HIGH PERFORMANCE AND RELIABLE MPPT SOLAR ARRAY REGULATOR FOR THE LOW MASS PCDU OF LISA PATHFINDER

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ABSTRACT

LISA PCDU is a very optimised and reliable Power Conditioning and Distribution Unit based on an unregulated 28 V bus, maximum power point tracker (MPPT). The high demanding specification in terms of mass, efficiency and performances can be fulfilled only with unconventional, less conservative solutions. An enormous effort has been done to prove the reliability and robustness of the adopted solutions. Moreover, LISA PCDU faces and solves typical problems of battery follower MPPTs: damage of Li-Ion batteries in case of overdischarge, operation without battery and power loss in Conductance to MPPT transitions.

The MPPT Solar Array Regulators module is one of the most impacted designs. The paper explains the main challenges faced and the relevant solutions adopted to achieve this highly optimised and reliable design.

1. INTRODUCTION

LISA Power Conditioning and Distribution Unit (PCDU) fulfils a very demanding specification in terms of mass (with big penalizations if not met), efficiency and performances. It is a 28 V unregulated bus, maximum power point tracker (MPPT) of the solar array (SA). Refer to [1] for more information.

Unconventional and less conservative solutions must be adopted to meet these requirements. At the same time, reliability and robustness of the product can not be compromised. References [2] and [3] are a clear example of the challenges that must be faced to develop this kind of flight product within the programmatic and budget constraints of a project. An enormous effort has been done in LISA PCDU to prove the EOL performances and the reliability of the solutions adopted.

LISA PCDU not only fulfils this demanding specification but also, in order to improve further the reliability of the PCDU, faces and solves typical problems of MPPT battery followers.

Li-Ion batteries can be damaged and becomes useless if the cell voltage goes below a minimum voltage. At these low voltages, it is not necessary to keep the Main Bus supplied in eclipse. LISA PCDU disconnects autonomously the battery form the Main Bus to minimise as much as possible the discharge current. When sunlight power is available it re-connects autonomously to charge the battery.

The use of a solid state relay enables this functionality and, at the same time, helps to achieve the tight required mass figure. The solid state relay based on MOSFETs saves 1 kg of PCDU mass.

Derived from this functionality, the design is very robust to operate without a battery connected to the bus at ground testing.

Another reliability improvement is a novel control method which allows recovering much of the power drop in a Conductance to MPPT transition within less than 3 ms. Then, the control circuitry waits for the MPPT control to find and operate at an average power within 1% WC of the maximum power point of the SA. Thus, the bus voltage drop during the time the MPPT control needs to start up is minimised. This prevents the false trigger of an LCL or FCL (essential loads) undervoltage in case the battery voltage is low, especially at entering/exiting eclipse with a cold SA.

The Solar Array Regulator (SAR) module of the PCDU is one of the most affected designs to fulfil all these requirements.

2. RELEVANT LOW MASS PCDU DRIVERS

LISA Pathfinder PCDU weights only 13.5 kg (2 kg less than the specified design requirement) while providing a peak output power capability of 850 W, implementing a 3x425 W MPPT module (>94% to 98.5% efficiency), 20+20 latching current limiters, 5+5 foldback current limiters, 32+32 protected heater switches, 11+11 pyrotechnic lines, plus nominal and redundant MIL-Bus 1553 TM/TC links.

Not one but many innovative design solutions made possible the fulfilment of the tight mass requirement. The following paragraphs explain the most relevant solutions adopted.

2.1 High efficiency design of the SA regulators

A low mass design becomes a challenge for the thermal management of the unit. Therefore, a big effort was done to reduce the power consumption of the PCDU at all levels.

For example, all the sensing resistors are sized to the minimum values; all bias currents of functions supplied directly from the SA or bus voltages are reduced to the

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minimum. These decisions require spending a big effort in WC analysis to prove the performances at EOL.
One of the most impacting decisions was to remove the output diode in each SAR converter.
The output diode in each SAR converter is usually used to avoid failure propagation to the bus and battery. It simplifies the failure contention at the cost of reducing the efficiency and increasing the power dissipation.
In LISA PCDU, the use of output diode would increase the losses in 20 W at full power. Clearly, an efficiency higher than 94.6 % at 850 W 28 V bus for VSA ≤ 60V, measured in the LISA EQM (including protection elements and control losses), is not possible with an output protection diode in each SA regulator. Besides, a maximum TRP of 60º would not be possible without the use of a heavy baseplate.
On the other hand, the protections to avoid failure propagation to the Main Bus and battery become a challenge without this diode. Later, it is explained how the removal of the output diode affects the design of the MPPT SAR converters.

