CSU200-2GAMP4-2CH

DATASHEET

KEY FEATURES

- Output power: 200 kW
- DC, 1-ph or 3-ph AC output
- Four-quadrant operation
- Regenerative up to full power
- Scalable up to 1.6 MW
- AC output voltage L-L: 485 V RMS
- AC output current: 240 A RMS
- Max DC output voltage: 1500 V / 3000 V
- Max DC output current: 1120 A
- Large-signal BW: 5 kHz
- Small-signal BW: 15 kHz
- Programmable V and I limits
- Voltage accuracy: 0,1%
- Current accuracy: 0,56%
- Peak efficiency: 95%
- Frequency accuracy: 1 mHz
- Meets IEEE Std. 1547.1
- CE Certified

PHIL
GRID
RENEWABLE ENERGY
E-MOBILITY
AEROSPACE
MARINE
ACADEMIC RESEARCH
TESTING

SYSTEM INTRODUCTION

The CSU200-2GAMP4-2CH (COMPISO System Unit 200 – Two Groups of four Amplifiers – Dual Channel) is a galvanically isolated bidirectional 200 kW emulation and test system providing two independent, galvanically isolated channels with 4 independent bidirectional switched-mode power amplifiers each. The 8 amplifiers can operate in several predefined AC and DC operation modes as well as a wide range of user-defined Hardware-in-the-loop (HIL)-based modes. The system can operate in current-control, voltage-control or mixed mode and can act as a source or sink with a seamless transition between sourcing power and regenerating power back to the supply grid. Featuring large-signal bandwidth of 5 kHz and small-signal bandwidth of 15 kHz, the system can generate harmonics up to the 100th order and interharmonics up to 15 kHz for smooth frequency sweeps.

The CSU200-2GAMP4-2CH can be controlled by an EGSTON Real-Time (RT) Processor or external HIL systems via ultra-fast optic fiber (SFP – Small Form Factor Pluggable) or analog interface.

The optional 4QAC Source software application enables the generation of arbitrary periodic waveforms whose amplitude, frequency, phase (time shift) and DC offset can be changed every 1 ms. The active and reactive power can be changed separately in each phase every 1 ms, enabling more complex test scenarios such as Low Voltage Ride Through, High Voltage Ride Through, and frequency drift.

The optional 4QDC Source software application is used to execute various DC tests, ranging from simple constant-current, constant-voltage or constant-power operation to more advanced scenarios such as emulation of PV arrays and batteries modelled on I-V curves. The system is scalable, and up to three units can be combined to provide 6 separate channels with up to 820 V DC each, or 3 DC Unipolar channels with up to 1500 V each. Two units with midpoint grounding can be combined to produce a single +/-1500 V DC bipolar channel.

Use case: With the necessary additional 4QDC applications (one per output channel), a 600 kW PV system with 6 independent strings of PV arrays with a V_{MPP} up to 800 V and I_{MPP} up to 125 A_{DC} (or 3 strings with a V_{MPP} up to 1450 V and I_{MPP} up to 125 A) can be emulated, with advanced test scenarios like time-varied I-V curves, PV array mismatch, partial shading, PID effect, panel aging etc.

Inverter test procedures according to EN 50530 could be simulated, as well as more complex scenarios for testing hybrid inverters, by dedicating two channels for the Grid, two for a 1500 V DC PV array, one for loads and one for a high-voltage battery bank.

