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CONVERTING POWER INTO CONFIDENCE

Application Note – Series connection of Power Units

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Product application note. The given values are susceptible to change without prior notice.

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1. Introduction

This document describes the best practices for series connection of two MPU-R3-500-63-FD power modules to double the voltage rating.

MPU-R3-500-63-FD is a power unit (PU) designed for 50 to 500V operation with optimal efficiency in the typical 400V battery voltage range as seen on Figure 1 (from product datasheet).

Each PU delivers 25kW. They are typically connected **in parallel** to achieve higher power levels. With the arrival of new high-end EVs as well as buses and heavy-duty vehicles, charging voltage can be up to 920V[1] to allow for ultra-fast charging (250-400 kW).

Two PU (or group of PUs) can be connected **in series** to deliver up to 920V. In doing so, there are several advantages:

- Each PU works at optimal efficiency (95%) at typical 800-850V. This is key for cooling sizing of ultra-fast power stations

Figure 1: MPU-R3-500-63-FD

- Charging compatibility with 400V batteries can be done both optimal efficiency and higher current
- When guidelines of this Application Note are followed, protections such as DC output fuse and reverse diode integrated rated for the 500V systems can still be use at 920V which is a key cost advantage
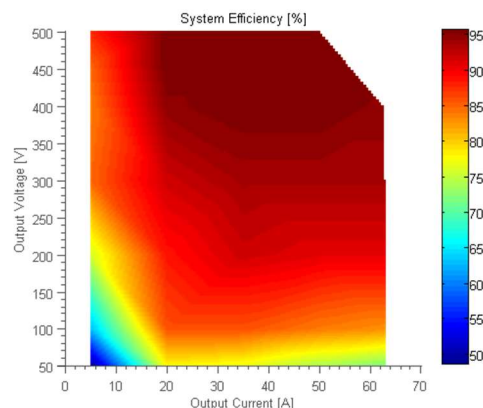
Common terms

MPU	Modular Power Unit
G2V	Grid-to-Vehicle
GUI	Graphical User Interface
CAN	Control Area Network
CANopen	Communication protocol to open and communicate with the Control Area Network
EDS	Electronic Data Sheet

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[1] As per CharIn DC power classes, maximum voltages in CCS are 920V (HPC150, HPC250 and HPC350)

2. Required Tools

2.1. Hardware

Two or more MPU-R3-500-63-FD (note that the output diode is required for series connection. MPU-R3-500-63-F is not supported)
One Insulation Monitoring Device compatible with IEC 61851-23 such as EVI-HV

2.2. CAN interface

For PC/CAN interface, it is recommended to use one of following USB transceivers:

- **Kvaser:** Leaf Light V2. Drivers can be downloaded from manufacturer website https://www.kvaser.com/product/kvaser-leaf-light-hs-v2/#/downloads
- **IXXAT:** USB-to-CAN V2 compact
- **National Instruments:** NI USB-8473 or NI USB-9861. NI-CAN drivers must be installed. They can be downloaded from : http://www.ni.com/download/ni-can-18.5/8074/en/

2.1. GUI environment

Recommended Graphical User Interface (GUI) is MPU Monitor. It is a Windows-based GUI for easy access to measurements, monitoring and configuration parameters. Operation is described in the MPU GUI user guide.
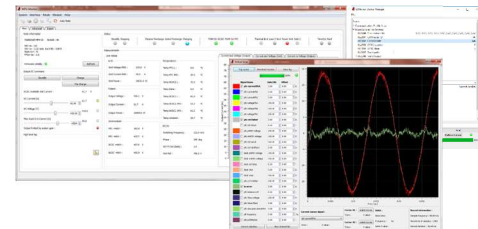
Although MPU Monitor is used in this application note, interfacing MPU-R3-500-63-FD-HV can be done with others CAN bus masters.
See Application Note AN001 Interfacing with CAN bus for step-by-step instructions on how to use a Python to interface the power modules

3. Electrical connection

Output of MPU-R3-500-63-FD-HV power modules can be connected
- in parallel to increase the output current (with virtually no limit on the number of paralleled units)
- in series to increase the output voltage provided that precautions below are respected

