Electric Drives
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Hydraulics

Linear Motion and
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Rexroth
Bosch Group

HMV0x.1R Supply Units
Smart Energy Mode

R911343308
Edition 01

Project Planning Manual

Title HMV0x.1R Supply Units
Smart Energy Mode

Type of Documentation Project Planning Manual

Document Typecode DOK-INDRV*-HMVR*SEM***-PR01-EN-P

Internal File Reference RS-d7566ca48fb324430a6846a500b705f1-2-en-US-3

Record of Revision

Edition	Release Date	Notes
01	12/2013	First edition

Published by Bosch Rexroth AG

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1 Important Notes

1.1 Documentations

⚠ WARNING **Personal injury and property damage caused by incorrect project planning for applications, machines and installations!**

Observe the safety instructions contained in the documentations of the drive system and the components of the Rexroth IndraDrive product range.

Documentations			
Title Rexroth IndraDrive …	Kind of documentation	Document typecode[1)] DOK-INDRV*-…	Material number R911…
Drive Systems with HMV01/02 HMS01/02, HMD01, HCS02/03	Project Planning Manual	SYSTEM*****-PRxx-EN-P	309636
Supply Units, Power Sections HMV, HMS, HMD, HCS02, HCS03	Project Planning Manual	HMV-S-D+HCS-PRxx-EN-P	318790
Additional Components and Accessories	Project Planning Manual	ADDCOMP****-PRxx-EN-P	306140
Drive Controllers Control Sections CSB01, CSH01, CDB01	Project Planning Manual	CSH********-PRxx-EN-P	295012
Control Sections CSE02, CSB02, CDB02, CSH02	Project Planning Manual	Cxx02******-PRxx-EN-P	338962

1) In the document typecodes, "xx" is a wild card for the current edition of the documentation (example: PR01 is the first edition of a Project Planning Manual)

Tab.1-1: Documentations – Overview

1.2 Purpose of This Documentation

This documentation

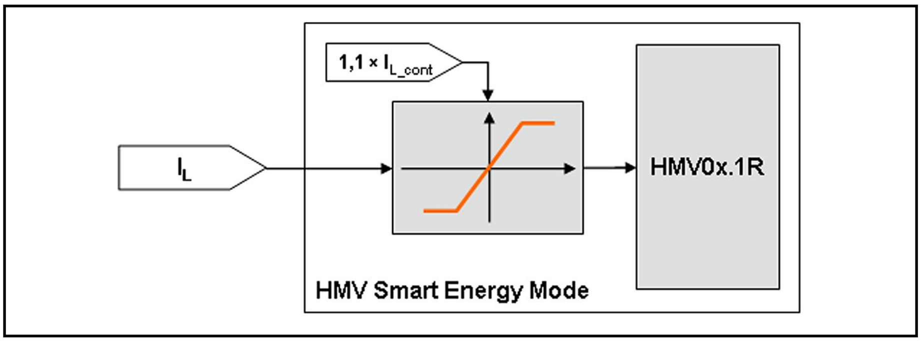
- provides information on the project planning of drive systems with HMV0x.1R-W0***-A-07-**FNN2** supply units (regenerative supply units with Smart Energy Mode)
- is a documentation supplementary to the documentations of the drive system and components of the Rexroth IndraDrive product range

2 Supply Units with Smart Energy Mode

2.1 Brief Description

Smart Energy Mode

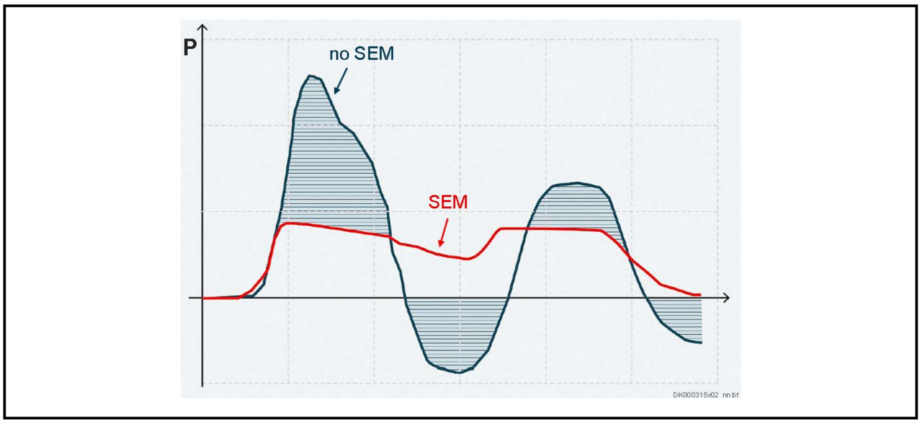
Regenerative HMV0x.1R supply units with Smart Energy Mode reduce current and power peaks on the mains side. The Smart Energy Mode limits the maximum device current to the 1.1-fold value of the nominal current.