SYSTEM DESCRIPTION AND OPERATION MODES

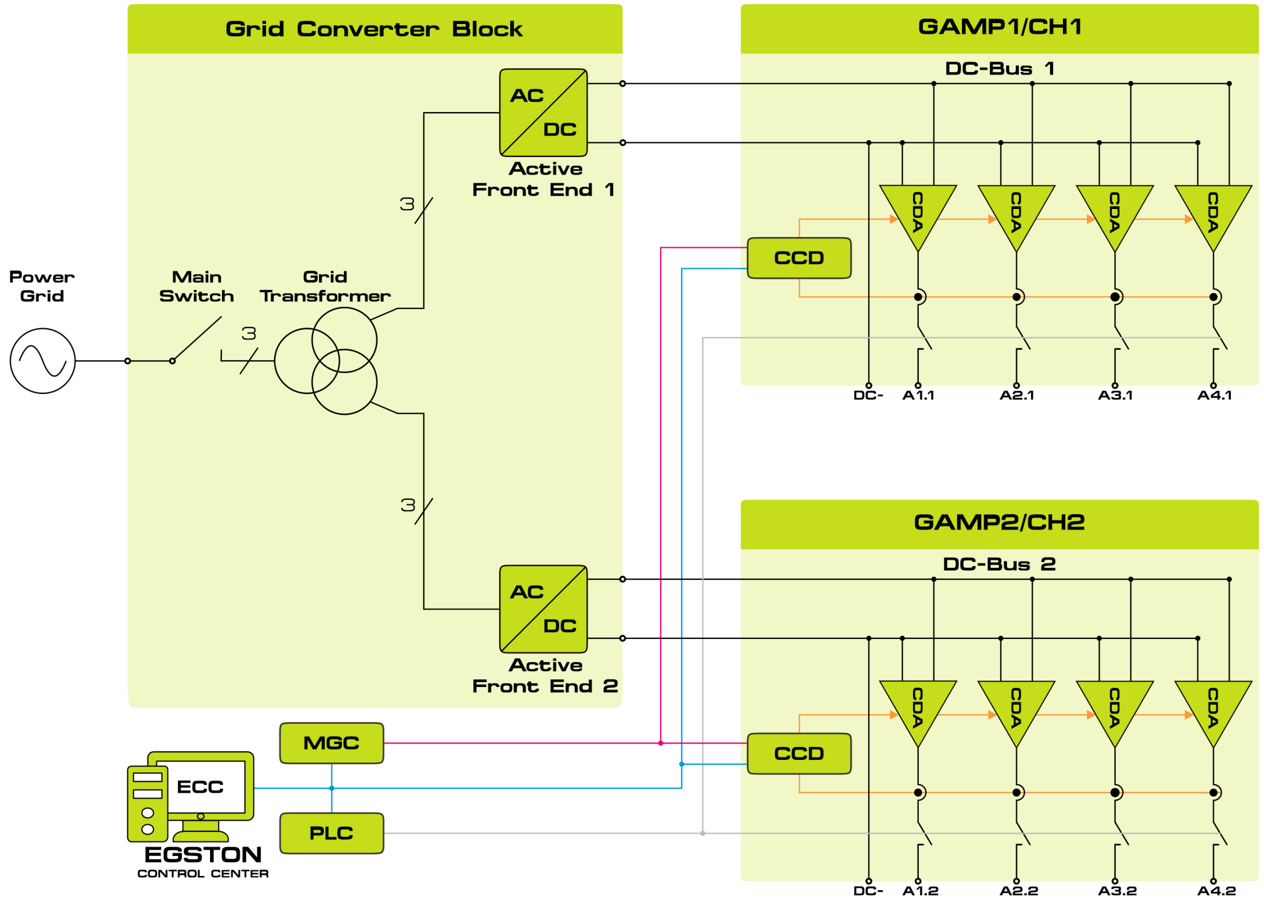


Figure 1. Simplified block diagram of the CSU200-2GAMP4-2CH system.

The CSU200-2GAMP4-2CH-HV connects to a three-phase + N power grid (three-phase four wire system) via a galvanic isolation transformer. A protective earth (PE) connection providing adeqaute grounding must also be available. The system can be adapted to connect to any three-phase power grid with a voltage from 400-690 V at 50 or 60 Hz. The transformer supplies two separate, galvanically isolated Active Front Ends (AFE's) that feed two independent DC buses with a DC-link voltage of 850 V. Each DC bus feeds a group of 4 independent COMPISO Digital Amplifiers (CDA's), thus providing two separate galvanically isolated channels (2CH), capable of individually operating in one of the available operating modes. Each group of amplifiers (GAMPs) is controlled by its own COMPISO Control Device (CCD) which is controlled by the Multi GAMP Controller (MGC) and one Programmable Logic Controller (PLC).

Each of the 2 separate channels can provide up to 100 kVA. The maximum power that can be sourced from or regenerated to the grid is 200 kVA. The output voltage and current of each amplifier are measured at its output terminal.

The CSU200-2GAMP4-2CH system physically consists of three cabinets housing the isolation transformer, power amplifiers and control electronics, and a desktop PC running EGSTON Control Center (ECC) software. An additional PC will be supplied for each licensed Software Application.

