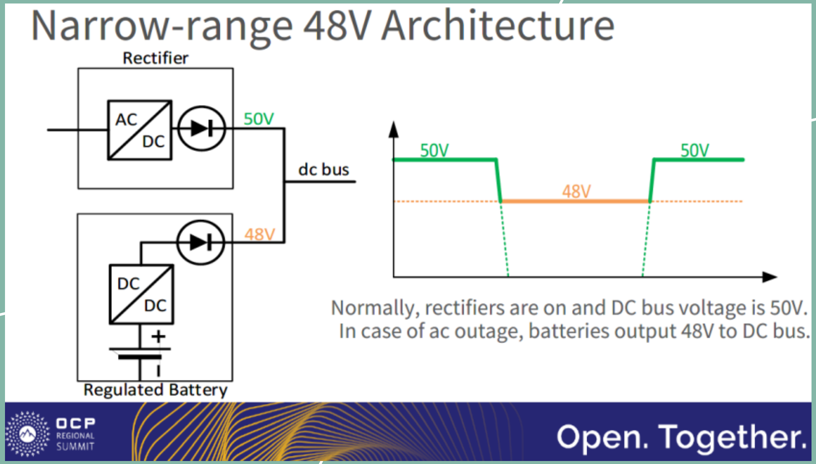
OCPV3 BBU: Ideal Battery Pack Configuration and highly efficient/responsive BiDir DCDC Converter



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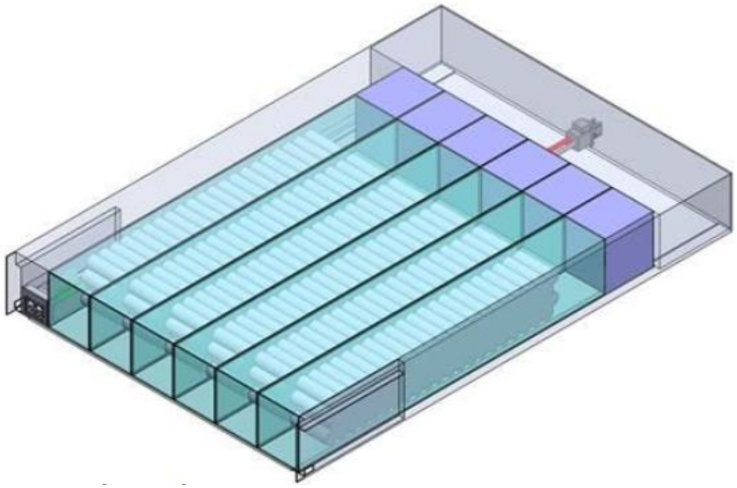
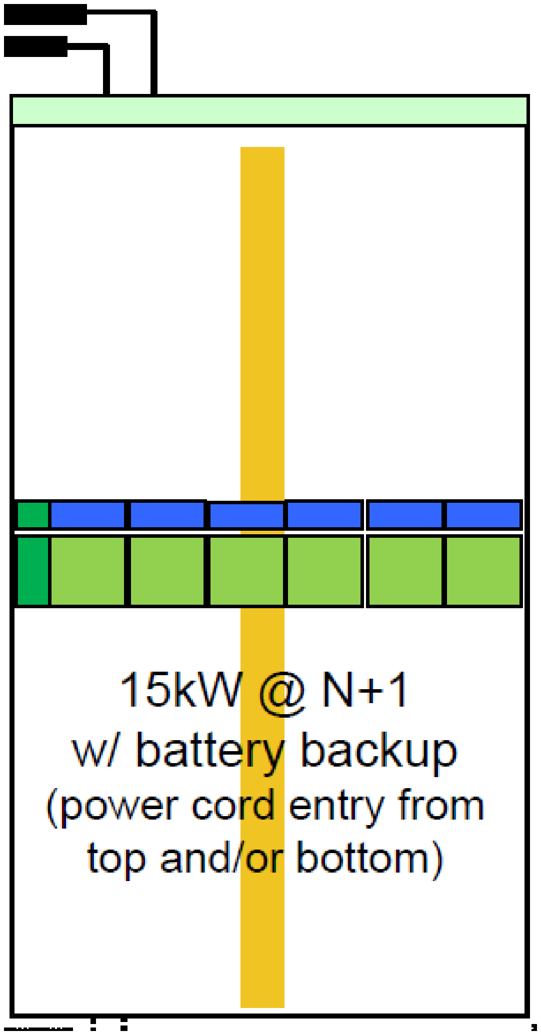
10th of March 2020

Agenda – Ideal Battery Pack Configuration and highly efficient/responsive BiDir DCDC Converter

