connected PV systems (SAFT):** none.
- **Specific VRLA battery design (Energys & Hawker):** see section1 of plan for dissemination.
- **Demand management through load switching, Interactive Power Conditioning, Ripple reduction for batteries and Grid power interface (TTA):** the level of industrial maturity has not been reached beyond prototype stage and, therefore, further development of the concept and protection of the knowledge before we can make it public is necessary.
- **UltraCapacitors Module BMOD0165 E048 (Maxwell Technologies SA) :** see next pages.



**Series: BMOD Energy
48 Volt Module**

- » Low Internal Resistance
- » High Energy Availability
- » Low Time Constant

› **Features:**

- » 48.6V Operating Voltage
- » Over 1M duty cycles
- » Low internal resistance
- » High energy density
- » Individually balanced cells
- » Mountable option included
- » Voltage and temperature sensor output included

› **Applications:**

- » Industrial
- » UPS
- » Power Quality
- » Telecommunication
- » Renewable energy



› **Overview:**

The Energy-type ultracapacitor product line gives industrial customers a much wider range of choices to meet their energy storage and power delivery requirements. The modules are specifically engineered to provide cost-effective solutions for UPS, telecommunications and other lighter duty industrial electronics applications.

In addition to meeting or exceeding demanding industrial application requirements for both watt-hours of energy storage and watts of power delivery per kilogram, all of these products will perform reliably for more than one million discharge-recharge cycles.

The proprietary architecture and material science on which BOOSTCAP® products are based enable continued leadership in controlling costs, flexibility in product offerings and allow application specific performance tailoring.

The cells used in the modules operate at 2.7 volts, enabling them to store more energy and deliver more power per unit volume than any other commercially available ultracapacitor.

› **Series Specifications:**

Item		Performance
Operating Temperature Range		-40 °C to +65 °C
Storage Temperature Range		-40 °C to +70 °C
Rated Voltage		48.6 V DC
Capacitance Tolerance		+20%
Resistance Tolerance		Max.
Temperature Characteristics	Capacitance Change	Within ± 5% of initial measured value at 25 °C (at -40 °C)
	Internal Resistance	Within 150% of initial measured value at 25 °C (at -40 °C)
Endurance	After 1500 hours application of rated voltage at 65 °C	
	Capacitance Change	Within 20% of initial specified value
	Internal Resistance	Within 60% of initial specified value
Shelf Life		After 1500 hours storage at 65 °C without load shall meet specification for endurance
Life Test	After 10 years at rated voltage and 25 °C	
	Capacitance Change	Within 30% of initial specified value
	Internal Resistance	Within 150% of initial specified value
Cycle Test	Capacitors cycled between specified voltage and half rated voltage under constant current at 25 °C (1 million)	
	Capacitance Change	Within 30% of initial specified value
	Internal Resistance	Within 150% of initial specified value

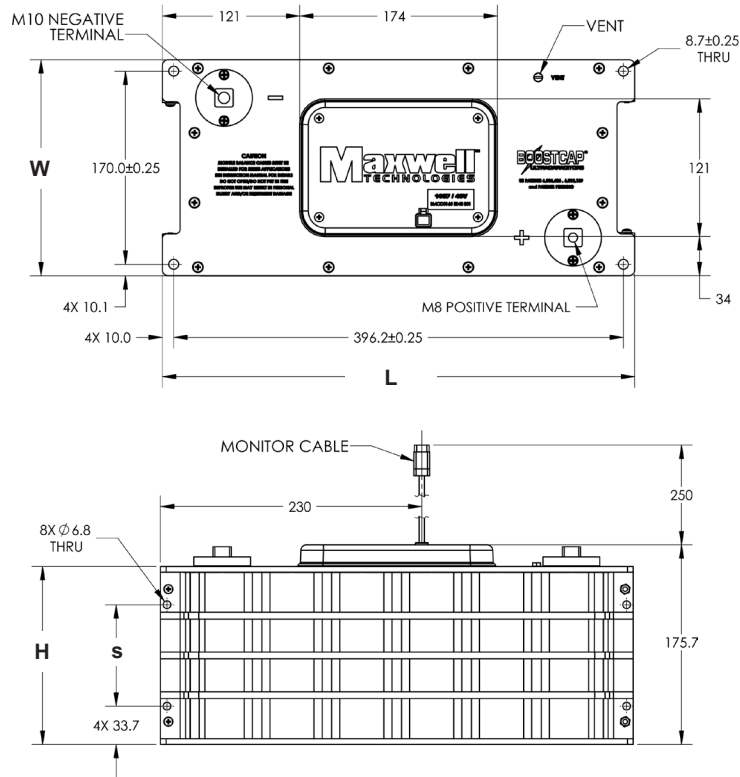
› **Product Specifications:**

Maxwell Part No.	Capacitance (F)	ESR, DC (mohm)	ESR, 1kHz (mohm)	Ic (mA)
BMOD0083 E048	80	16.0	12.8	3.0
BMOD0110 E048	110	12.0	9.6	4.2
BMOD0165 E048	165	8.5	6.3	5.2