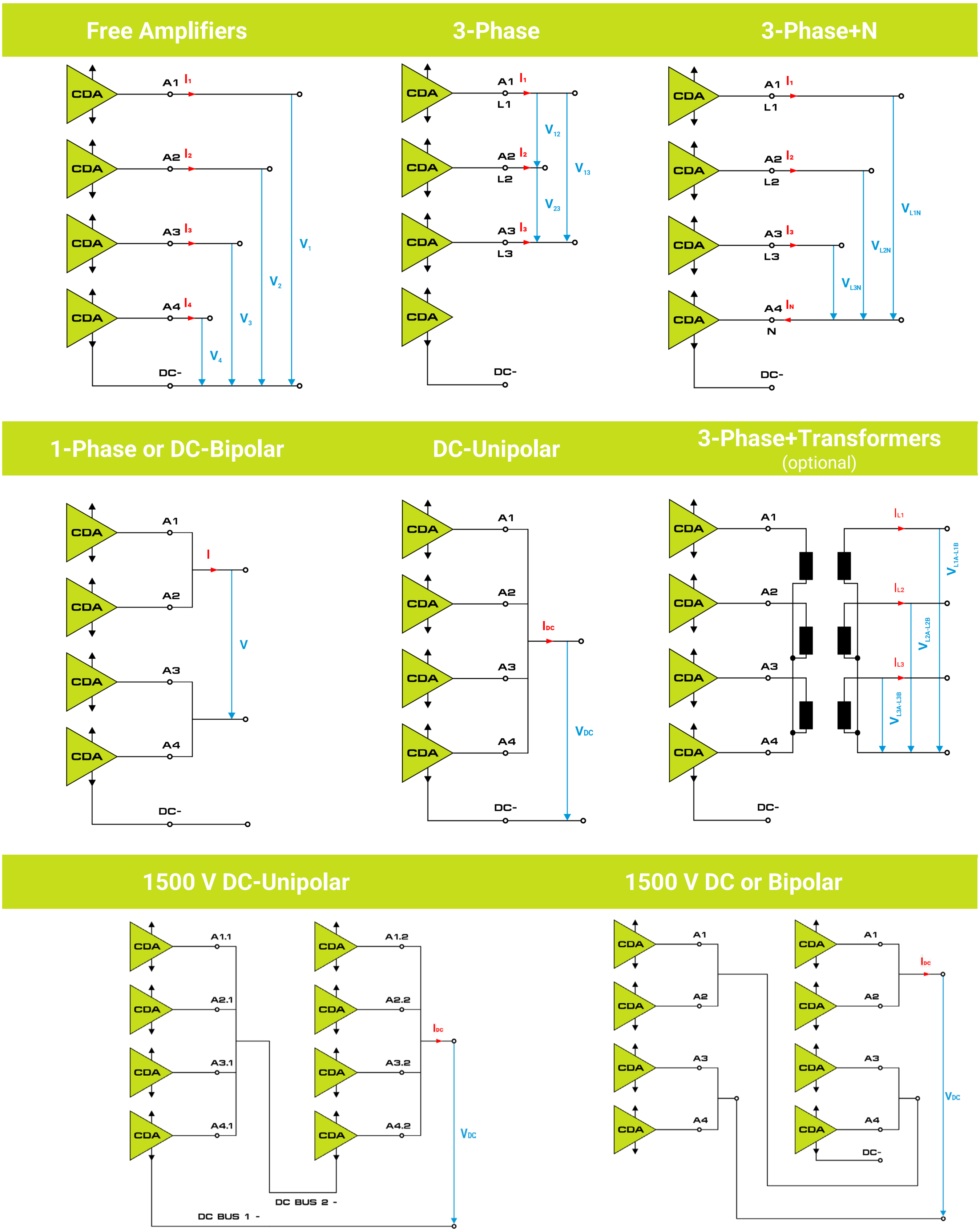


Figure 2. Operation modes for CSU200-2GAMP4-2CH

The available voltage, current and power range in each operation mode are listed in Table 1. In each operation mode, the system can operate either as a power source or a sink. The ranges listed in Table 1 are valid for both directions. Output power is limited to 200 kW in DC bipolar and DC unipolar operation modes by voltage or current derating.

Table 1. Available voltage, current and power range in each operation mode. All values are per channel (GAMP), except when noted otherwise

Operation mode: Free amplifiers		Per channel	
AC mode[1]			
DC offset voltage	V_{DC}	420 V DC	
Minimum AC voltage	V_{min}	0 V RMS	
Maximum AC voltage	V_{max}	280 V RMS	
Minimum AC current	I_{min}	0 A RMS	
Minimum AC current	I_{max}	120 A RMS	
Maximum active power	P_{max}	33,6 kW	
Maximum apparent power	S_{max}	33,6 kVA	
DC mode (unipolar)			
Minimum DC voltage	V_{min}	20 V DC	
Maximum DC voltage	V_{max}	820 V DC	
Minimum DC current	I_{min}	-140 A DC	
Maximum DC current	I_{max}	140 A DC	
Maximum power	P_{max}	100 kW	
Operation mode: Three-phase		**Per channel**	**In parallel**
Minimum LL voltage	$V_{LL\ min}$	0 V RMS	0 V RMS
Maximum LL voltage	$V_{LL\ max}$	485 V RMS	485 V RMS
Minimum current	$I_{L\ min}$	0 A RMS	0 A RMS
Maximum current	$I_{L\ max}$	120 A RMS	240 A RMS
Maximum current @ 10% $V_{LL\ max.}$	$I_{L\ max,}$ 10% $V_{LL\ max}$	120 A RMS	240 A RMS
Maximum current @ $V_{LL\ max.}$	$I_{L\ max,}$ $V_{LL\ max}$	120 A RMS	240 A RMS
Maximum active power	P_{max}	100 kW	200 kW
Maximum apparent power	S_{max}	100 kVA	200 kVA
Max app. power @ 10% $V_{LL\ max}$	$S_{max,}$ 10% $V_{LL\ max}$	10 kVA	20 kVA
Max app. power @ $V_{LL\ max}$	$S_{max,}$ $V_{LL\ max}$	100 kVA	200 kVA
Operation mode: Three-phase + N		**Per channel**	**In parallel**
Minimum LL voltage	$V_{LL\ min}$	0 V RMS	0 V RMS
Maximum LL voltage	$V_{LL\ max}$	485 V RMS	485 V RMS
Maximum LN voltage	$V_{LN\ max}$	280 V RMS	280 V RMS
Minimum current	$I_{L\ min}$	0 A RMS	0 A RMS
Maximum current	$I_{L\ max}$	120 A RMS	240 A RMS
Maximum current @ 10% $V_{LL\ max}$	$I_{L\ max,}$ 10% $V_{LL\ max}$	120 A RMS	240 A RMS
Maximum current @ $V_{LL\ max}$	$I_{L\ max,}$ $V_{LL\ max}$	120 A RMS	240 A RMS
Maximum active power	P_{max}	100 kW	200 kW
Maximum apparent power	S_{max}	100 kVA	200 kVA
Max. app. power @ 10% $V_{LLmax.}$	$S_{max,}$ 10% $V_{LL\ max}$	10 kVA	20 kVA
Max. app. power @ $V_{LL\ max}$	$S_{max,}$ $V_{LL\ max}$	100 kVA	200 kVA

Table 1. (continued)