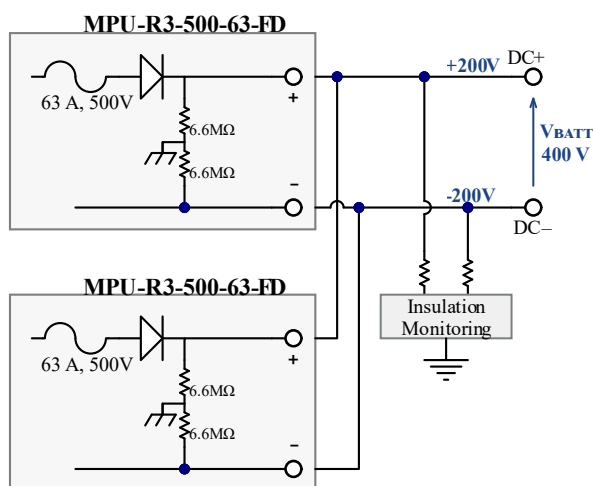In call cases, AC inputs and LV are to be connected in parallel. See product datasheet chapter multi-unit operation

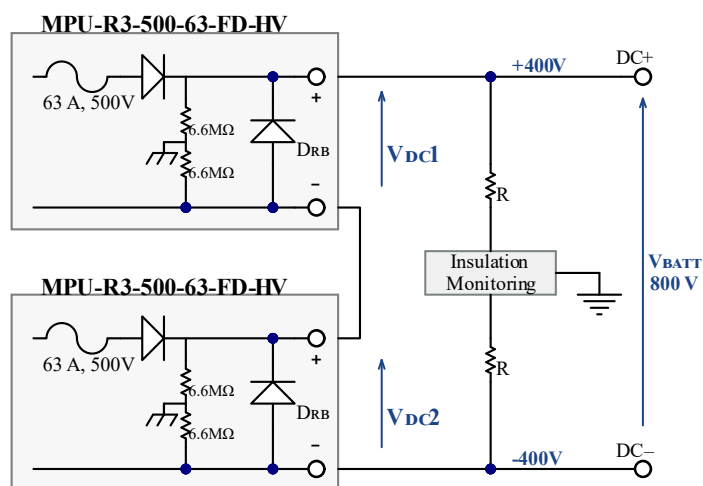**Figure 2: Parallel connection**

Figure 3 Series connection

The outputs of two MPU-R3-500-63-FD-HV can be connected in series to obtain a combined output of 920V provided that three precautions are observed:

First, the voltage from any output to PE[2] shall not exceed the maximum voltage rating
- Standard version of MPU-R3: ±500 V
- -HV version of MPU-R3: ±920 V .

Second, the output connections of each power supply should have a reverse biased diode wired across them (D$_{RB}$ in Figure 3). In the event both power supplies do not turn on or off at the same time, or if the load becomes a short circuit[3], then D$_{RB}$ will protect the power supplies from any applied reverse voltage. D$_{RB}$ is included by default from MPU HW revision 3.6.x. For previous HW versions, D$_{RB}$ need to be added. A 950V rated with Peak Forward Surge Current of at least 100A, such as 1N5408 is recommended.

Third, that an Insulation Monitoring Device (IMD) is installed to detect any ground fault. Using an IEC 61851-23 compatible IMD is usually enough to ensure that first condition is met. Note that IMD should be rated for the full voltage (920V).

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[2] Protective Earth (PE), also known as Ground or Chassis

[3] If the load is short-circuited, DC+ of one power supply will be connected to DC- of the other. Thanks to the diode, no reverse voltage is applied and the 500V rated fuses on each supply will operate safely to break the short.

4. Recommended control strategies

Series connection of current sources is a well-known problem. Typically, current sources naturally work in parallel and conversely, voltage sources naturally work in series.

When two current sources connected in series, the voltage split between them is undefined and thus, the power may not be shared evenly. This section shows that MPU-R3-500-63-FD-HV with is default parameters, share load evenly even with the simpler control strategy in a typical EV charging application.

Warning:
This application note contains recommendations and best-practices on multi-unit operation. User must test in final application to ensure safe and reliable operation.
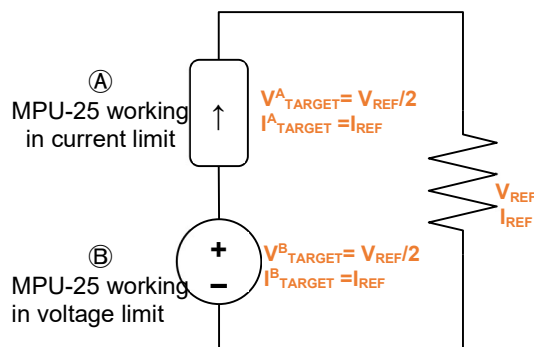
4.1.   No strategy : equal split of references

Both sources get their voltage and current limit based on EV settings.
- Current target (or setpoint) for both sources it the same as the current requested by the EV.
- Voltage target for both sources is half the voltage requested by the EV.