2.2 Avoiding electromechanical relays in the battery switch

LISA PCDU uses a solid state switch for connection and disconnection of the battery to the Main Bus based on power MOSFETs. The advantages over electromechanical relays in terms of mass and reliability seem clear.
However, a careful and optimise design of the electronics around the battery switch is necessary to retain the mass and reliability targets. Despite the little higher dissipation of the battery switch at full battery current and the extra number of components, LISA battery switch saves up to 1 kg of mass at unit level.
Besides, as explain later, the solid state switch enables new functionalities of the battery switch like the battery isolation during flight operation to protect the battery.

2.3 Avoiding electromechanical relays in the pyro chain

Another area of improvement is a pyrotechnic driving module that, implementing the classical security barriers required for this kind of circuits, substitutes all the relay-based barriers by solid state MOSFET-based switches.
The same comments as in 2.2 before can be done regarding the design of the electronics around the security barriers.

2.4 Minimizing bus capacitor

The MEA bandwidth is push to the limit to minimize the output capacitor while keeping the required stability margins.
Complex WC analysis and accurate control models were done from the beginning to guarantee the required output impedance at EOL with the required stability margins.

2.5 Mechanical concept of the unit

The unit mechanical concept and bus bar implementation also contribute in a relevant way to the achievement of the required mass figure.

3. RELEVANT RELIABILITY PCDU DRIVERS

Apart from the reliability issues derived from the unconventional solutions that must be adopted to meet the requirement specification (which by themselves are a design challenge), LISA PCDU also faces and solves typical problems of MPPT designs for unregulated buses.
Typical battery follower PCDUs are designed relying too much in the presence of a low impedance battery connected to the Main Bus.
This is not the case at ground testing or the case of a very cold battery (high battery impedance) in which the PCDU should not limit to operate properly but also retain reliability and robustness.
Besides, as Li-Ion batteries can be damaged if they are overdischarged, LISA PCDU protects a discharged battery at flight operation by isolating the battery from the Main Bus in eclipse when it is not needed.
Finally, the impedance of the battery could not be low enough to avoid large transients bus voltage drops when the SAR converters fail to deliver power in Conductance to MPPT transitions.

3.1 Autonomous isolation of the battery in flight operation in case of overdischarge and operation without battery

The predictable and controllable connection and disconnection action of the solid state relay enables the isolation of the battery and its connection in flight operation, where the external pre-conditioning of the bus capacitor is not possible. Since Li-Ion batteries are damaged if the cell voltage goes below a minimum voltage, this is a very desirable function for the battery switch.
This is an important advantage over electromechanical relays which are difficult to manage in the connection and disconnection to the bus capacitor. These actions are safe only if certain and stable conditions are given: no switch current and equal voltages at both sides of the relay. Thus, arcing and large inrush current can be avoided respectively. These conditions can be guaranteed only with an external pre-conditioning of the bus capacitor, not possible in flight operation.
LISA PCDU isolates the battery from the Main Bus in case of a low battery voltage and no solar power available. At this minimum battery voltage, no essential load is connected and, therefore, the battery is not

necessary for operation. The energy stored in the battery harness is dissipated in the switch without any stress for the switch.

As soon as the SA power becomes available again, the battery is connected to the bus capacitor avoiding any stress in the battery switch. The connection occurs only when the bus voltage is a little bit higher than the battery voltage to avoid the large inrush current to charge the bus capacitor (or energy dissipation) in the switch.

This new functionality is a big change at PCDU level since the battery can be disconnected from the bus at flight operation.

Typical unregulated buses are design accounting for a permanent connection of the battery. A ground testing, this battery could not be present and the design enables operation without battery but becomes less robust to failures or human errors.

Derived from this new functionality, LISA PCDU is robust and reliable operating without a battery connected.