Operation mode: Single-phase[2]		Per channel	In parallel	In series
Minimum voltage	V_{min}	0 V RMS	0 V RMS	0 V RMS
Maximum voltage	V_{max}	565 V RMS	565 V RMS	1050 V RMS
Maximum current	I_{max}	240 A RMS	480 A RMS	240 A RMS
Maximum current @ 10% V_{max}	$I_{max,}$ 10% V_{max}	240 A RMS	480 A RMS	240 A RMS
Maximum current @ V_{max}	$I_{max,}$ V_{max}	177 A RMS	354 A RMS	190 A RMS
Maximum active power	P_{max}	100 kW	200 kW	200 kW
Maximum apparent power	S_{max}	100 kVA	200 kVA	200 kVA
Max. app. power @ 10% $V_{max.}$	$S_{max,}$ 10% V_{max}	13.5 kVA	27 kVA	25 kVA
Max. app. power @ V_{max}	$S_{max,}$ V_{max}	100 kVA	200 kVA	200 kVA
Operation mode: Three-phase + N (with 3rd harmonic injected)		**Per channel**	**In parallel**	
Minimum LL voltage	$V_{LL\ min}$	0 V RMS	0 V RMS	
Maximum LL voltage	$V_{LL\ max}$	555 V RMS	555 V RMS	
Maximum LN voltage	$V_{LN\ max}$	320 V RMS	320 V RMS	
Minimum current	$I_{L\ min}$	0 A RMS	0 A RMS	
Maximum current	$I_{L\ max}$	120 A RMS	240 A RMS	
Maximum active power	P_{max}	100 kW	200 kW	
Maximum apparent power	S_{max}	100 kVA	200 kVA	
Operation mode: Three-phase (with 3rd harmonic injected)		**Per channel**	**In parallel**	
Minimum LL voltage	$V_{LL\ min}$	0 V RMS	0 V RMS	
Maximum LL voltage	$V_{LL\ min}$	555 V RMS	555 V RMS	
Minimum current	$I_{L\ min}$	0 A RMs	0 A RMs	
Maximum current	$I_{L\ max}$	120 A RMS	240 A RMS	
Maximum active power	P_{max}	100 kW	200 kW	
Maximum apparent power	S_{max}	100 kVA	200 kVA	
Operation mode: Three-phase + transformers (n = Vs/Vp; $_{x = 1, 2, 3}$)		**Per channel**	**In parallel**	
Minimum voltage	V_{Lx}	0 V	0 V	
Maximum voltage	$V_{Lx\ max}$	n × 485 V	n × 485 V	
Minimum current	$I_{Lx\ min}$	0 A	0 A	
Maximum current	$I_{Lx\ max}$	(1/n) × 120 A	(1/n) × 120 A × 2	
Maximum active power	P_{max}	100 kW	200 kW	
Maximum power	S_{max}	100 kVA	200 kVA	

Table 1. (continued)

Operation mode: DC bipolar		Per channel	In parallel	In Series
Minimum voltage	V_{min}	-800 V	-800 V	-1500 V
Maximum voltage	V_{max}	800 V	800 V	1500 V
Minimum current	I_{min}	-280 A	-560 A	-280 A
Maximum current	I_{max}	280 A	560 A	280 A
Maximum current @ 10% V max	I_{max}, 10% V_{max}	280 A	560 A	280 A
Maximum current @ V max	I_{max}, V_{max}	125 A	250 A	133 A
Maximum power	P_{max}	100 kW	200 kW	200 kW
Maximum power @ 10% Vmax		22.4 kW	44.8 kW	42 kW
Maximum power @ Vmax		100 kW	200 kW	200 kW
Operation mode: DC unipolar 820 V		**Per channel**	**In parallel**	
Minimum voltage	V_{min}	20 V	20 V	
Maximum voltage	V_{max}	820 V	820 V	
Minimum current	I_{min}	-560 A	-1120 A	
Maximum current	I_{max}	560 A	1120 A	
Maximum current @ 10% V_{max}	I_{max}, 10% V_{max}	560 A	1120 A	
Maximum current @ V_{max}	I_{max}, V_{max}	122 A	244 A	
Maximum power	P_{max}	100 kW	200 kW	
Maximum power @ 10% V_{max}	P_{max}, 10% V_{max}	45.9 kW	91.8 kW	
Maximum power @ V_{max}	P_{max}, V_{max}	100 kW	200 kW	
Operation mode: DC unipolar 1500 V			**In Series**	
Minimum voltage	V_{min}		40 V	
Maximum voltage	V_{max}		1500 V	
Minimum current	I_{min}		-560 A	
Maximum current	I_{max}		560 A	
Maximum current @ 10% V_{max}	I_{max}, 10% V_{max}		560 A	
Maximum current @ V_{max}	I_{max}, V_{max}		133 A	
Maximum power	P_{max}		200 kW	
Maximum power @ 10% V_{max}	P_{max}, 10% V_{max}		84 kW	
Maximum power @ V_{max}	P_{max}, V_{max}		200 kW	

[1] The CDA output voltage has a DC offset of 420 V (with respect to the DC- terminal).
[2] Due to single-phase load on the AFE, power derating applies if the frequency of the output voltage is less than 100 Hz, as shown in Figure 8.