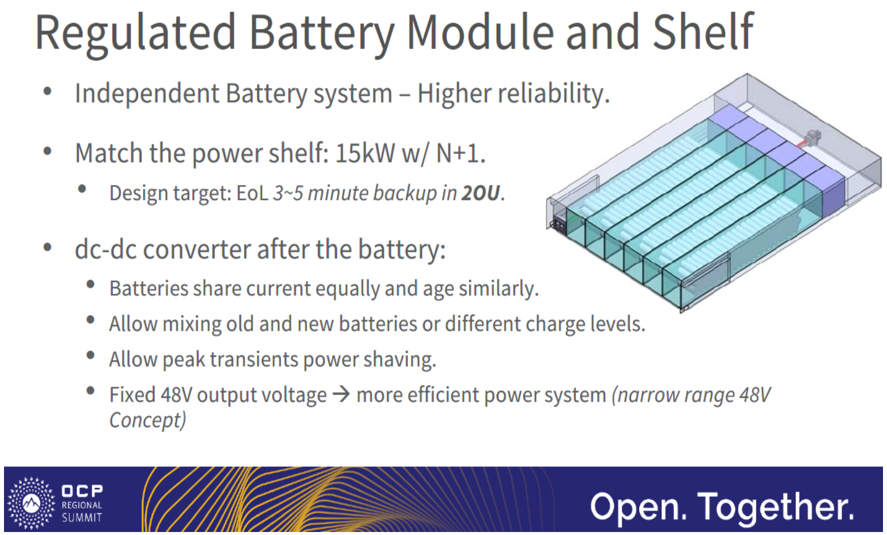
1. OCPV3 BBU design targets
2. Ideal BBU Battery Pack Configuration
3. Non-Isolated DC/DC Converter Design
4. Ctrl Concept Simulation Results & Eff. Calculations





OCPV3 BBU design targets

- Design target: EoL 5 minute backup in 2OU
- DC-DC Converter after the battery:
  - Batteries share current equally and age similarly.
  - Allow mixing old and new batteries or different charge levels.
  - Allow peak transient power shaving.
  - Fixed 48V output voltage (maybe 50V in Power shaving mode)
- Ramp the BBU output within 2ms (discussion range is 2-10ms)



Cell Specification

(using Murata VTC4 high power and VTC5 high energy cells as an example)

18650VTC4

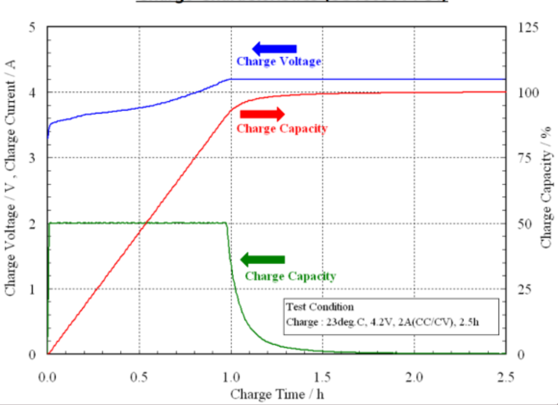
2. Performance — at room temperature,2.5V cut off

Nominal Capacity (0.2C discharge)	2100mAh 7.77Wh	average capacity 3.70V (average discharge voltage)
Rated Capacity (0.2C discharge)	2000mAh 7.40Wh	minimum capacity
Capacity at 1C	2002mAh 7.30Wh	average capacity
Capacity at 10A	2035mAh 7.01Wh	average capacity
Nominal Voltage	3.7V	
Internal Impedance	12mΩ Typ.	measured by AC1kHz
Cycle Performance	60% Min. of Initial capacity at 500 cycles	10A discharge

* Standard Charge Condition

Charge Method	: constant current constant voltage
Charge Up Voltage	: 4.2± 0.05V
Charge Current	: 2.0A
Charge Time	: 2.5h
Ambient Temperature	: 23°C

Charge Characteristics (US18650VTC4)



Cell Type (18650)	VTC4	VTC5
Nominal Voltage	3.7V	3.6V
Maximum Voltage	4.25V	
Charging Voltage	4.2V	
Cut off Voltage	2.5V	
Cont. Max. Charge Curent	4A	
Rated Capacity	2Ahr	2.5Ahr
Cont. Max. Discharge Curent	30A	20A
Battery impedance	12mΩ	13mΩ
Cell Energy	7.4WHr	8.8WHr

18650VTC4 Datasheet

18650VTC5 Datasheet

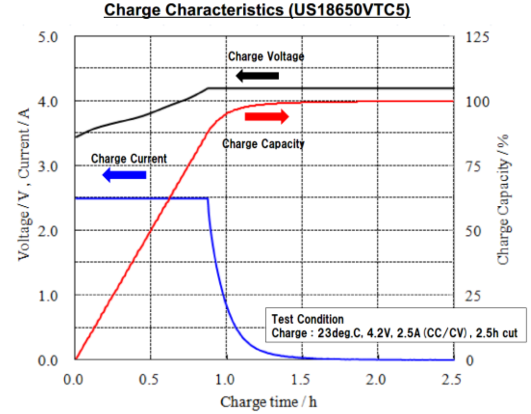
18650VTC5

Nominal Capacity (0.2C discharge)	2600mAh 9.36Wh	average capacity 3.60V (average discharge voltage) at room temperature,2.0V cut off
Rated Capacity (0.2C discharge)	2500mAh 9.00Wh	minimum capacity at room temperature,2.0V cut off
Capacity at 1C	2563mAh 9.23Wh	average capacity at room temperature,2.5V cut off
Capacity at 10A	2577mAh 8.80Wh	average capacity at room temperature,2.5V cut off
Nominal Voltage	3.6V	
Internal Impedance	13.0mΩ Typ.	measured by AC1kHz
Cycle Performance	70% Min. of Initial capacity at 300 cycles	10A discharge at room temperature,2.5V cut off