I_L	Device current
I_{L_cont}	Nominal current
Fig.2-1:	*Current Limitation with HMV0x.1R and Smart Energy Mode*

In the following texts, the abbreviation "SEM" is used for "Smart Energy Mode".

Example of Application:



P	Mains power
SEM	Example of application with Smart Energy Mode
no SEM	Example of application without Smart Energy Mode
Fig.2-2:	*Mains Power with and without SEM*

Result with SEM:

- Reduced energy consumption
- Improved mains compatibility
- Smaller components with equal machine performance

Improved energy efficiency by SEM

Supply Units with Smart Energy Mode

Supply Units of FNN2 Design

HMV0x.1R-W0***-A-07-**FNN2**

"FNN2" in the type code identifies supply units with SEM.

☞ HMV0x.1R without SEM cannot be subsequently equipped with SEM.

Firmware

HMV0x.1R devices with SEM use the following firmware:

FWL-VRC01*-A**-01VRS-NN (RS ≥ 14; mat. no.: R911332326)

Applications

In applications with high power peaks in the DC bus, HMV0x.1R devices without SEM cause high mains-side current peaks. HMV0x.1R devices with SEM reduce these current peaks and thereby the mains pollution.

Advantages

- Cost-efficient sizing of fuses and lines (smaller cross section) on the mains side
- With identical nominal power, the SEM avoids device overload. HMV0x.1R with SEM are thermally less loaded than HMV0x.1R without SEM
- Reduced power dissipation in mains filter and mains choke
- Less space required in the control cabinet

Pertinent Parameters None

Pertinent Diagnostic Messages None

2.2 Functional Description

The firmware recognizes HMV0x.1R devices with SEM and reduces the peak current to the 1.1-fold nominal current. The limitation only influences the limit value of the command current.

Overcurrent and thermal overload are monitored. The device current is limited to the minimum of the three limit values.

2.3 Project Planning

2.3.1 How to Proceed

Steps

1. **Determine power requirements of the installation**
   - Existing installation:

     Determine power requirements by oscilloscope recording in IndraWorks. Record the following parameters in each axis:
     - S-0-0051, Position feedback value 1
     - S-0-0084, Torque/force feedback value
     - S-0-0380, DC bus voltage
     - S-0-0382, DC bus power

     Calculate DC bus power by summation of all S-0-0382.
   - New installation:

     Determine mechanical power of the individual axes by means of velocity curve and torque curve.

     Afterwards, calculate entire DC bus power by means of constant for motor and controller efficiency and summation of the individual powers.

   Result: Course of the entire DC bus power of all axes.

2. **Take mains voltage into account:**
   - A lower mains voltage permits a bigger DC bus voltage excursion and thereby the SEM is more effective.
   - If the mains voltage is too high, this requires a mains transformer.
3. **Dimensioning: Supply unit, fuses, power lines, mains filter, mains choke**
   - Select power of HMV0x.1R:

     The continuous power of HMV0x.1R must be greater than the average DC bus power of all drives.
   - Dimension mains fuse and mains-side lines. When doing this, take the reduced peak current of HMV0x.1R into account.
   - Select mains filter and mains choke:

     See data in the Project Planning Manual "Drive Systems with HMV01/02, HMS01/02, HMD01, HCS02/03" (R911309636).

   Result: HMV0x.1R with SEM

4. **Dimension the DC bus capacitance:**
   1. Determine start value for DC bus capacitance:

      Determine maximum energy by means of the positive power limit.

