Data Dictionary — M5BAT Exide1 OCSM Lead-Acid BESS

Machine-readable codebook for the published one-second-resolution operational dataset. Per-year Parquet files `Exide1_BMS_{year}.parquet` and `Exide1_BSC_{year}.parquet` (2017–2025); index `timestamp_utc` (UTC, 1-second resolution). Naming convention `{physical_quantity}_{unit}_{source_table}`. BMS columns: 8 · BSC columns: 23 · total 31. Generated 2026-07-09.

Overview

Column	Tbl	Unit	Type	Availability	Description
power_dc_W_bms	BMS	W	float32	2017-2025	DC active power at battery terminals
current_A_bms	BMS	A	float32	2017-2025	DC current at battery terminals
voltage_bat_V_bms	BMS	V	float32	2017-2025	DC bus voltage at battery terminals
soc_pct_bms	BMS	%	float32	2017-2025	State of charge estimated by BMS
energy_charge_Wh_bms	BMS	Wh	int64	2017-2025	Cumulative DC energy charged (odometer counter)
energy_discharge_Wh_bms	BMS	Wh	int64	2017-2025	Cumulative DC energy discharged (odometer counter)
flag_imbalance_voltage_bms	BMS	–	int64	2017-2025	Battery-level DC voltage imbalance warning flag
flag_alarm_voltage_imbalance_bms	BMS	–	int64	2017-2025	Battery-level DC voltage imbalance alarm flag
power_ac_kW_bsc	BSC	kW	float64	2017-2025	AC active power at grid connection point
frequency_Hz_bsc	BSC	Hz	float64	2017-2025	Grid frequency measured at AC terminal
temperature_degC_bsc	BSC	°C	float64	2017-2025	Battery cabinet air temperature; measured by the BMS te…
energy_charge_kWh_bsc	BSC	kWh	float64	2017-2025	Cumulative AC energy charged (odometer counter)
energy_discharge_kWh_bsc	BSC	kWh	float64	2017-2025	Cumulative AC energy discharged (odometer counter)
energy_charge_recon_kWh_bsc	BSC	kWh	float64	2017-2025 (full record)	Cumulative AC charge energy, reconstructed by time-inte…
energy_discharge_recon_kWh_bsc	BSC	kWh	float64	2017-2025 (full record)	Cumulative AC discharge energy, reconstructed by time-i…
flag_fcr_active_bsc	BSC	–	int64	2017-2025	Power/frequency (PQ) regulation mode active
flag_standby_bsc	BSC	–	int64	2017-2025	Standby mode active
flag_stop_bsc	BSC	–	int64	2017-2025	Stop mode active
flag_failure_bsc	BSC	–	int64	2017-2025	Fault/failure mode active
flag_const_bsc	BSC	–	int64	2017-2025	Constant power mode active
flag_qod_bsc	BSC	–	int64	2017-2025	Quality-of-Delivery mode active
flag_wait_bsc	BSC	–	int64	2017-2025	Wait/initializing mode active
power_ac_setpoint_kW_bsc	BSC	kW	float64	2017-2025	AC active power setpoint from supervisory controller
power_reactive_kvar_bsc	BSC	kvar	float64	2017-2025	AC reactive power
power_reactive_setpoint_kvar_bsc	BSC	kvar	float64	2017-2025	AC reactive power setpoint from supervisory controller
power_apparent_kVA_bsc	BSC	kVA	float64	2017-2025	AC apparent power
current_ac_A_bsc	BSC	A	float64	2017-2025	AC RMS current
voltage_bat_V_bsc	BSC	V	float64	2017-2025	DC battery voltage measured at inverter DC input
voltage_inv_V_bsc	BSC	V	float64	2017-2025	Inverter-side DC voltage; differs from battery terminal…

Column	Tbl	Unit	Type	Availability	Description
current_A_bsc	BSC	A	float64	2017-2025	DC battery current measured at inverter DC input
flag_cmd_fullcharge_bsc	BSC	–	int64	2017-2025	Full charge command issued by supervisory controller