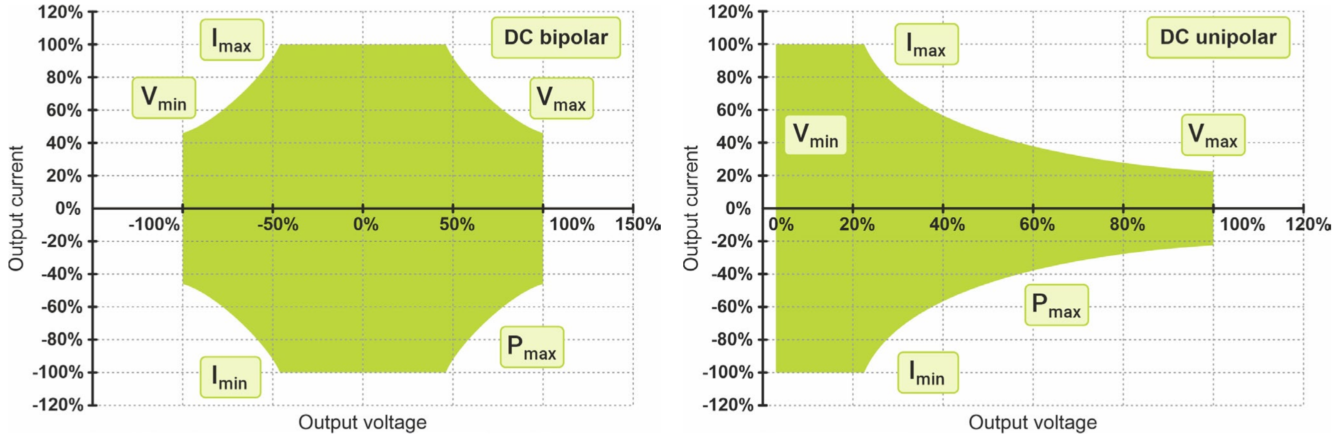


Figure 3. Power limits for DC bipolar and DC unipolar operation modes (per channel).

For all AC operation modes, the maximum available output voltage is reduced at higher output frequencies as illustrated in Figure 4 (for resistive loads) and Figure 5 (for inductive loads). This reduction is due to an increased voltage drop across the internal output filter at higher output frequencies. Output voltage derating additionally applies at frequencies above 5 kHz to avoid overheating the output filter capacitors, as illustrated in Figure 6, and output current derating at higher frequencies is necessary to avoid overheating the internal output inductor and output contactors, as illustrated in Figure 7.