      Determine maximum energy below the negative power limit.
   2. Check DC bus capacitance:

      In motive and regenerative operation, integrate the DC bus power depending on the positive and negative power limit of HMV0x.1R.

      In doing so, the DC bus energy value must not fall below the minimum DC bus energy (or the mains peak voltage) and it must not exceed the maximum DC bus energy (or the braking resistor switch-on threshold).

Supply Units with Smart Energy Mode

3. If necessary, increase the DC bus capacitance and check it again.

Result: Value of the minimum required DC bus capacitance.

Mains Voltage

The tolerance range of the DC bus voltage (U_{DC_min} … U_{DC_max}) depends on the mains voltage value. The smaller the mains voltage, the better the effect of the SEM, because the DC bus voltage excursion is bigger.

U_{LN} [V_{rms}]	U_{DC_min} [V]	U_{DC_nom} [V]	U_{DC_max} [V]	ΔU_{DC} [V]
400	566	750	820	254
480	679	750	820	141

Tab.2-1: Tolerance Range of the DC Bus Voltage

DC Bus Capacitance

Select the energy store (DC bus capacitor unit) such that the DC bus voltage cannot fall to the mains peak. Otherwise, the SEM does not take effect, because the device current cannot be limited.

The maximum energy that the DC bus can output depends on the total DC bus capacitance and the minimum allowed DC bus voltage (mains peak).

When the DC bus voltage corresponds to the nominal value at the moment of the discharging process, the maximum energy difference is calculated as follows:

$$\Delta E_{DC\_nom\_min} = \frac{C_{DC}}{2}\left(U^2_{DC\_nom} - U^2_{DC\_min}\right)$$

C_{DC} Total DC bus capacitance

U_{DC_nom} Nominal DC bus voltage (750 V, controlled)

U_{DC_min} Minimum DC bus voltage (mains peak)

Fig.2-3: Maximum DC Bus Energy that can be Output during the Feeding Operation

The DC bus must always make power peaks available when the HMV0x.1R device is at its power limit (current limit).

When drives regenerate energy via the DC bus to the mains in regenerative operation, the current limitation takes effect by analogy to the feeding process:

Negative power peaks in the DC bus smaller than the negative power limit of HMV0x.1R are stored in the DC bus in the form of energy. The DC bus voltage rises.

Dimension the total DC bus capacitance in such a way that the DC bus voltage does not reach the braking resistor switch-on threshold. This avoids additional losses in the system and overload of the braking resistor of HMV0x.1R.

When the DC bus voltage corresponds to the nominal value at the moment of the regenerative process, the following formula applies to the maximum energy that can be absorbed in the DC bus:

$$\Delta E_{DC\_max\_nom} = \frac{C_{DC}}{2}\left(U^2_{DC\_max} - U^2_{DC\_nom}\right)$$

C_{DC}	Total DC bus capacitance
U_{DC_nom}	Nominal DC bus voltage (750 V, controlled)
U_{DC_max}	Maximum DC bus voltage (braking resistor switch-on threshold)