* Standard Charge Condition

Charge Method	: constant current constant voltage
Charge Up Voltage	: 4.2± 0.05V
Charge Current	: 2.5A
Charge Time	: 2.5h
Ambient Temperature	: 23°C

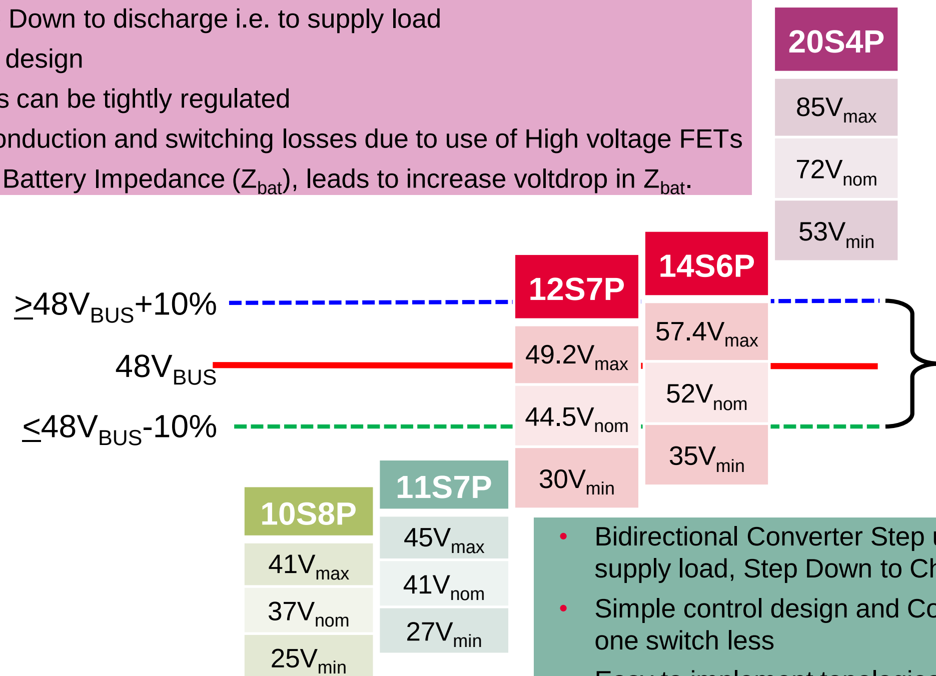
Charge Characteristics (US18650VTC5)



Battery Pack Configuration
A pack voltage always below 48V is beneficial

- Bidirectional Converter with
  - step up to charge
  - Step Down to discharge i.e. to supply load
- Simple design
- Outputs can be tightly regulated
- High conduction and switching losses due to use of High voltage FETs
- Higher Battery Impedance (Z_{bat}), leads to increase voltdrop in Z_{bat}.

To regulate the Bus Voltage tightly, V_{Bat} range shall always be above or below 10% of $48V_{Bus}$



- Bidirectional Converter with
  - Step up and Step down to Discharge to supply load
  - Step Down to Charge
- Complex and Costlier Design
- Poor Regulation of Bus Voltage when $V_{Bat} \cong$ Vout

- Bidirectional Converter Step up to Discharge i.e. to supply load, Step Down to Charge
- Simple control design and Constant Switching Losses, one switch less
- Easy to implement topologies like Interleaved/Multiphase etc.,
- Outputs can be tightly regulated during discharge (less ripple)
- Complex Control loop design to respond to tranisients
- Within Safe Voltage (SELV) range

➢ Step up to supply the load and Step down to charge the battery using Bidirectional Converter is preferred due to
  - Low BOM Cost
  - Less Design Complexity
  - Flexible to adapt topologies (like Multiphase)

Battery Pack Analysis (1)