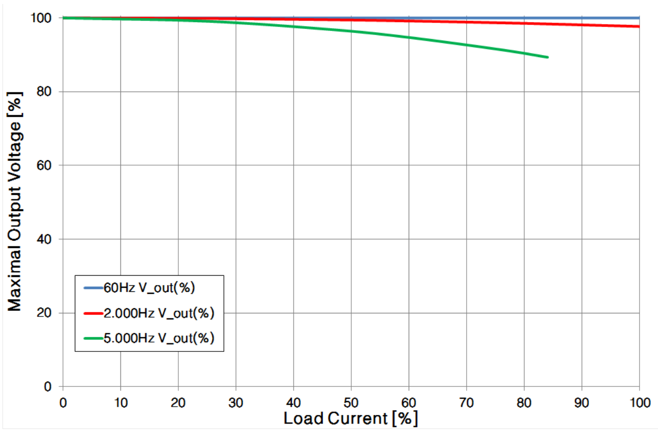


Figure 4. Maximum AC output voltage VS resistive load current

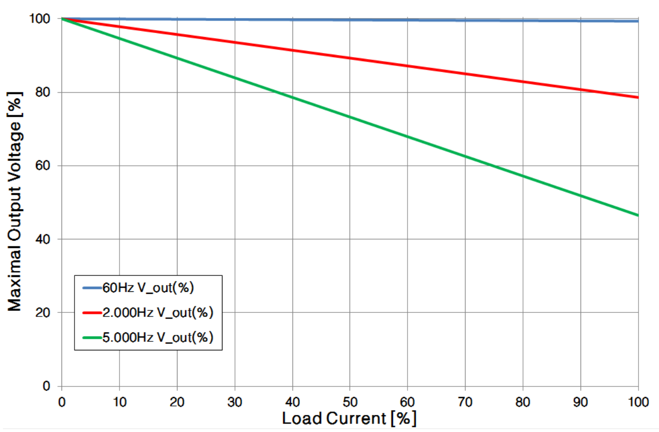


Figure 5. Maximum AC output voltage VS inductive load current

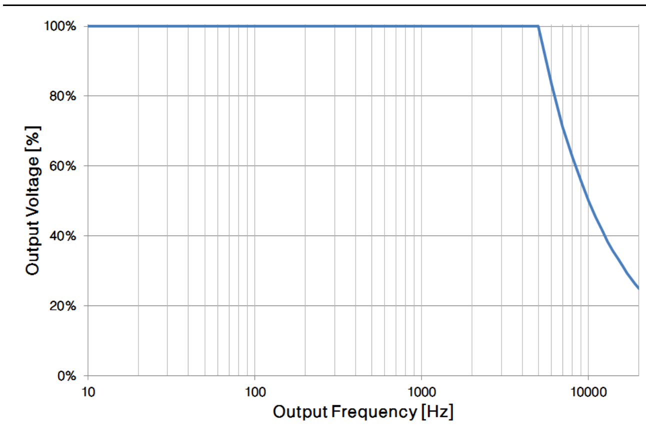


Figure 6. Maximum output voltage versus output frequency

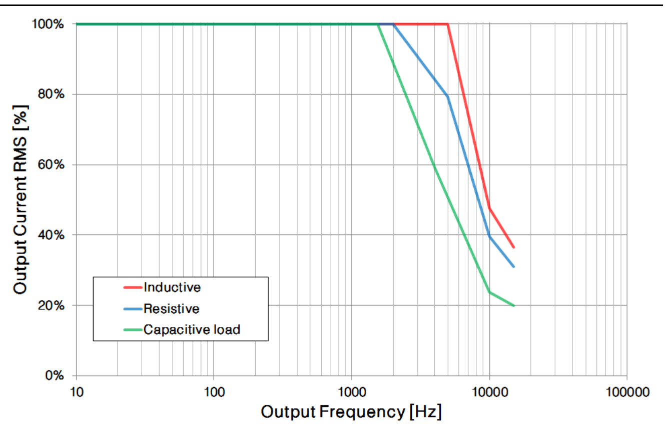


Figure 7. Maximum output current versus frequency for different load types

When the system operates in single-phase operation mode, the output power needs to be derated depending on the output frequency according to Figure 8. Derating is introduced to limit the variation of the DC-link voltage under safe operating voltage limit (875 V). The Red line in Figure 8 represents the output power of the standard system, and the blue line represents the power of the system with the additional 30 mF (±5%) capacitors of the DC link. At full capacity P_{MAX} corresponds to 200 kW. For each AC operation mode, the values in Figures 4-8 represent the percentages of the maximum voltage and current values from Table 1 for each mode.

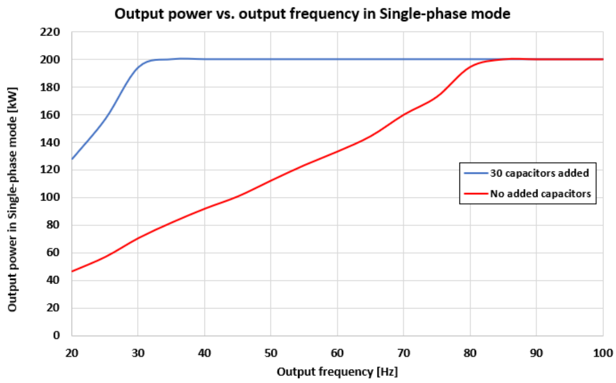


Figure 8. Power derating in single-phase operation mode.

GENERAL SYSTEM PROPERTIES

The electrical properties presented in Table 2 are valid for an ambient temperature of 25°C.

Table 2. General system properties

System properties		
Number of independent amplifiers		8 (in 2 groups of 4 amps each)
Rated system power	P_{OUT}	200 kW
System overload for 60 s	I_{OUT_60s}	1,2×I_{OUT} (only for DC operation modes)
System overload for 2 s	I_{OUT_2s}	1,35×I_{OUT} (only for DC operation modes)
Peak system efficiency	η	95% (at rated output power)
Output harmonics range		Up to the 100th harmonic at 50 Hz fundamental
Interharmonics and subharmonics		0,1 Hz to 5 kHz (full voltage) 5-15 kHz (reduced voltage)
Adjustable limits		Current, voltage
Adjustable trips		Current, voltage, power
System protections		Overvoltage, overcurrent, short circuit, overtemperature, humidity
Rated insulation voltage		1600 V_{DC} (DC+ to ground, DC– to ground, and output to ground)
Connection to main supply		Permanent
Overvoltage category		II
Protection class		I
Degree of pollution		2
Relative humidity(Non Condensing)		Average: 75% Maximum: 85% for a maximum of 30 days distributed evenly over the year
Operating ambient temperature		5-30°C
Maximum altitude		2000 m
Ingress protection		IP20 (per IEC 60529)
Noise level (sound pressure level)		< 82 dB (at operator's normal position and bystanders' positions)
Certification		
CE Certified		
The product conforms with the following harmonized standards:		
Safety requirements		EN 61010-1:2020 EN 62477-1:2012 IEC 61000-6-2:2016
Radio-frequency disturbance		EN 55011:2016 + A1:2017
Electromagnetic interference		EN IEC 61000-6-2:2019
The product is compliant with the following European regulations:		
Low Voltage Directive		2014/35/EU
EMC Directive		2014/30/EU
RoHS Directive		2011/65/EU

Table 2. (continued)