Thanks to the soft start and stop features with CHAdeMO and IEC 61851-23 compliant voltage and current ramps, loads is well shared during transients.
In a typically EV charging application, this configuration typically behaves as the current leader strategy (see Strategy A in 4.2). The power source with the lowest current measurement acts as the leader. The other source will work in voltage regulation mode, but its voltage will be close to half since the EV typically requests a voltage setpoint (V_{REF}) slightly higher than its battery voltage.

Ⓐ
MPU-25 working in current limit

$V^A_{TARGET} = V_{REF}/2$
$I^A_{TARGET} = I_{REF}$

V_{REF}
I_{REF}

Ⓑ
MPU-25 working in voltage limit

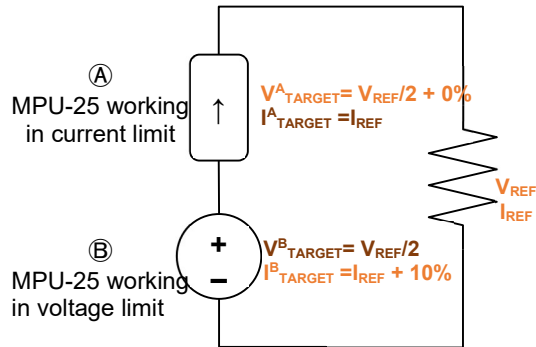$V^B_{TARGET} = V_{REF}/2$
$I^B_{TARGET} = I_{REF}$

4.2.   Strategy A: current leader

One source (Ⓐ) is configured to work in current limitation mode (current leader) by having its voltage target artificially higher than required.
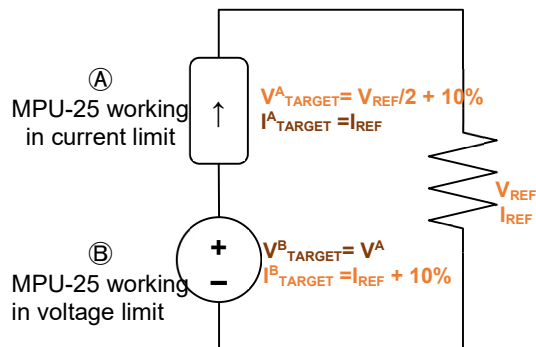Reciprocally, the other source (Ⓑ) works in voltage mode by having is current target raised up.

Advantages from "No strategy": known leader.

$V^A_{TARGET} = V_{REF}/2 + 0\%$
$I^A_{TARGET} = I_{REF}$

MPU-25 working in current limit Ⓐ

V_{REF}
I_{REF}

$V^B_{TARGET} = V_{REF}/2$
$I^B_{TARGET} = I_{REF} + 10\%$

MPU-25 working in voltage limit Ⓑ

4.3.   Strategy B: current leader + voltage follower

Same as previous strategy but Ⓑ follows the voltage from A. Voltage split between both sources is better but has higher communication (and configuration) needs.
Advantages from "Strategy AB": better power share in case of V$_{REF}$ >> actual battery voltage.