› **Product Properties:**

Maxwell Part No.	Rth (C/W)	Isc (A)	Emax (Wh/kg)	Pmax (W/kg)	Pd (W/kg)
BMOD0083 E048	0.39	3,900	2.48	4,100	1,600
BMOD0110 E048	0.33	4,300	2.91	4,900	1,900
BMOD0165 E048	0.25	4,800	3.81	6,600	2,600

› **Dimensions:**



Part Number	Vol (l)	Mass (kg)	Size (mm)			
			L (+/- 0.25)	W (+/- 0.25)	H (+/- 0.5)	s (+/- 0.5)
BMOD0083 E048	8.5	11.0	416.2	190.1	103.2	53.7
BMOD0110 E048	9.8	12.4	416.2	190.1	120.2	70.7
BMOD0165 E048	12.6	14.2	416.2	190.1	156.7	89.3

Product dimensions and specifications may change without notice. Please contact Maxwell Technologies directly for any technical specifications critical to application.

› **Markings: Modules are marked with the following information**

Rated capacitance, rated voltage, product number, name of manufacturer, positive and negative terminal, warning marking, serial #

› **Mounting Recommendations:**

Modules can be secured at 8 locations, 4 front face and/or 4 bottom face, at provided holes for M8 bolts. Follow user manual instructions for terminal, balance and output connections.

Patent Pending

Worldwide Headquarters

MAXWELL TECHNOLOGIES
9244 Balboa Avenue • San Diego, 92123 CA, USA
PHONE: +(1) 858 503 3300
FAX: +(1) 858 503 3301
EMAIL: info@maxwell.com

European Office

MAXWELL TECHNOLOGIES SA
CH-1728 Rossens • Switzerland
PHONE: +41 (0) 26 411 85 00
FAX: +41 (0) 26 411 85 05
EMAIL: info@maxwell.com

> **Additional Technical Information:**

Capacitance and ESR, DC measured per document 1007239

I_c = Leakage current after 72 hours, 25°C I_{sc} = short circuit current (maximum peak current)

R_{th} = Thermal resistance

$$E_{max} = \frac{\frac{1}{2} CV^2}{3600 \times mass} \qquad P_{max} = \frac{V^2}{\frac{4R (1kHz)}{mass}} \qquad P_d = \frac{0.12V^2}{\frac{R (DC)}{mass}}$$

**Disclaimer of Warranty/Limitation of Liability
for Uses in Life Support Devices or Critical Systems**

Maxwell Technologies, Inc. and its Affiliates (“Maxwell”) provide no warranties of any kind either express or implied, including (without limitation) the implied warranties of merchantability and fitness, for uses of its products as components in life support devices or critical systems.

“Life support devices” are devices or systems, which (a) are intended for surgical implant into a living body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with the instructions provided in the labeling can be reasonably expected to result in bodily injury to the user. An example of a life support device includes, but is not limited to, a heart pacemaker.

A “critical system” is any system whose failure to perform can affect the safety or effectiveness of a higher level system, or cause bodily or property injury by loss of control of the higher level device or system. An example of a critical system includes, but is not limited to, aircraft avionics.

Maxwell will not be liable to you for any loss or damages, either actual or consequential, indirect, punitive, special, or incidental, arising out of or relating to these terms.

Patent Pending

Worldwide Headquarters

MAXWELL TECHNOLOGIES
9244 Balboa Avenue • San Diego, 92123 CA, USA
PHONE: +(1) 858 503 3300
FAX: +(1) 858 503 3301
EMAIL: info@maxwell.com

European Office

MAXWELL TECHNOLOGIES SA
CH-1728 Rossens • Switzerland
PHONE: +41 (0) 26 411 85 00
FAX: +41 (0) 26 411 85 05
EMAIL: info@maxwell.com