Grid converter block		
Grid Connection Type		Three Phase four Wire
Rated input power	S_{IN}	230 kVA
Rated input voltage	V_{AC}	400 V RMS ±10% (or 480 V_{RMS} ±10%)
Input frequency range	f	47,5–63 Hz
Rated input current	I_{IN}	332 A RMS (for 400 V RMS input), 277 A RMS (for 480 V RMS input)
Inrush current	I_{INRUSH}	2484 A_{PEAK}
Power factor	PF	≈1 (also with partial load and at energy regeneration)
Input current THD	THDi	< 5%
DC-link voltage	$V_{DC\text{-}link}$	850 V
CDA electrical characteristics		
Maximum DC power	P_{DC}	115 kW (continuous)
Maximum AC power [3]	P_{AC}	33,6 kVA (continuous)
Output freq. large signal[3]	f_{OUT_LS}	0,1 Hz to 5 kHz
Output freq. small signal[3]	f_{OUT_SS}	5–15 kHz
Output frequency resolution[3]		±1 mHz
Output phase resolution[3]		±0,01°
Output voltage THD[3]	THDu	< 0,04% (at 50/60 Hz, no load condition) < 0,09% (at 400 Hz, no load condition)
Switching frequency	f_{SW}	125 kHz
Delay time (typical)	t_d	28 µs (setpoint-to-output)
Voltage slew rate	SR	12 V/µs (maximum slew rate of output voltage with a resistive load)
Output voltage accuracy		±1 V
Output current accuracy		±1,4 A (current offset compensation available)
Output voltage ripple	ΔV_{OUT}	3 Vpp maximum
Output contactors		
Rated operational voltage	U_e	1800 V DC or V RMS
Rated insulation voltage	U_i	1800 V DC or V RMS
Rated operational current	I_e	250 A
Max making current DC τ = 15 ms (per pole)		5000 A
Max making current AC cos φ = 0.8 (per pole)		5000 A
Max breaking current DC τ = 15 ms (per pole)		500
Max breaking current AC cos φ = 0.8 (per pole)		800 A

Table 2. (continued)

Voltage and current measurement	
Voltage measurement range	±1000 V (DC or AC peak)
Common-mode voltage range	±1200 V (DC or AC peak)
Voltage measurement accuracy	±1 V (0.1% of measurement range)
Current measurement range	±250 A (DC or AC peak)
Current measurement accuracy	±1,4 A (0,56% of measurement range)
Measurement resolution	16 bits
Measurement sample rate	1 MS/s (per channel)
Measurement bandwidth	0,1 Hz–100 kHz (-3 dB)

[3] Only the AC component of the output voltage is considered, as the CDA output voltage has a DC offset of 420 V. The values characterizing AC operation are valid for all AC modes.

COMMUNICATION ARCHITECTURE & INTERFACES

The basic properties of the communication protocols and interfaces supported by the CSU200-2GAMP4-2CH are presented in Table 3, and the communication architecture is illustrated in Figure 9. Supported HIL platforms are listed in Table 3.

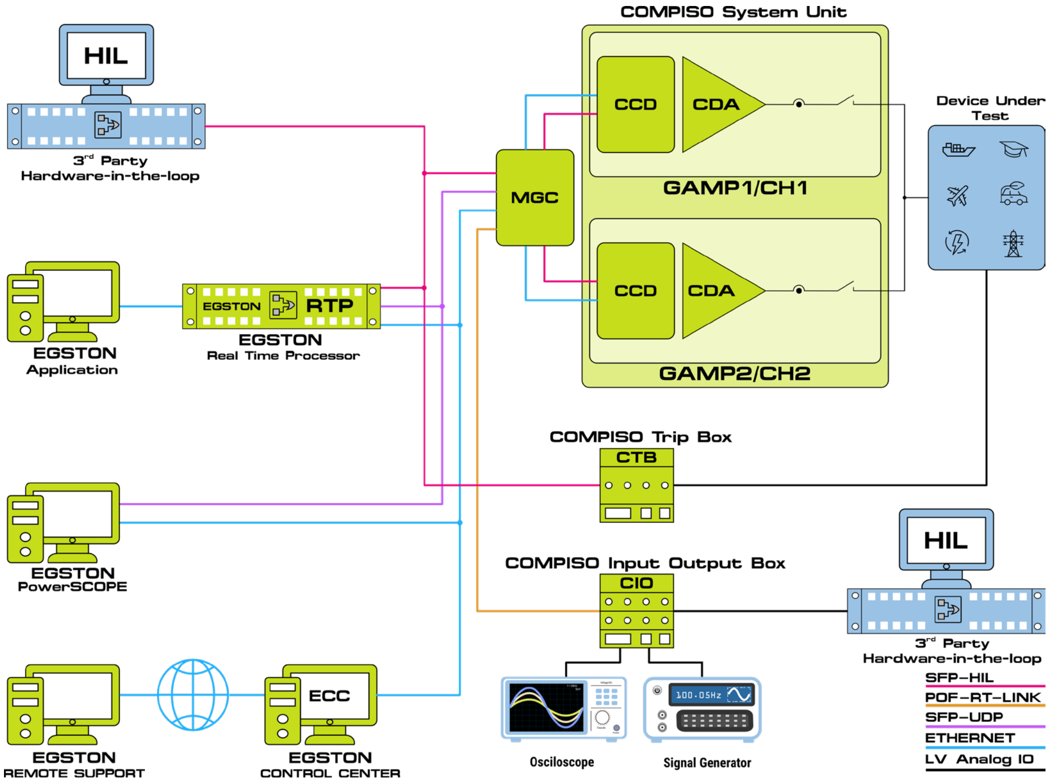


Figure 9. COMPISO communication architecture.