3.1.1 Operation without battery connected

At ground testing, it is normal practice to test the PCDU without a battery (or emulator) connected. The MEA loop guarantees no overvoltage at the bus voltage. However, some precautions are put on the user manual to avoid any abnormal start-up transient condition. For example, the bus capacitor must be pre-conditioned before SAR operation for proper initialization of the electronics.

LISA PCDU design enables the use of the PCDU without a pre-conditioning of the bus voltage. The PCDU can start-up from the SA with a proper Main Bus formation and a proper initialization of all the electronics.

Clearly, this requirement is derived from the autonomous disconnection of the battery at flight operation.

The impact in the MPPT SAR design is also clear: it should be capable to deliver power to a fully discharge bus capacitor in a controlled way to raise the bus voltage. Later, the impacts in the MPPT SAR design are more detailed.

3.2 Avoiding sudden loss of SA power when most needed

Typical MPPT regulators exhibits sudden power drops in conductance to MPPT transitions. When MEA demands more power than available in the SA, the MEA loop becomes unstable and the SAR converters saturate to maximum duty cycle (SA voltage collapses to the bus voltage).

Instead of increasing the SA power, the Main Bus sees a sudden drop of power until the MPPT reacts and finds the maximum power. The battery delivers this power with a voltage drop that depends on the battery impedance.

The expected steady state voltage drop after the transition to MPPT is:

$$\Delta v_{drop\_dc} = \frac{(P_{user\_1} + P_{bat\_0} - P_{mp} \cdot \eta)}{V_{bus}} \cdot (R_{bat} + R_{harness\_bat}) \quad (1)$$

where P_{user_1} is the user load after the transition, P_{bat_0} the power into the battery before the transition in conductance mode and P_{mp} the maximum power of the SA. This is the normal and expected voltage drop that can not be avoided.

The additional transient voltage drop during the MPPT start-up time (SA collapses to the bus voltage) is given by the following equation:

$$\Delta v_{drop\_transient} = \frac{\eta \cdot P_{mp} - V_{bus} \cdot I_{sc}}{V_{bus}} \cdot (R_{bat} + R_{harness\_bat}) \quad (2)$$

A useful and design-oriented approximation is given by:

$$\Delta v_{drop\_transient} \approx P_{mp} \cdot \frac{\eta \cdot V_{mp} - V_{bus}}{V_{bus} \cdot V_{mp}} \cdot (R_{bat} + R_{harness\_bat}) \quad (3)$$

P_{mp} is the maximum power available in the SA, V_{mp} is the voltage at maximum power point, η the efficiency of the SARs and R_{bat}+$R_{harness}$ the impedance of the battery connection.

Typically, this transient lasts from 100 ms to 500 ms since the MPPT action is slow and needs to start-up and to find the operating point.

From (3), the WC maximum voltage drop is for maximum impedance in the battery path, maximum power in the SA, maximum SA voltage and minimum bus voltage. WC for LISA PCDU is: Z_{bat_path}= 80 mΩ, V_{mp}= 80 V, P_{mp}= 900 W (a higher P_{mp} is not considered since the bus load can not overpass this value and no conductance to MPPT transition would result), V_{bus}= 23 V, η= 95 %, then v_{drop}= 2 V. This 2 V should be added to the normal expected voltage drop. The bus voltage could drop below 21 V, low enough to switch off the FCLs of the essential loads.

This WC conditions can be found during eclipse to sunlight transition where the SA is cold and I_{sc} is low but the SA voltage is high.

This undesired transient degrades the Main Bus quality and may result in an unexpected trigger of an LCL or FCL output.

LISA PCDU avoids this unwanted behaviour minimizing the duration of this transient voltage drop to less than 3 ms. Thus, a more reliable and predictable PCDU is obtained.

4. IMPACTS IN THE MPPT SAR DESIGN

The SA characteristics for the LISA Pathfinder mission are 6 SA sections, 34 V minimum MPPT voltage hot case EOL; 91 V maximum V_{oc} voltage cold case; 23 A maximum I_{sc} current. No reduction of the SA available power is allowed, even after one failure in the PCDU.
This requirement together with stringent mass and efficiency/dissipation requirements leads to a highly optimised SAR design in which a single module accommodates the power of all the SA sections connected in parallel.
Clearly, the reliability of this module becomes a challenge for the following reasons:

- The compactness of the module is a challenge to avoid failure propagation between redundant functions.
- The high efficiency claims for a high optimization of all auxiliary and protections functions. Less conservative solutions must be adopted and many WC and FMECA analyses are required to prove the EOL performance and the reliability. Detail knowledge of the components parameters are required to achieve this high optimisation.
- The SA input is a critical hot line that should be double isolated.