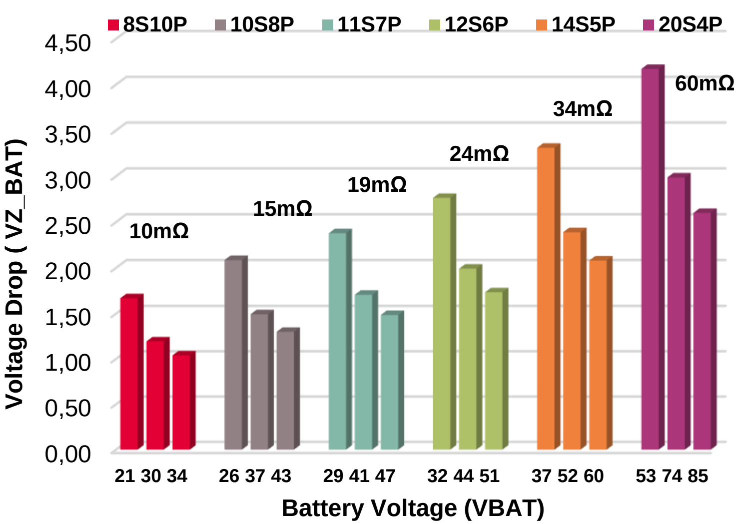
← $<45V_{nom}$ → 48V ← $>48V_{nom}$ →

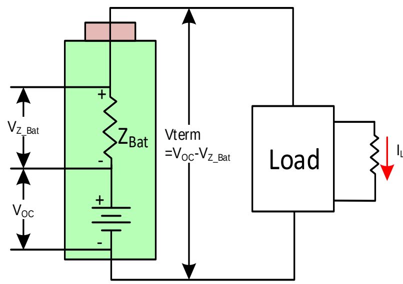
Description	8S10P		10S8P		11S7P		12S6P		14S5P		20S4P	
	VTC4	VTC5	VTC4	VTC5	VTC4	VTC5	VTC4	VTC5	VTC4	VTC5	VTC4	VTC5
No. Of Cells in Series	8		10		11		12		14		20	
No. Of Cells in parallel	10		8		7		6		5		4	
No. Of cells per pack	80		80		77		72		70		80	
Charging Voltage (V_{bat_char}=**4.1V**/cell)	32.8		41.0		***45.1***		49.2		57.4		82.0	
Cut off Voltage (V_{Bat_cut}=**2.5V**/Cell)	20.0		***25.0***		27.5		30.0		35.0		50.0	
Maximum Voltage (V_{Bat_Max}=**4.25V**/Cell)	34.0	34.0	**42.5**	42.5	**46.8**	46.8	51.0	51.0	59.5	59.5	**85.0**	85.0
Nominal Voltage (V_{Bat_nom})	29.6	28.8	**37.0**	36.0	**40.7**	39.6	44.4	43.2	51.8	50.4	**74.0**	72.0
Minimum Voltage (VBat_min= $V_{BAT\_Cut} - V_{Z\_Bat}$)	21.2	21.3	**26.5**	26.7	**29.2**	29.4	32.0	31.7	37.4	37.7	**53.0**	53.3
Battery Pack Impedance (Ω)	0.010	0.010	0.015	0.016	0.019	0.020	0.024	0.026	0.034	0.036	0.060	0.065
Pack Capacity (Ahr)	20.0	25.0	16.0	20.0	14.0	17.5	12.0	15.0	10.0	12.5	8.0	10.0
Cont. Max. Discharge Current of pack (A)	300.0	200.0	240.0	160.0	210.0	140.0	180.0	120.0	150.0	100.0	120.0	80.0
Nominal Pack Energy (Whr) @ V_{Bat_nom}	571.3	694.8	**571.3**	694.8	**549.9**	668.7	514.2	625.3	499.9	608.0	**571.3**	694.8
Minimum Pack Energy (Whr) @ $_{VBat\_Min}$	423.9	533.3	**423.9**	533.3	**408.9**	514.5	383.9	476.1	373.9	470.8	**423.9**	533.3
DCDC Converter												
Efficiency of the converter in boost mode	95%											
Output power of the converter(W)	3500											
Input Power (W)	3684											
Nominal Input Current (A) @ V_{Bat_nom}	124.47	127.92	99.57	102.34	90.52	93.04	82.98	85.28	71.12	73.10	49.79	51.17
Maximum Input Current (A) @ V_{Bat_min}	173.83	172.72	139.06	138.18	126.14	125.31	115.16	116.07	98.54	97.83	69.53	69.09
Minimum Input Current (A) @ V_{Bat_max}	108.36	108.36	86.69	86.69	78.81	78.81	72.24	72.24	61.92	61.92	43.34	43.34
Capacity required for 5 Minutes (Whr)	307.02											

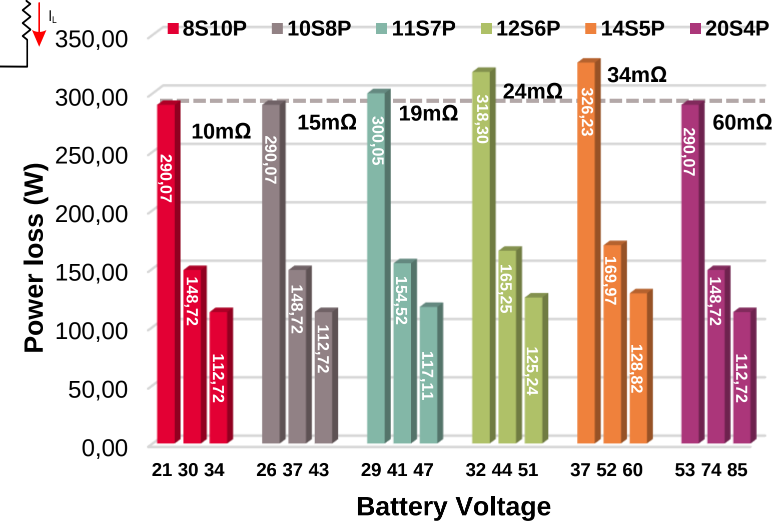
- To regulate bus voltage to 48V
  - 10S8P is the preferred Combinations
  - Achieve maximum efficiency