BMS — battery management system (DC side)

power_dc_W_bms

unit: W · type: float32 · availability: 2017-2025

register: Exide1_LT_i_P_DC · scale: none

DC active power at battery terminals

Notes. Signed: positive = discharging, negative = charging. Stored in physical units by BMS (no scaling factor applied). Occasional sentinel values (2345 / 2356) are device placeholder codes for BMS communication errors and are treated as NaN in this dataset.

current_A_bms

unit: A · type: float32 · availability: 2017-2025

register: Exide1_LT_i_I_DC · scale: none

DC current at battery terminals

Notes. Signed: positive = discharging, negative = charging. Used for DCIR calculation. Sentinel value pattern (2345 / 2356) indicates BMS communication error.

voltage_bat_V_bms

unit: V · type: float32 · availability: 2017-2025

register: Exide1_LT_w_U_DC · scale: none

DC bus voltage at battery terminals

Notes. Nominal system voltage ≈ 600 V (300 series cells, 299 after the 2023 bypass); typical operating range ≈ 610–630 V. Used for DCIR calculation. Sentinel value 2345 / 2356 indicates BMS communication error.

soc_pct_bms

unit: % · type: float32 · availability: 2017-2025

register: Exide1_LT_w_SoC · scale: none

State of charge estimated by BMS

Notes. Proprietary BMS algorithm (manufacturer-internal SoC model). Not independently calibrated. Sentinel value 2345 indicates BMS communication error.

energy_charge_Wh_bms

unit: Wh · type: int64 · availability: 2017-2025

register: Exide1_LT_dw_Eges_lad · scale: 32bit_reconstruct

Cumulative DC energy charged (odometer counter)

Notes. Reconstructed from two 16-bit register words (dw_Eges_lad_high << 16 | dw_Eges_lad_low). Counter resets to zero after BMS power cycle or counter overflow (~4.3 GWh). Use incremental differences (delta) for energy throughput calculations.

energy_discharge_Wh_bms

unit: Wh · type: int64 · availability: 2017-2025

register: Exide1_LT_dw_Eges_entlad · scale: 32bit_reconstruct

Cumulative DC energy discharged (odometer counter)

Notes. Same construction and caveats as energy_charge_Wh_bms. Absolute value (unsigned); does not include charging.

flag_imbalance_voltage_bms

unit: – · type: int64 · availability: 2017-2025

register: Exide1_LT_x_Warn_Spannung_unausgeglichen_Bat · scale: none

Battery-level DC voltage imbalance warning flag

Notes. Boolean: 1 = warning active, 0 = normal. Triggered when voltage spread across battery strings exceeds BMS threshold. Corresponds to the sulphation-related warning discussed in the paper.

flag_alarm_voltage_imbalance_bms

unit: – · type: int64 · availability: 2017-2025

register: Exide1_LT_x_Alarm_Spannung_unausgeglichen_Bat · scale: none

Battery-level DC voltage imbalance alarm flag

Notes. Boolean: 1 = alarm active, 0 = normal. Higher severity than flag_imbalance_voltage_bms. Triggers protective shutdown if sustained.

BSC — power-conversion-system controller (AC side)

power_ac_kW_bsc

unit: kW · type: float64 · availability: 2017-2025

register: i_P_AC · scale: none

AC active power at grid connection point

Notes. Signed: positive = discharging to grid (generation), negative = charging from grid. Primary FCR control signal. Unit confirmed as kW (no scaling factor in BSC firmware; validated against nameplate rating ±630 kW).

frequency_Hz_bsc

unit: Hz · type: float64 · availability: 2017-2025

register: w_freq · scale: auto (see notes)