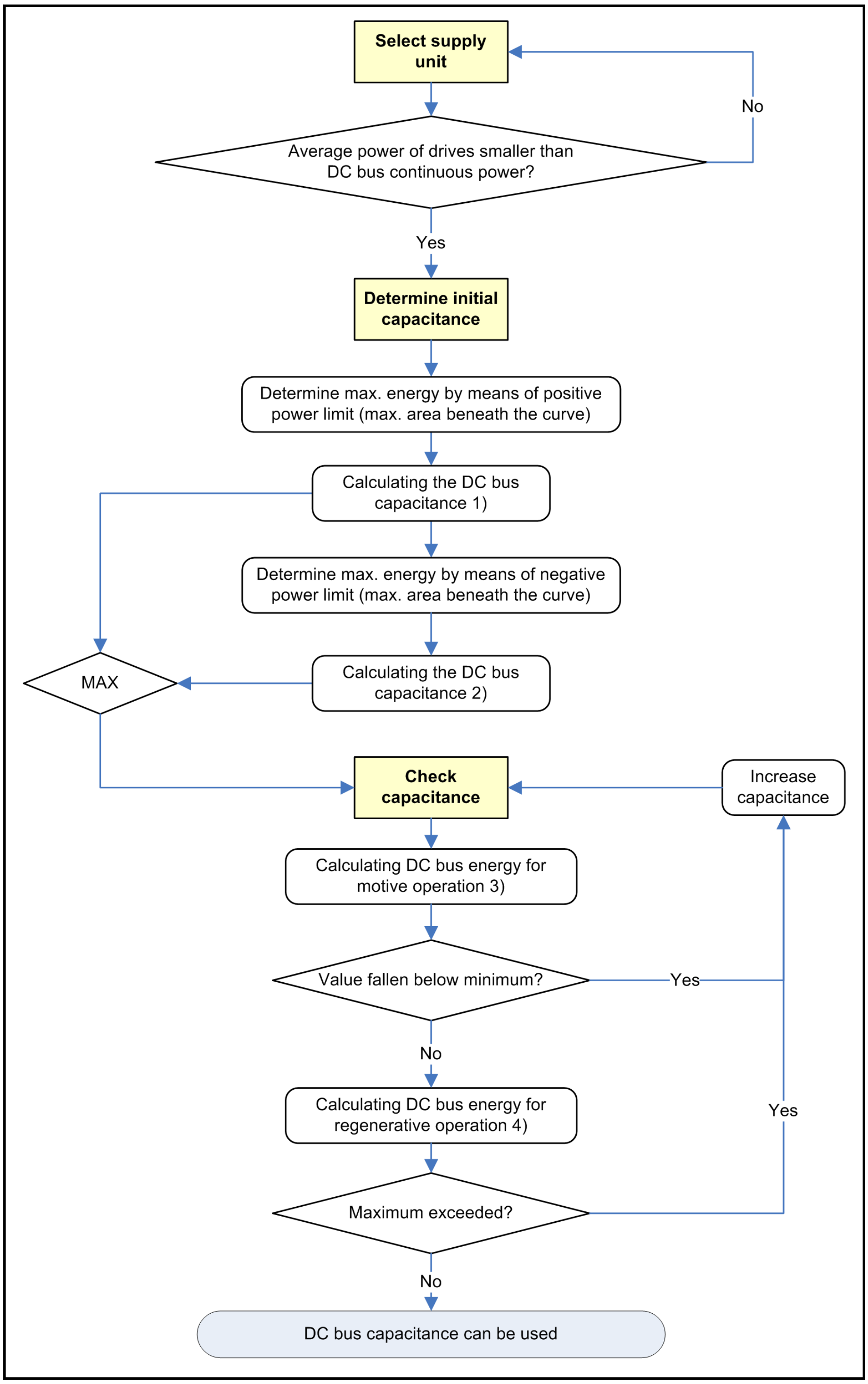
Fig.2-4: Maximum DC Bus Energy that can be Absorbed during Regenerative Operation

☞ Low mains voltage makes sense for the SEM because the squared DC bus voltage is used for the calculation.

The smaller the mains voltage, the bigger the maximum energy difference in the DC bus at equal DC bus capacitance.

Supply Units with Smart Energy Mode

Summary of the Basic Project Planning Steps



1) Formula fig. 2-3 "Maximum DC Bus Energy that can be Output during the Feeding Operation" on page 8
2) Formula fig. 2-4 "Maximum DC Bus Energy that can be Absorbed during Regenerative Operation" on page 9
3) Formula "Motive Operation, Feeding" on page 12
4) Formula "Regenerative Operation, Regenerative" on page 13

Fig.2-5: Sizing the DC Bus Capacitance

The "Check capacitance" step is required because the course of the DC bus voltage must be taken into account to safely dimension the DC bus capacitance (see chapter 2.3.2 "Cases of Operation with SEM" on page 12).

Project Planning Software

The project planning software **HMV_SmartEnergyMode.exe** by Rexroth is used to size the DC bus capacitance.

The project planning software works with the following variables:

- DC bus power profile

  (The DC bus power profile must be available as an ASCII file with the time values and the corresponding power values.)
- Supply unit (selection list)
- Mains voltage (selection list)
- Voltage offset to the mains peak as safety reserve (it is necessary to enter a value)

The project planning software calculates the minimum required DC bus capacitance depending on the voltage offset to the mains peak.