Moreover, LISA PCDU, as seen before, faces and solves typical problems of MPPT, unregulated buses which impacts dramatically the SAR design:

- Avoiding loss of power in conductance to MPPT transitions.
- Start-up from SA without battery connected and without Main Bus pre-conditioning.

These new functionalities try to improve the reliability of the design but, at the same time, demands careful analysis to prove that the reliability of the other functions is not compromised.

4.1 SA power management

The SAR modules comprises 3 DC-DC converters in parallel fed from the same SA voltage and in hot redundancy with equal current sharing both in MPPT and conductance mode. The specification requires a current matching better than 10 % in all operating modes.
Each regulator has a total output power capability of 425 W, being two of them able to cope with 850 W, which is the actual maximum power need.
The MPPT is capable to find the maximum power point with an error less than 1 % of this power at EOL. Details of the MPPT operation can be found in [4].
Figure 1 shows a simplified schematic of the power core of one SAR converter with the auxiliary protection elements.

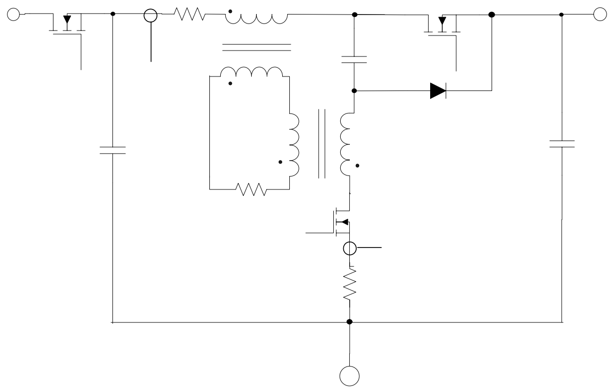

Figure 1 Simplified electrical circuit of one SAR DC-DC converter.

The 3 DC-DC converters behave as voltage-controlled output current sources under MEA control. An output current loop is closed in each converter to achieve the current source behaviour. It has good bandwidth (around 20 kHz) to achieve good stability margins in the MEA loop.
The following section explains the regulation of the SAR converters to achieve equal power sharing under MPPT control.

4.1.1 MPPT control of the parallel converters

The three SAR converters have to share the SA power during the MPPT control meeting the required stability margins. A current sharing better than 10 % is required.
The MPPT control comprises three hot redundant control stages. They find the maximum power of the whole SA. This power must be shared equally among the SAR converters. Therefore, one unique, failure free signal should determine the operating point of the SAR converters. This signal is the majority voted result of the three redundant MPPT controls signals.
This signal should be the reference to an inner control loop in each regulator, thus the same operating point can be guaranteed in each SAR converter.
The inner output current loop for the MEA control can not be used since this is an unstable loop in MPPT operation. The only inner loop that guarantees input current sharing with accuracy is an input current loop. The input current loop in the Super Buck converter exhibits a very good dynamic response. It is a single pole at the cross-over frequency.
Therefore, the MPPT signal is the current reference for an input current loop in each SAR converter. The bandwidth of the input current loop does not need to be high since the MPPT command is slow. An inner bandwidth of 4 kHz is more than enough.
A novel control mechanism avoids any resonance of the input filter to appear in the loop gains. Thus, better stability figures are achieved.

4.1.1.1 Test results

The following Bode measurements show the good stability margins for the input current loop at different operating conditions. The measurements were taken in one SAR converter of the EQM module.