Grid frequency measured at AC terminal

Notes. Primary FCR activation signal; assembled from different data sources across periods. 2017-2021: raw integer values auto-scaled to Hz by BESSDataLoader (×0.01 if median ~5000; ÷1000 if median ~50000). 2022-2025: sourced from auxiliary measurement unit (Data_Messung.parquet), column ui_netzfrequenz_1s_mHz ÷ 1000. Data unavailable for January–September 2022 (column absent in source file for that period); those rows contain NaN.

temperature_degC_bsc

unit: °C · type: float64 · availability: 2017-2025

register: i_T_Batt · scale: ×0.1

Battery cabinet air temperature; measured by the BMS temperature sensor and relayed via the BSC (not an independent BSC sensor)

Notes. Single-point measurement inside the battery cabinet. Ambient temperature sensor (i_T_Ambient) was defective throughout the observation period (constant 0 °C) and is not published.

energy_charge_kWh_bsc

unit: kWh · type: float64 · availability: 2017-2025

register: dw_E_AC_Wirk_Lad · scale: 32bit_reconstruct (2017-2021 only)

Cumulative AC energy charged (odometer counter)

Notes. 2017-2021: reconstructed from 16-bit high/low register pair by BESSDataLoader. 2022-2025: stored as combined float64. Counter may reset after BSC power cycle. Use incremental differences for throughput calculations.

energy_discharge_kWh_bsc

unit: kWh · type: float64 · availability: 2017-2025

register: dw_E_AC_Wirk_Entlad · scale: 32bit_reconstruct (2017-2021 only)

Cumulative AC energy discharged (odometer counter)

Notes. Same construction and caveats as energy_charge_kWh_bsc.

energy_charge_recon_kWh_bsc

unit: kWh · type: float64 · availability: 2017-2025 (full record)

register: (derived from i_P_AC / power_ac_kW_bsc) · scale: time-integral of power_ac_kW_bsc (charge = integral of negative power)

Cumulative AC charge energy, reconstructed by time-integration of AC active power

Notes. PROVENANCE: reconstructed at export time by rectangular time-integration of power_ac_kW_bsc, because the on-board AC energy counter energy_charge_kWh_bsc is populated only from 2022 onward (uninitialised 0xFFFF before 2022). Validated against that counter to <1% over the 2022-2025 overlap. Cumulative across the exported years in ascending order (starts at 0 in the first exported year); sample gaps are capped at 5 s and contribute no energy. Use period-to-period differences to obtain charge throughput / round-trip efficiency.

energy_discharge_recon_kWh_bsc

unit: kWh · type: float64 · availability: 2017-2025 (full record)

register: (derived from i_P_AC / power_ac_kW_bsc) · scale: time-integral of power_ac_kW_bsc (discharge = integral of positive power)

Cumulative AC discharge energy, reconstructed by time-integration of AC active power

Notes. Same reconstruction, provenance and caveats as energy_charge_recon_kWh_bsc.

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flag_fcr_active_bsc

unit: – · type: int64 · availability: 2017-2025

register: x_BSC_Opmode_PQ · scale: none

Power/frequency (PQ) regulation mode active

Notes. Boolean: 1 = PQ-regulation mode active. This is predominantly FCR, in which the BSC adjusts AC power proportionally to grid-frequency deviation from 50 Hz per the ENTSO-E FCR specification, but it may also include other set-point-driven PQ operation; it is therefore not an exclusive FCR indicator.

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flag_standby_bsc

unit: – · type: int64 · availability: 2017-2025

register: x_BSC_Opmode_Silent · scale: none

Standby mode active

Notes. Boolean: 1 = standby. System connected but not providing FCR.

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flag_stop_bsc

unit: – · type: int64 · availability: 2017-2025

register: x_BSC_Opmode_Stop · scale: none

Stop mode active

Notes. Boolean: 1 = system stopped (no grid connection).

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flag_failure_bsc

unit: – · type: int64 · availability: 2017-2025

register: x_BSC_Opmode_Failure · scale: none

Fault/failure mode active

Notes. Boolean: 1 = failure state.