MPU-25 working in current limit Ⓐ

$V^A_{TARGET} = V_{REF}/2 + 10\%$
$I^A_{TARGET} = I_{REF}$

V_{REF}
I_{REF}

MPU-25 working in voltage limit Ⓑ

$V^B_{TARGET} = V^A$
$I^B_{TARGET} = I_{REF} + 10\%$

5. Experimental assessment

This chapter shows typical characteristics of two MPU-R3-500-63-FD-HV working in series to achieve 920V
                                 Connection of power units are done as shown on
Figure 4 with both units connected to the same AC grid (parallel connection) and their outputs in series. A disconnection switch was added to perform the load dump test
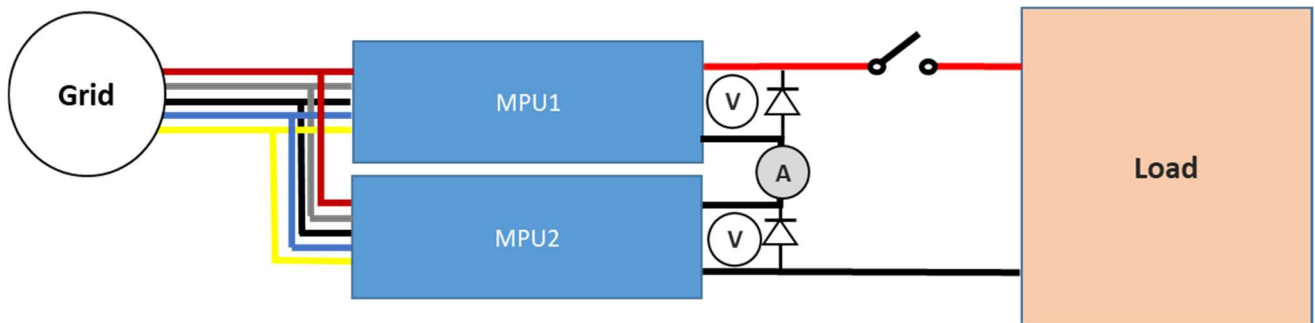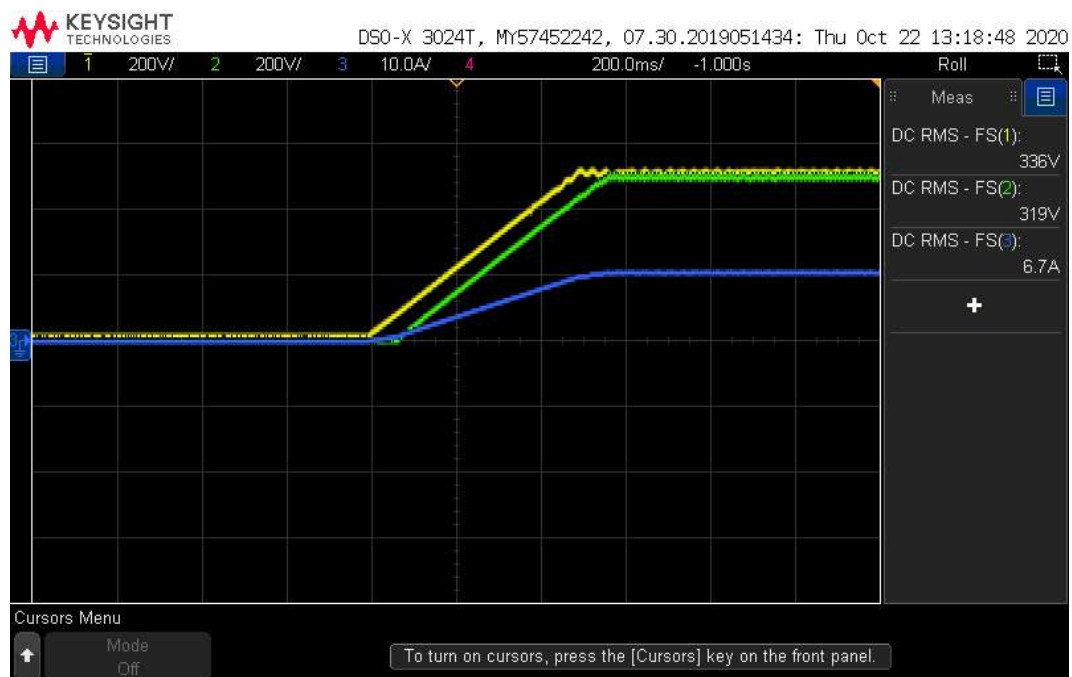Position of current and volage probes are shown on figure
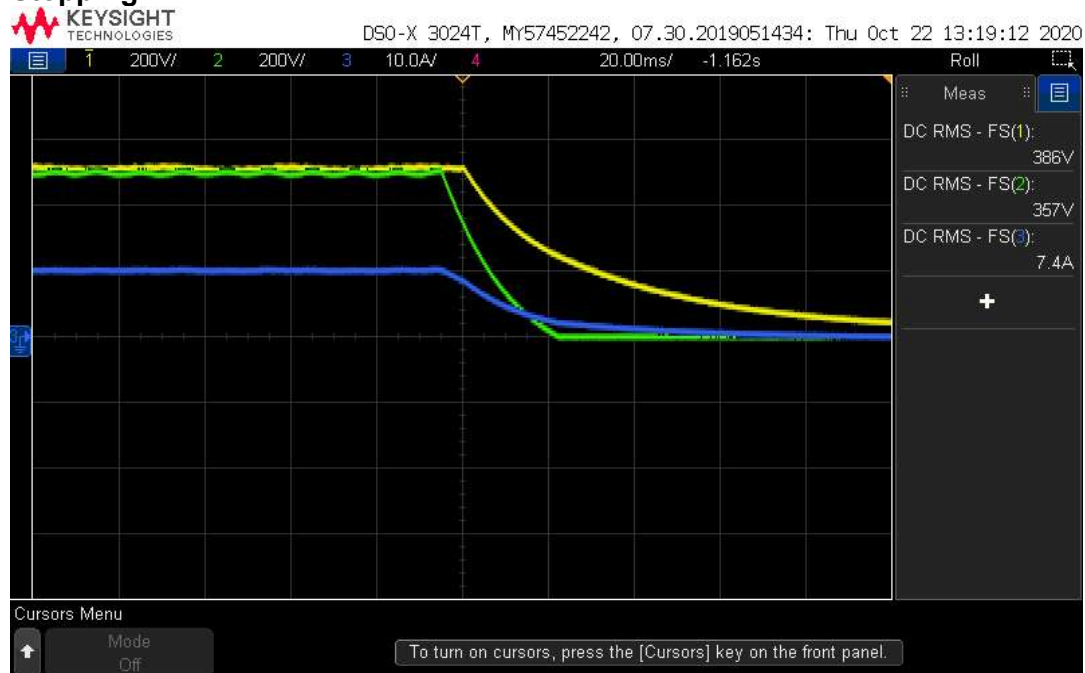