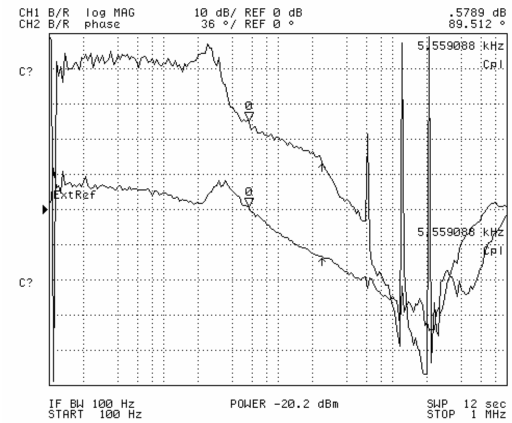

Figure 2 Input current loop gain VSA=34 V, ISA=10 A (Start 100 Hz, stop 1 MHz)

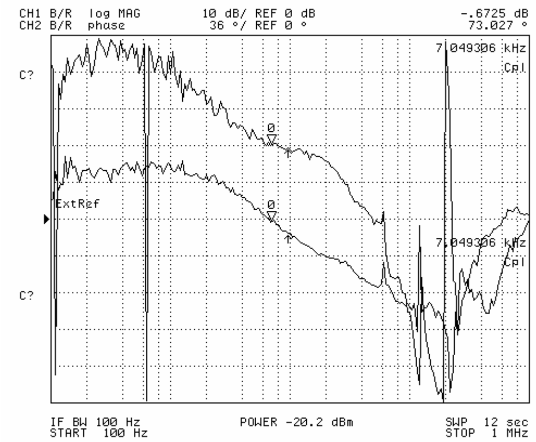

Figure 3 Input current loop gain VSA=60 V, ISA=7.5 A (Start 100 Hz, stop 1 MHz)

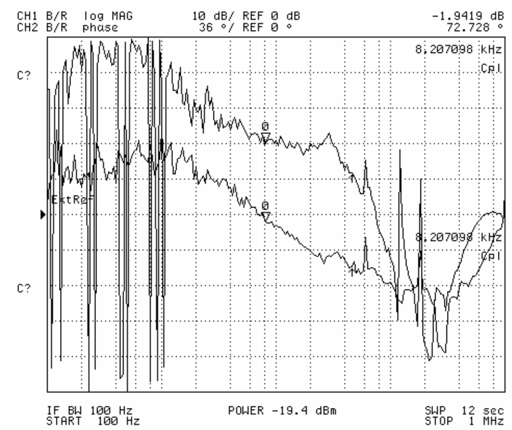

Figure 4 Input current loop gain VSA=80 V, ISA=6 A (Start 100 Hz, stop 1 MHz)

4.2 Avoiding the output diode in the SAR converters

The high efficiency requirement does not allow using an output diode in each SAR converter to avoid failure propagation to the Main Bus. Avoiding the output diode saves 20 W of power dissipation at full SA power.

Figure 5 shows the efficiency measurements taken in the EQM SAR module.

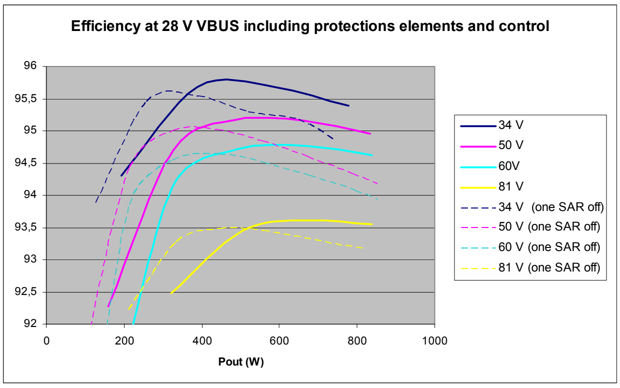

Figure 5 SAR module efficiency figures including control and protections elements

The absence of the output diode complicates the detection and contention of failures in the SAR module. This point was considered from the beginning of the MPPT design.

4.2.1 Dealing with the SC to ground of the Main Bus

A clean routing of the bus line was done to guarantee double isolation of this critical line. Definition of net classes and properties in the schematics enable automatic check of the double isolation rules during the PCB routing.

All the failures in the converter leading to a Main Bus SC to ground can be detected looking at the current of the ground inductor. The current rise rate is limited by this inductor.

The SAR protection detects a fault current in the ground path (positive current) and opens the ground switch MOSFET (refer to *Figure 1*). The action over this switch is fast enough to avoid the saturation of the ground inductor. *Figure 6* shows the actuation of this protection.

This is not a latching protection but a hysteretic protection. If the converter is operating properly and the ground current becomes negative, then the body diode of protection MOSFET allows proper operation of the converter. If the current is negative enough the protection MOSFET switches on again and the high efficiency is recovered.