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flag_const_bsc

unit: – · type: int64 · availability: 2017-2025

register: x_BSC_Opmode_Const · scale: none

Constant power mode active

Notes. Boolean: 1 = constant-power mode, used for maintenance/equalization charging. Capacity tests are run under PQ control, not in this mode.

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flag_qod_bsc

unit: – · type: int64 · availability: 2017-2025

register: x_BSC_Opmode_QoD · scale: none

Quality-of-Delivery mode active

Notes. Boolean: 1 = QoD mode (reactive power / voltage support).

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flag_wait_bsc

unit: – · type: int64 · availability: 2017-2025

register: x_BSC_Opmode_Wait · scale: none

Wait/initializing mode active

Notes. Boolean: 1 = system initializing or waiting for grid synchronization.

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power_ac_setpoint_kW_bsc

unit: kW · type: float64 · availability: 2017-2025

register: i_P_Set_AC · scale: none

AC active power setpoint from supervisory controller

Notes. In FCR mode this is the frequency-derived power command computed by the supervisory controller (FSC). In other modes it reflects the manually dispatched setpoint.

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power_reactive_kvar_bsc

unit: kvar · type: float64 · availability: 2017-2025

register: i_Q_AC · scale: none

AC reactive power

Notes. Signed convention follows IEEE standard (positive = inductive). Not analysed in the paper; included for future power quality studies.

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power_reactive_setpoint_kvar_bsc

unit: kvar · type: float64 · availability: 2017-2025

register: i_Q_Set_AC · scale: none

AC reactive power setpoint from supervisory controller

Notes. Companion to power_ac_setpoint_kW_bsc.

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power_apparent_kVA_bsc

unit: kVA · type: float64 · availability: 2017-2025

register: i_S_AC · scale: none

AC apparent power

Notes. The 2017-2021 values were restored from the completed inverter-side source export (Data_2017_2021_InvLT); an earlier intermediate export had omitted this register for that period. Relationship: $S^2 = P^2 + Q^2$.

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current_ac_A_bsc

unit: A · type: float64 · availability: 2017-2025

register: i_I_AC_RMS · scale: ×0.1

AC RMS current

Notes. The 2017-2021 values were restored from the completed inverter-side source export (Data_2017_2021_InvLT); an earlier intermediate export had omitted this register for that period.

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voltage_bat_V_bsc

unit: V · type: float64 · availability: 2017-2025

register: w_U_DC_Batt · scale: ×0.1

DC battery voltage measured at inverter DC input

Notes. BSC measurement point (inverter DC terminals). Differs from voltage_bat_V_bms (battery pole terminals) by cable resistance. Included for cross-validation; BMS value is authoritative.

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voltage_inv_V_bsc

unit: V · type: float64 · availability: 2017-2025

register: w_U_DC_Inv · scale: ×0.1

Inverter-side DC voltage; differs from battery terminal voltage by cable resistance drop

Notes. Available across the full record. The 2022-2025 values were restored from the corrected source export (Data_2022_2025_neu); an earlier intermediate export had omitted this register for 2022+. Used for cable resistance estimation: R_cable = (voltage_bat_V_bsc − voltage_inv_V_bsc) / current_A_bsc.

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current_A_bsc

unit: A · type: float64 · availability: 2017-2025

register: i_I_DC_Batt · scale: ×0.1

DC battery current measured at inverter DC input

Notes. BSC measurement point (inverter DC terminals). Signed: positive = discharging, negative = charging. Included for cross-validation with current_A_bms.

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flag_cmd_fullcharge_bsc

unit: – · type: int64 · availability: 2017-2025

register: x_cmd_FullCharge · scale: none

Full charge command issued by supervisory controller

Notes. Boolean: 1 = full-charge command active. Issued periodically to counteract sulphation buildup. Available across the full record; the 2022-2025 values were restored from the corrected source export (Data_2022_2025_neu). An earlier intermediate export had omitted this register for 2022+, which made the equalization fraction read ~0 for those years (a data artifact, not a real cessation of equalization charging).