Table 3. Communication protocols and interfaces supported by the CSU200-2GAMP4-2CH

Supported commercial HIL platforms	
SFP interface	OPAL-RT National Instruments RTDS Speedgoat Typhoon HIL dSPACE
Analog interface	Any HIL system with low-voltage analogue input/output signals
Programming interfaces	
Modbus, MATLAB, Python, Java, C/C++	
SFP-HIL ultra-high-speed interface	
Digital RT communication between each GAMP within the CSU and an external HIL RT processor (or an EGSTON Power RT Processor) over optic-fibre cable. Receives voltage or current setpoints and transmits measured voltages and currents.	
Data rate	5 Gbps
Latency	≤ 1 µs
Setpoint time step	4 µs
Setpoint update frequency	250 kHz

Table 3. (continued)

SFP-UDP			
Digital RT data transfer from the GAMPs within the CSU to the EGSTON PowerSCOPE, transmitting measured voltages, currents and setpoints set via the SFP–HIL to the CCD.			
Data rate	1 Gbps (1000BASE-T)		
Ethernet interface (non-RT communication between CSU, ECC and EGSTON Power applications PC)			
Transmission protocol	TCP		
Data rate	100 Mbps		
Recommended cable category	CAT 6a or better		
POF-RT-link-high-speed RT interface (RT communication between the CSU and external COMPISO Input/Output Boxes (CIOs))			
RT-link interface to connect CIOs is optional and not part of the product delivery.			
Number of CIOs connected to CSU	3. Each CIO provides 4 analog input and 4 analog output channels.		
Cable	2,2 mm jacketed plastic optic-fiber cable		
Upload (CIO to CSU)	Sample rate	1 MS/s per channel (there are 4 channels in one CIO)	
	Latency	≤ 45,5 µs (from the analog input of CIO to the CSU output)	
Download (CSU to CIO)	Sample rate	256 kS/s per channel (there are 4 channels in one CIO)	
	Latency	≤ 5 µs (from the CSU output to the analog output of the CIO)	
Low-voltage analog interface between CIOs and external HIL platforms			
Analog input signals	Drives amplifier output voltages or currents.		
Analog output signals	Analog low-voltage outputs that transmit high-power voltage and current measurements from the CDAs.		
Input/output voltage range	-10 V to 10 V		
Input impedance	50 kΩ		
Sampling rate	250 kHz		
ADC resolution	16 bit		
Low-voltage digital interface (digital interface between the CIOs and external HIL platforms)			
Digital input signals	Can be transmitted from CIO over POF–RT-link to the CCD. CCD sends the digital values over POF– or SFP–RT-link to external HIL or EGSTON RT Processor for further processing.		
Digital output signals	External HIL or EGSTON RT Processor can send digital values via SFP to the CSU control to drive the digital output signal of the CIOs.		
Logic levels (3,3 V LVCMOS)	Input voltage levels:	$2 V \le V_{IN\_HIGH} \le 3{,}6 V$	$-0{,}3 V \le V_{IN\_LOW} \le 0{,}8 V$
	Output voltage levels:	$3{,}1 V \le V_{OUT\_HIGH}$	$V_{OUT\_LOW} \le 0{,}2 V$
Maximum currents (3,3 V LVCMOS)	Input current:	$I_{IN\_MIN} = -5 µA$	$I_{IN\_MAX} = 5 µA$
	Output current:	$I_{OUT\_MIN} = -100 µA$	$I_{OUT\_MAX} = 100 µA$

COOLING REQUIREMENTS

Table 4. Cooling requirements

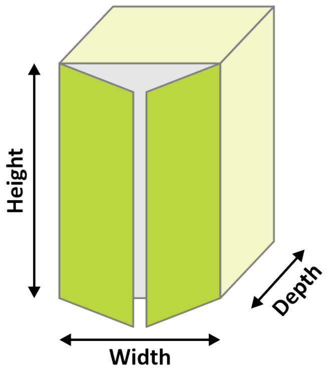
Ambient conditions	
Operating temperature	5–30°C
Maximum altitude	2000 m
Ingress protection	IP20 (per IEC 60529)
Noise level (sound pressure level)	< 82 dB (at operator's normal position and bystanders' positions)
Liquid cooling (CDAs)	
Cooling media	Water, ethylene glycol, propylene glycol, glycol–water solutions
Minimum required cooling power	8,0 kW (for all 8 CDAs operating at full power)
Coolant pressure range	2,5–3 bar
Coolant flow rate	28 l/min (for all 8 CDAs; coolant inlet temperature 20°C)
To avoid condensation, temperature of the cooling liquid must be kept higher than the ambient temperature.	
Forced-air cooling (cabinets)	
Maximum heat dissipation per CSU200-2GAMP4-2CH at full power	10,5 kW_{th}

TECHNICAL DATA: MECHANICAL PROPERTIES

The CSU200-2GAMP4-2CH system consists of Three fixed free-standing cabinets. The dimensions and weight of each cabinet are listed in Table 5.

Table 5. Dimensions and weight of CSU200-2GAMP4-2CH cabinets

Mechanical data (cabinet dimensions)								
	Width		Depth		Height		Weight	
	mm	ft	mm	ft	mm	ft	kg	lb
Cabinet 1 Transformer	800	2.62	1200	3.94	2110	6.92	1400	3086
Cabinet 2 AFE	800	2.62	1200	3.94	2110	6.92	1000	2205
Cabinet 3 Amplifiers	800	2.62	1200	3.94	2110	6.92	800	1764
Total	2400	7.87	1200	3.94	2110	6.92	3200	7055



TESTING CAPABILITIES ACCORDING TO STANDARDS

Power grid:

- IEEE Std. 1547.1; usable as simulated area electric power systems source
- IEC 61000-3-12; meets requirements for power sources

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