Figure 4 Test setup scheme

Legend

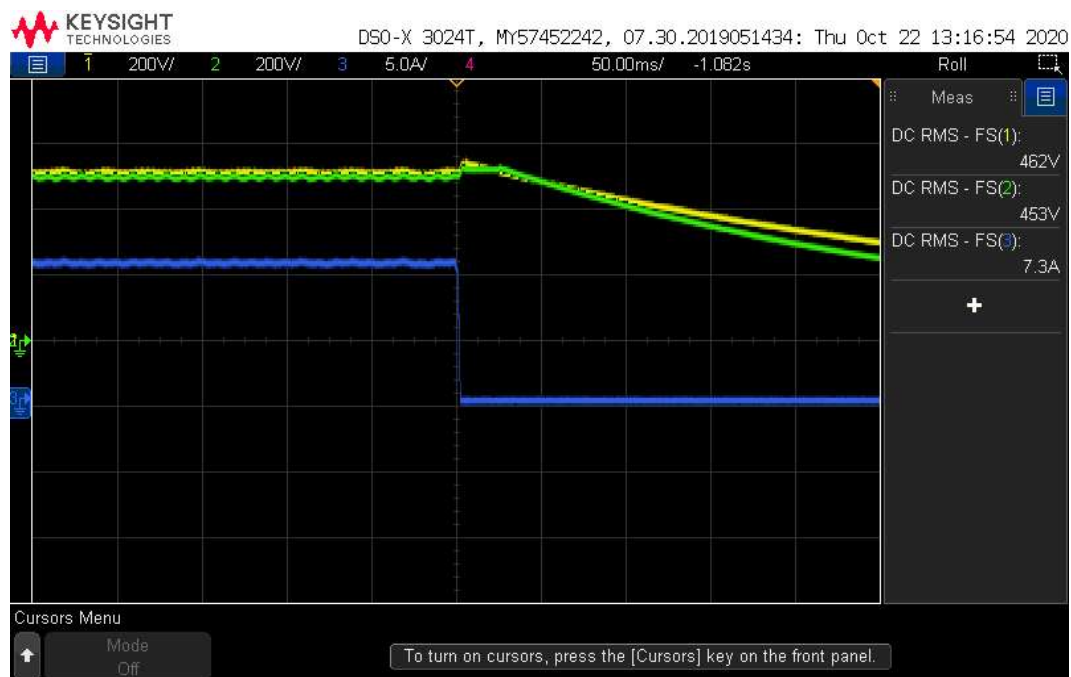|	
🟨	V_{OUT} PU1
🟩	V_{OUT} PU2
🟦	I_{OUT}

- **Startup**

- **Stopping**

- **Load dump (sudden disconnection)**

6. Practical considerations for series/parallel connection

In a typical multioutlet charging station, at least 6 DC contactors are required to allow for two charging connectors with simultaneous EV charging (cf. IEC 61851-23 ED 2.0[4] Annex GG Multioutlet (AC/DC isolated) DC EV charging station)