Battery pack Analysis (2)

Battery Pack	8S10P		10S8P		11S7P		12S6P		14S5P		20S4P	
	VTC4	VTC5	VTC4	VTC5	VTC4	VTC5	VTC4	VTC5	VTC4	VTC5	VTC4	VTC5
Battery Pack Impedance (Ω)	**10mΩ**	**10mΩ**	**15mΩ**	**16mΩ**	**19mΩ**	**20mΩ**	**24mΩ**	**26mΩ**	**34mΩ**	**36mΩ**	**60mΩ**	**65mΩ**
Maximum Voltage drop in Battery Impedance ($V_{Z\_Bat\_max}$) @ V_{Bat_min}	1.67	1.80	2.09	2.25	2.38	2.56	2.76	2.34	3.31	3.56	4.17	4.49
Nominal Voltage drop in Battery Impedance ($V_{Z\_Bat\_nom}$) @ V_{Bat_nom}	**1.19**	**1.33**	**1.49**	**1.66**	**1.71**	**1.90**	1.99	2.22	**2.39**	**2.66**	**2.99**	**3.33**
Minimum Voltage drop in Battery Impedance ($V_{Z\_Bat\_min}$) @ V_{Bat_Max}	1.04	1.13	1.30	1.41	1.49	1.61	1.73	1.88	2.08	2.25	2.60	2.82



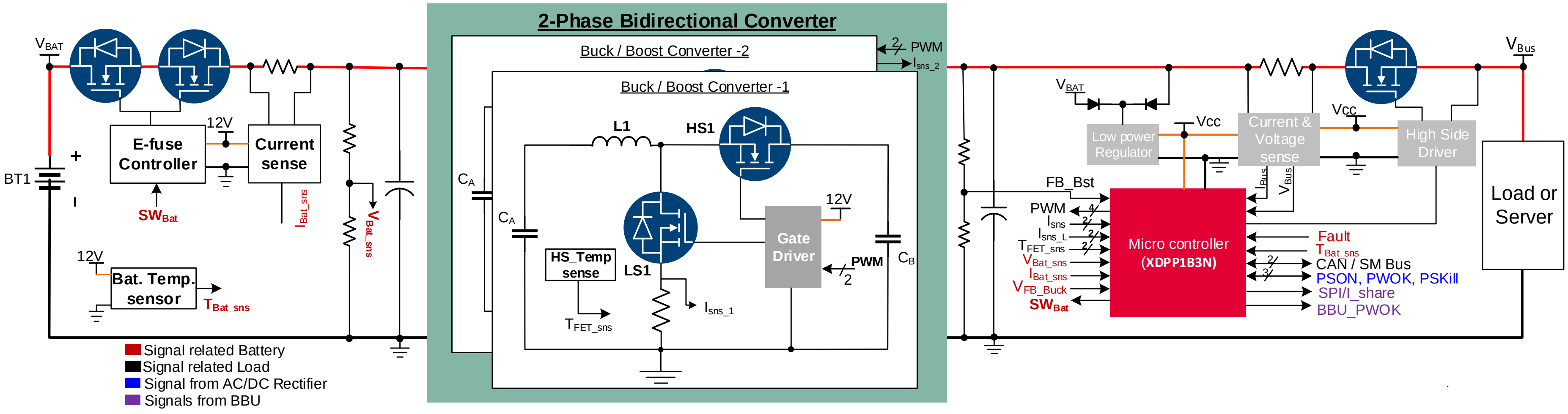




Non-Isolated DC/DC Converter Specfication

	Buck Mode (Charging)	Boost Mode(Discharging)
Source	50V AC/DC Rectifier	10S/11S Configuration
Input Voltage (Vin)	$47V_{min}$ $50V_{nom}$ $58V_{Max}$	$25V_{min}$ (2.5V X 10S) $37V_{nom}$ (37V X 10S) $45V_{Max}$ (4.1V X 11S)
Output Voltage (Vout)	37Vmax.(i.e. 3.9V X 10S)	48V
Output Current (Iout)	• Charge the batteries with 1C (i.e. 20A for 2.5hr‘s) • Adjustable	63A for 5-Minutes
Peak Current (Ipk)	-	Not Available
Control	CC, CV	CC, CV
Accuracy and Ripple	$\pm$1% Ripple: <0.25%	0.25%
Over Voltage Protections	Cut off: 42V Re-on: 40V	Cut off: 52V Re-on: 48V
Under Voltage Protections	Cut off: $26.5V_{Bat}$, Reon: $28V_{Bat}$	• Constant current operation above 62.5A • Shuts off, if output is <42V for 20ms

Highly efficient & responsive Bi-Directional Buck Boost Battery Converter for 3kW output



Design Features

- Digital Solution for bidirectional operation
- Flexible to adapt various topologies and Switching techniques (i.e. 1 to 3 Phases)
- Precision Monitoring
- Easy to implement features like
  - Power shaving
  - Load sharing
  - Hot swap with soft transition
  - Limiting Inrush current