When the ground switch is opened to protect the Main Bus, the converter would operate in a highly dissipative state. This dissipative state could damage the other converters. Although the opening of the ground switch is not latching itself, it is necessary to stop the converter permanently to avoid failure propagation. After the ground switch is opened, the converter is latched to an off state after 20 ms.

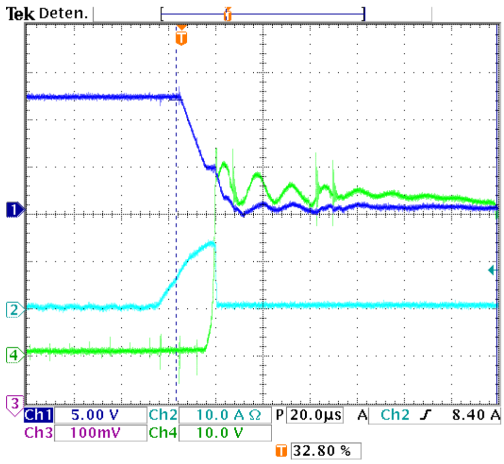

Figure 6 Actuation of the SC to ground protection (20 µs/div) (Cyan: fault ground current (10 A/div), green: drain-source voltage of ground switch (10 V/div, blue: gate-source of ground switch (5 V/div))

4.2.2 Dealing with the SC between Main Bus and SA

A SC between Main Bus and SA can lead to a permanent loss of SA power or an overcharge of the battery. The system detects these failures saturating the failure free MPPT or MEA signal to zero power respectively.
The detection of this failure is quite simple with an output diode: a failed converter keeps the anode voltage high when it should be zero.
Without output diode, the only way to detect a failed converter is looking at the coherence of the failure free MEA/MPPT signal with the output/input flowing current in each converter.
The current of a failed converter will be always higher than the required by the MEA or MPPT signals. The protection detects this condition and opens the input switch to isolate the failed converter from the SA.
Care should be taken if the same current sensor is used for control and protection. A failure in the control current sensor leading to a zero current measurement is a permanent SC of the SA to the Main Bus. In this condition, the protection also fails to detect the failure. The use of different current sensors seems the most robust solution but penalizes the component count and the power dissipation. The same current sensor can be used if the failures in the current sensor are detected by dedicate protections.

4.3 Avoiding the power loss in Conductance to MPPT transitions

The LISA MPPT develops a novel control mechanism that minimizes the Main Bus voltage drop during the MPPT start-up and searching.
The MPPT control detects a conductance to MPPT transition and regulates the SAR converters to operate in a point close to the maximum power point during the whole MPPT start-up time, avoiding the duty cycle saturation. An initial big bus voltage drop can not be avoided but its duration is limited to less than 3 ms.
The operating point during the MPPT start-up is kept almost constant, thus minimizing the transient bus voltage drop. This point is at a SA voltage below the maximum power voltage. The mechanism self adapts to the I-V curve of the SA. In WC conditions, the stand by point delivers the 83 % of the maximum power point.
Since the large voltage drop is limited to a time duration less than 3 ms, it is possible to avoid a false UV trigger of the LCLs or FCLs if they are programmed so.
The SAR converters share equally the total SA power during the transient with the required stability margins.
This mechanism is single failure free. Moreover, it could stand a failure in one SAR converter and a failure in the control.

4.3.1 Test results

Figure 7 shows a conductance to MPPT transition taken in the EQM model. The transient is caused by increasing the bus power over the maximum available in the SA.
The SA simulator is programmed with V_{oc}= 65 V, I_{sc}=17.1 A, V_{mp}= 58 V and I_{mp}= 16.5 A. The bus voltage is 29 V and the battery is in EOC. Before the load transient, the operating point was close to MPP with a bus load of 800 W. An LCL is closed and a load step of 6 A happens.
The measured impedance of the battery simulator and harness is around 57 mΩ.
Eq. (1) gives 0.12 V for the steady state drop. Eq. (2) gives an additional transient drop of 0.82 V for these conditions when the SA collapses. Thus, the total bus voltage drop is around 0.95 V. *Figure 8* shows the detailed transient. The measured big voltage drop is around 1.06 V, in line with 0.95 V. Thanks to the novel control strategy, the transient lasts only 3 ms, not the whole MPPT start-up time (500 ms).
After the big drop and during the MPPT start-up time, the bus voltage drop is only 0.3 V, in line with more than 83 % of the P_{mp} delivered during this time. Eventually, when the MPPT finds the maximum power point, the bus voltage drop is 0.1 V as expected by (1).
No LCL or FCL undervoltage was triggered during the transient.