A modular system would include several parallel connected power units. Contactors are used to dynamically change the configuration depending on the power needed on each output
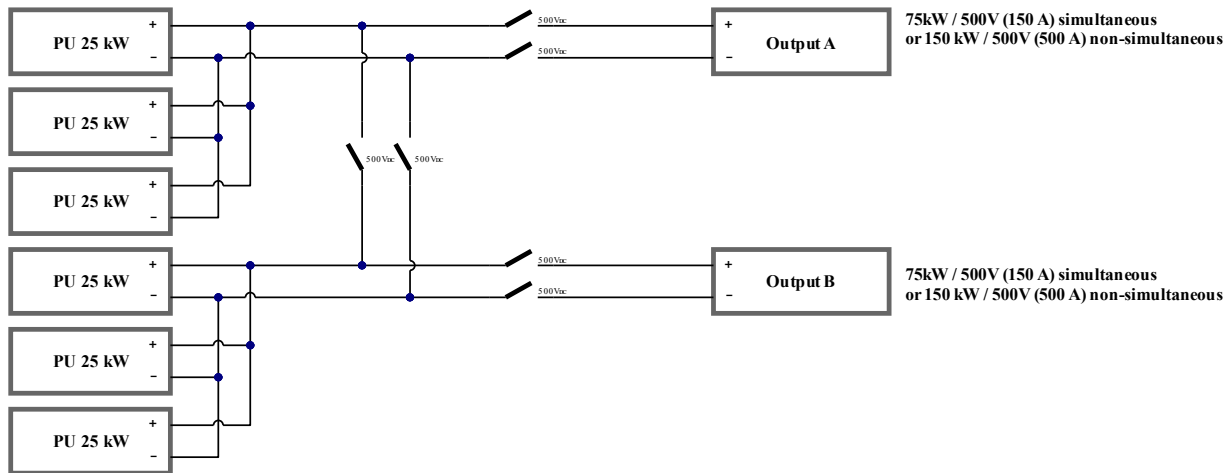

Figure 5: Example of parallel connection of PUs for 150kW, 500V

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[4] As of this writing ED 2 of IEC 6851-23 is an unpublished draft. Forecasted publication date is end 2021

By leveraging the techniques shown on this application note, a system with series-parallel connection can be designed. This requires 3 additional contactors (to the 6 already needed in a parallel only configuration) but makes the system much more flexible
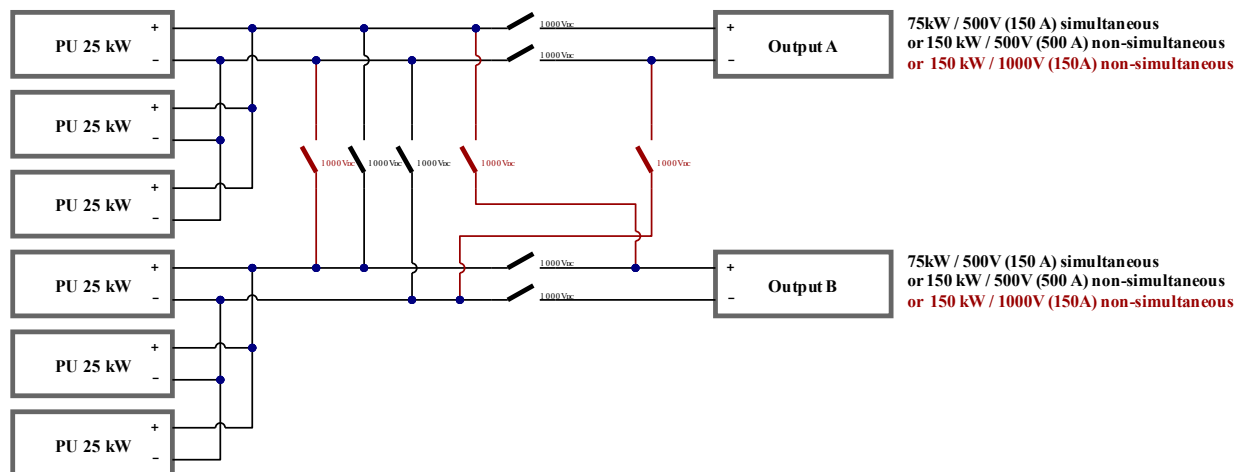

Figure 6: Example of series/parallel connection of PUs for 150kW at 500V or 100V