Interface

- CAN/PMBus/SPI interface

Power stage

- Interleaved Topology
  - Reduction of input and output ripples
  - Improves dynamic response
  - Reduces power consumption in light load
  - Reduces filter dimensions
- High Power density Solution with BIC MOSFETs and Gate drivers
- High switching frequency

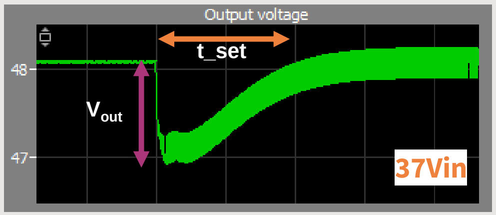
Protection

- Low Rds_on and High Current Devices for Protection switches

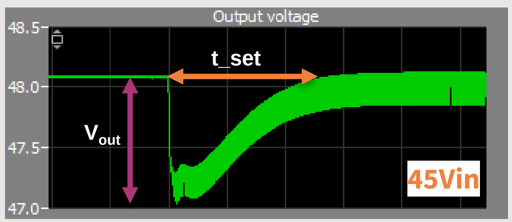
Very responsive Bi-Directional Buck Boost: ~.5ms Dynamic Response to load step from 0A – 60A

Two-phase boost response

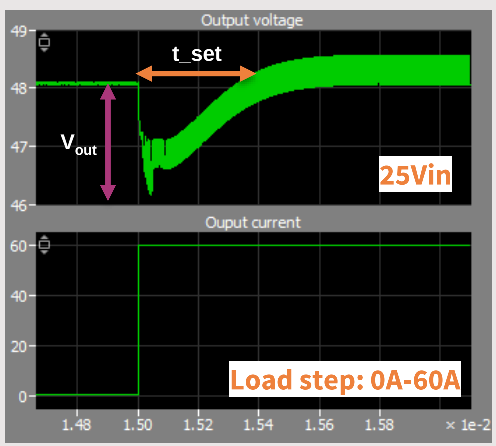
Nominal Vin 37V	
V_{out} undershoot	1.2V
Settling time (t_set)	0.45ms
Vo ripple	340mV



Max. Vin 45V	
V_{out} undershoot	1.1V
Settling time (t_set)	0. 52ms
Vo ripple	270mV



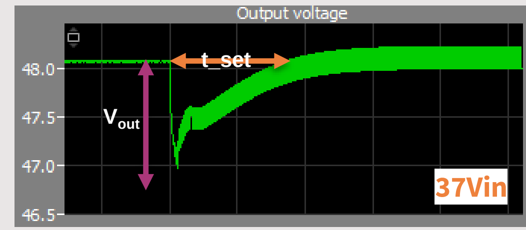
Min. Vin 25V	
V_{out} undershoot	1.9V
Settling time (t_set)	0. 5ms
Vo ripple	500mV



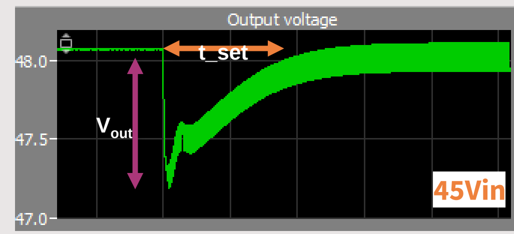
C	1mF
ESR	8mΩ
L/phase	6µH
DCR	5mΩ

Three-phase boost response

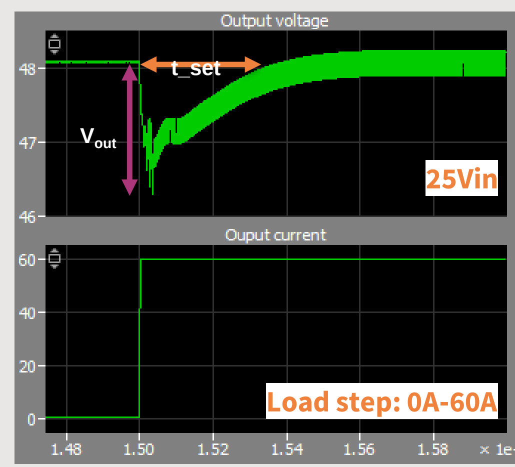
Nominal Vin 37V	
V_{out} undershoot	1.1V
Settling time (t_set)	0.45ms
Vo ripple	230mV



Max. Vin 45V	
V_{out} undershoot	0.8V
Settling time (t_set)	0. 5ms
Vo ripple	180mV