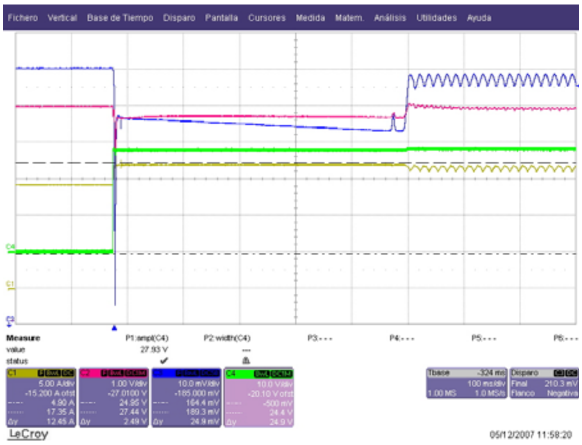

Figure 7 Conductance to MPPT transition (V_{oc}=65 V, I_{sc}=17.1 A, I_{mp}=16.5 A, V_{mp}=58 V) (100 ms/div), (Blue: SA voltage (5 V/div), yellow: SA current (5 A/div), magenta: bus voltage (1 V/div), green: LCL output (10 V/div))

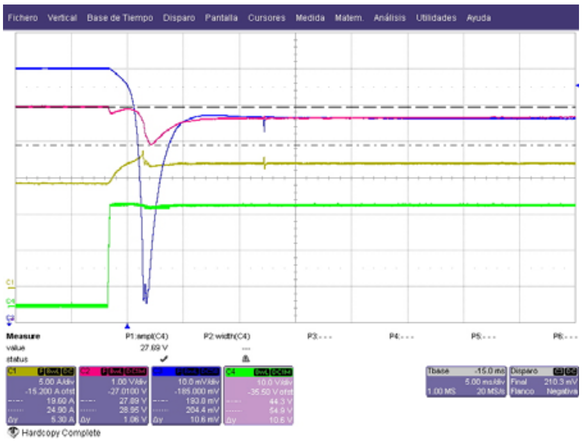

Figure 8 Detail of Figure 7: Big voltage drop and recovery in 3 ms (5 ms/div), (Blue: SA voltage (5 V/div), yellow: SA current (5 A/div), magenta: bus voltage (1 V/div), green: LCL output (10 V/div))

4.4 Power fault recovery with isolated battery and PCDU operation without battery

The isolation of the battery in flight operation changes some design concepts of the SAR converters and MEA module. Clearly, the SAR converters in LISA PCDU are required to start-up without a battery connected to the bus and with a fully discharge bus capacitor.

Since the SA regulators behave as current sources controlled by MEA, a controlled rise rate of the bus voltage can only be done under supervision of MEA.

A soft-start mechanism is implemented in the battery module where MEA resides. A bus undervoltage circuit triggers a soft start action in MEA module after power on reset or each time the bus voltage drops. Thus, MEA control the rise slew rate of the bus voltage. This mechanism is failure free.

MEA should start the soft-start action only when the SAR converters are ready to track the MEA signal. Synchronization between SAR converters and MEA is required to start-up when the SA converters can operate properly. This synchronization is also failure free.

MEA power supply comes directly from the SA when the battery switch is open and SA power is available (the same supply used in the SAR converters). Thus, it is possible to initialise correctly the MEA circuitry that controls the bus start-up. When the auxiliaries DC-DC converters are operative, the MEA SA supply is disabled to reduce power dissipation.

The soft start action allows a proper start-up from the SA without any bus overvoltage and a proper autonomous connection of the battery switch.

When the bus voltage is slightly higher than the battery voltage, the battery switch closes and the battery starts to charge at the maximum programmed current if the solar array power is enough or at the maximum power point of the SA.

4.4.1 Test results

Figure 9 shows a power fault recovery. At eclipse, the battery voltage reached a dangerous low voltage and disconnected from the bus. The bus collapsed to 0 V.

When there is solar power, the bus rises in a soft-start manner and the battery is connected once the bus is slightly over the battery voltage. Thus, no stress is imposed over the battery switch MOSFETs.

Figure 10 shows a start-up from SA power without battery connected (ground testing operation). The bus voltage reaches the EOC value without any overvoltage.

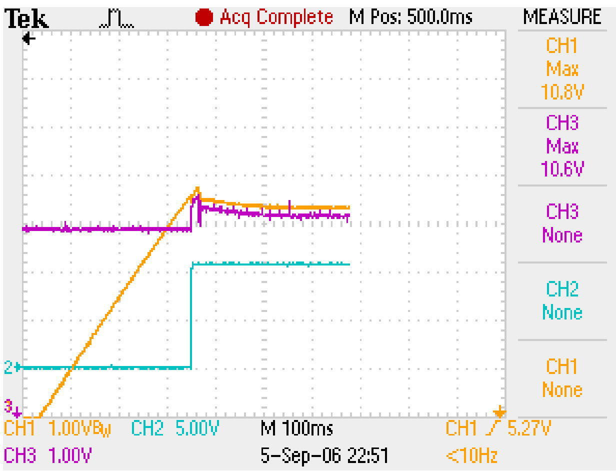

Figure 9 Power fault recovery with battery isolated from the bus and its autonomous connection 100 ms/div (Yellow: Bus voltage (1 V/div), Magenta: Battery voltage (1 V/div), Blue: On command of battery switch (5 V/div))

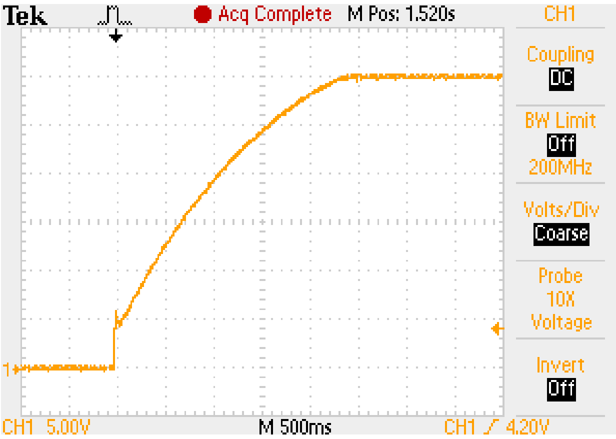

Figure 10 Start-up from SA without battery connected at ground testing
500 ms/div (Yellow: Bus voltage (5V/div))

5. CONCLUSIONS

LISA Pathfinder PCDU weights only 13.5 kg (2 kg less than the specified design target) while providing a peak output power capability of 850 W, implementing a 3x425 W MPPT module (>94% to 98.5% efficiency), 20+20 latching current limiters, 5+5 foldback current limiters, 32+32 protected heater switches, 11+11 pyrotechnic lines, plus nominal and redundant MIL-Bus 1553 TM/TC links.

Not one but many innovative design solutions made possible the fulfilment of the tight mass requirement while being compliance with the rest of high demanding requirements.

In general, these solutions are less conservative and require spending an enormous effort in analysis to prove the EOL performance and the reliability of the design.

Moreover, in order to further increase reliability, LISA PCDU faces and solves many typical problems of MPPT, unregulated designs:

- The Li-Ion battery is autonomously isolated from the bus in case of overdischarge when it is not needed for operation. Once there is SA power, the battery connects autonomously to the bus to be charged at maximum power. This mechanism protects the Li-Ion battery which becomes damaged in case of a low voltage cell.
- The PCDU is reliable in the operation without a battery connected to the bus. It starts-up properly from the SA with a fully discharged bus. No pre-conditioning of the SA is required. The PCDU can even tolerate a failure in this condition.
- The typical bus voltage drop in a conductance to MPPT transition is minimized. The initial SA power collapse is limited to a time less than 3 ms. Then, during the MPPT start-up, the SA deliver a minimum of the 83 % of the maximum power point. Thus, the bus voltage drop is minimised and the PCDU becomes more reliable and predictable.

All these features make LISA PCDU a low mass, high performance and reliable PCDU.

6. REFERENCES

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