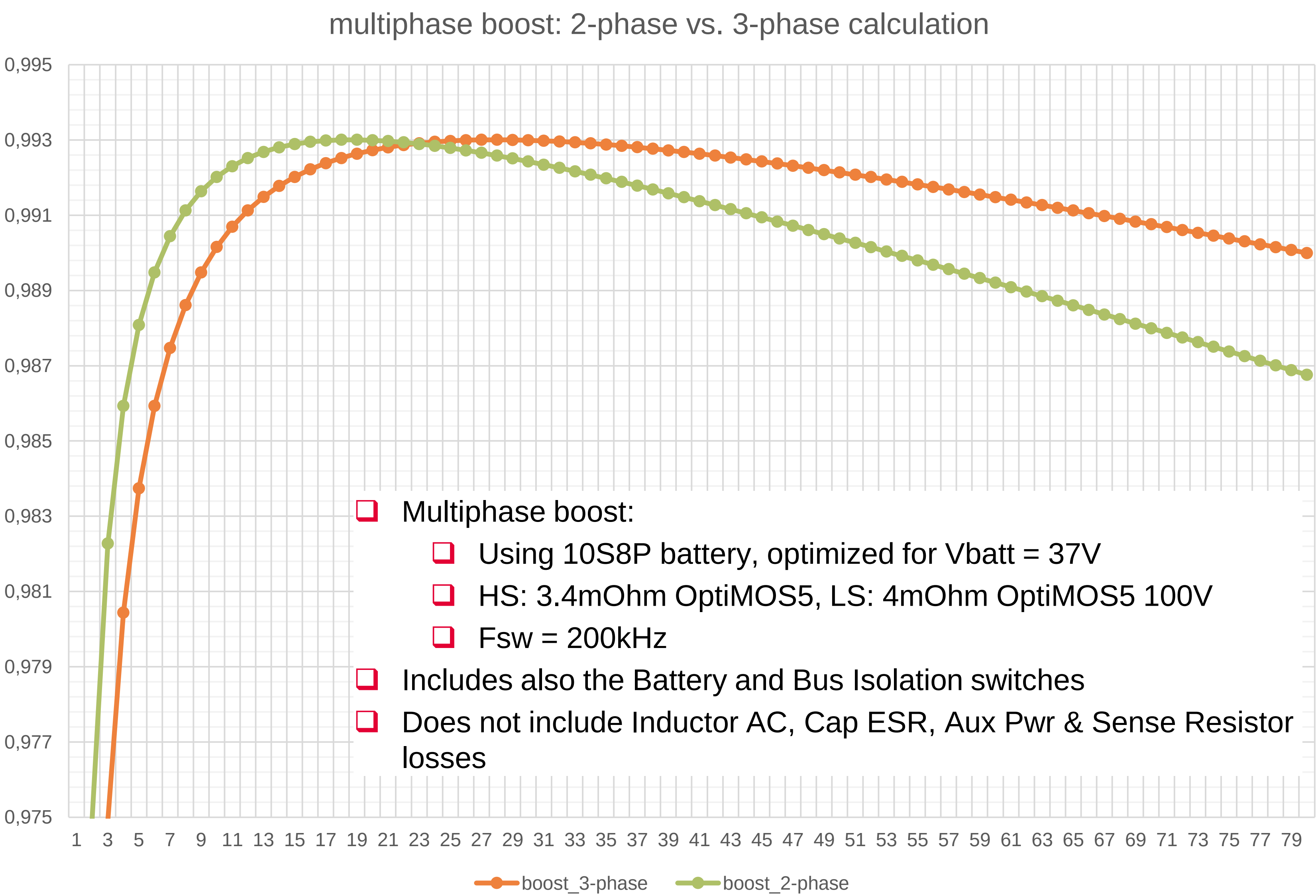


Min. Vin 25V	
V_{out} undershoot	1.76V
Settling time (t_set)	0. 5ms
Vo ripple	340mV



C	1mF
ESR	8mΩ
L/phase	6µH
DCR	5mΩ

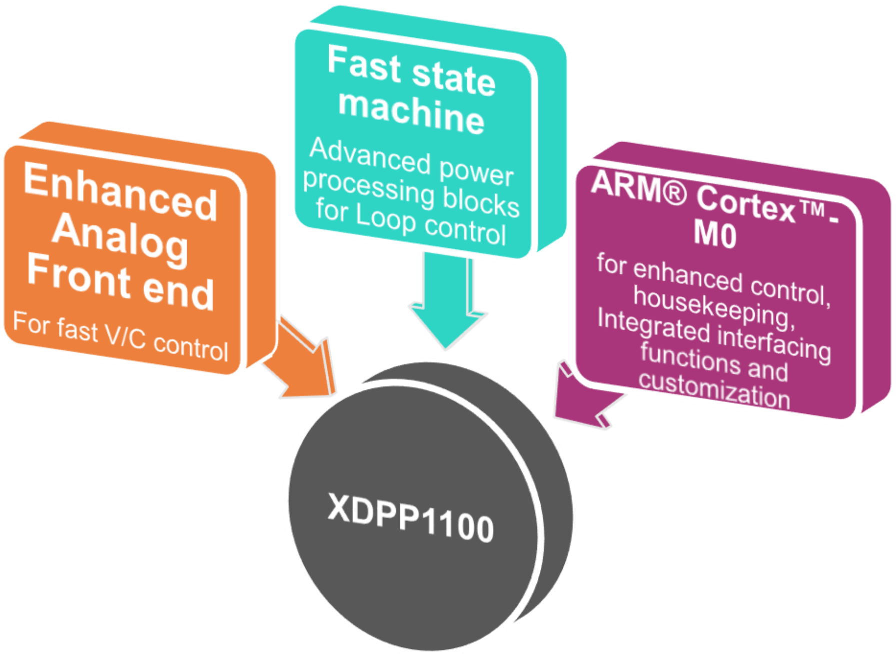
Efficiency Comparison – Boost

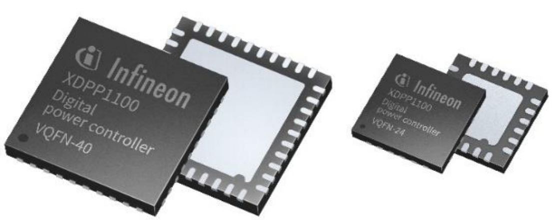


- Multiphase boost:
  - Using 10S8P battery, optimized for Vbatt = 37V
  - HS: 3.4mOhm OptiMOS5, LS: 4mOhm OptiMOS5 100V
  - Fsw = 200kHz
- Includes also the Battery and Bus Isolation switches
- Does not include Inductor AC, Cap ESR, Aux Pwr & Sense Resistor losses

Benefits of fast XDPP1100 Digital Controller in OCPV3 Battery Converter

Infineon's Digital controller with a Unique combination of **State-machine + MCU**





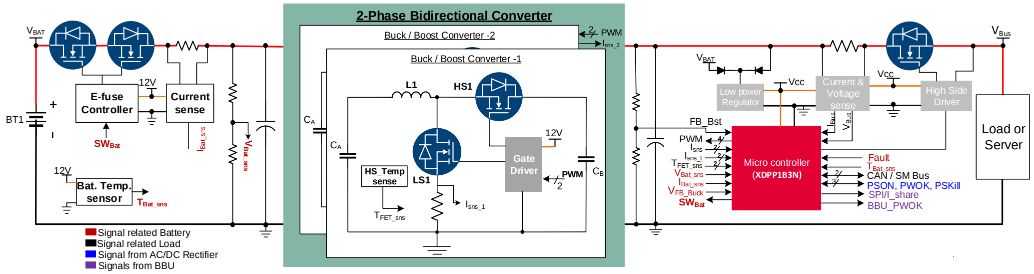
40pin 6x6mm & **24 pin 4x4mm**

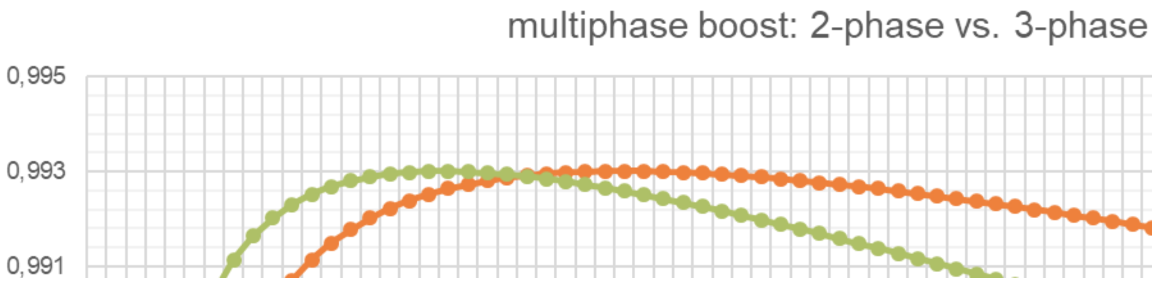
Key Benefits in this application
Fast state machine for Loop control
Faster CPU with extra Bandwidth
ARM® Cortex™-M0 for customization
Enhanced digital PWMs capable of implementing several isolated and non-isolated topologies using a single Ctrl
Infineon FTR Technology (non-linear)
System Robustness with Advance protection
Negligible internal current consumption
Can provide different Vout to work with peak power shaving

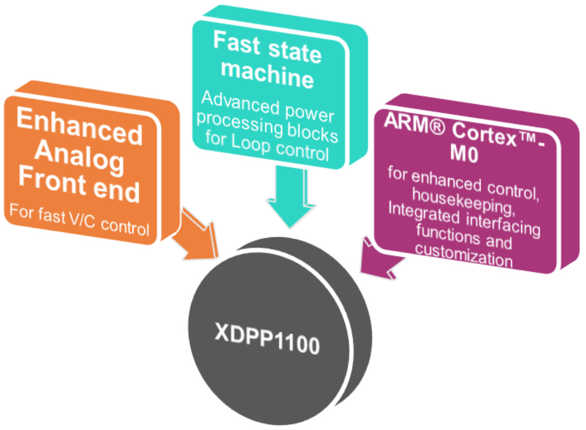
- https://www.infineon.com/dgdl/Infineon-XDPP1100-Q040-DataSheet-v01_02-EN.pdf?fileId=5546d462700c0ae6017084a8c9070d2a

OCPV3 BBU: Ideal Battery Pack Configuration and highly efficient/responsive BiDir DCDC Converter

- Pack voltage that is either above the 48V level or always below it in all SOC states is desired
- Pack voltage always below 48V is beneficial from SELV and Battery Converter standpoint
- For a 10s8p battery pack a highly efficient & responsive Bi-Directional Converter with a low BOM topology can be implemented
- Infineon XDPP1100 Digital Controller with fast state machine and MCU provides fast dynamic response







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