Current Limit, Power Limit

The following current and power limits are active for HMV0x.1R with SEM:

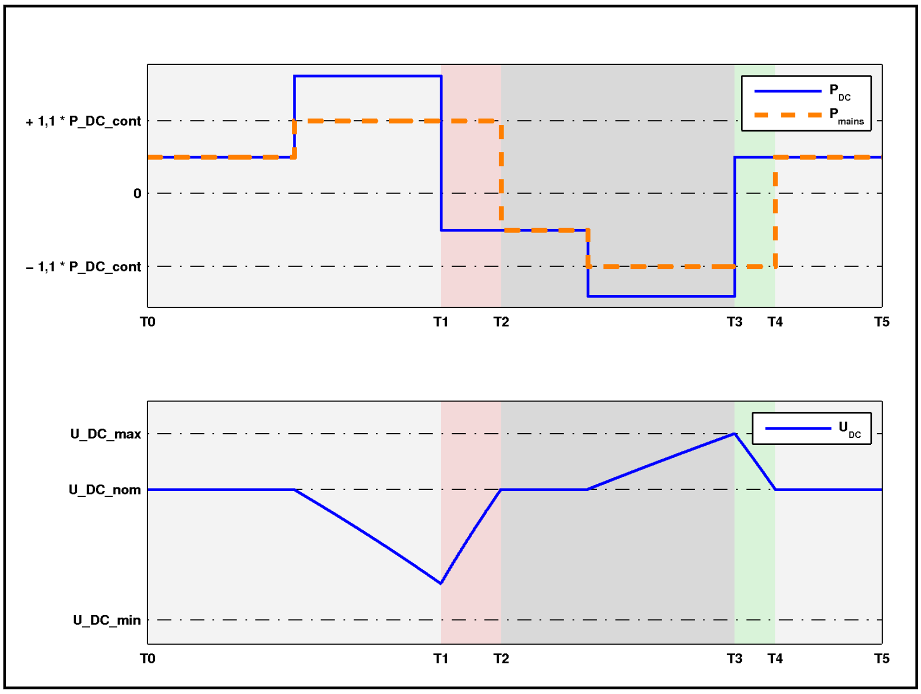
Supply unit	Max. device current [A]	Max. device power at U_{LN} = 400 V [kW]	Max. device power at U_{LN} = 480 V [kW]
HMV01.1R-W0018	28,6	19,8	23,8
HMV01.1R-W0045	71,5	49,5	59,4
HMV01.1R-W0065	103,4	71,5	85,8
HMV01.1R-W0120	199,1	132	158,4
HMV02.1R-W0015	25,3	16,5	19,8

Tab.2-2: Current and Power Limits of HMV0x.1R with SEM

2.3.2 Cases of Operation with SEM

Depending on the total DC bus power P_{DC} (corresponding to the load profile of the drives) and the DC bus voltage U_{DC}, there are 4 cases of operation:

- Motive operation, feeding
- Regenerative operation, feeding
- Regenerative operation, regenerative
- Motive operation, regenerative



Picture above	DC bus power profile (blue, solid line); mains power (orange, dashed line)
Picture below	DC bus voltage
$+1.1\times P_{DC\_cont}$	Positive power limit of supply unit
$-1.1\times P_{DC\_cont}$	Negative power limit of supply unit
U_{DC_max}	Maximum DC bus voltage (braking resistor switch-on threshold)
U_{DC_nom}	Nominal DC bus voltage (HMV0x.1R: 750 V)
U_{DC_min}	Minimum DC bus voltage (mains peak)
T0…T1	Motive operation, feeding
T1…T2	Regenerative operation, feeding
T2…T3	Regenerative operation, regenerative
T3…T4	Motive operation, regenerative
T4…T5	Motive operation, feeding

Fig.2-6: Cases of Operation of HMV0x.1R with SEM

Motive Operation, Feeding

HMV0x.1R feeds energy, DC bus loses energy:

- Condition:
  – $P_{DC}(t) \geq 0$
  – $U_{DC}(t) \leq U_{DC\_nom}$
- The **maximum** DC bus voltage corresponds to the nominal DC bus voltage

- If $P_{DC}(t) > 1.1 \times P_{DC\_cont}$, the DC bus capacitance must supply the additional energy
- The DC bus voltage must not fall to the mains peak. This means that the DC bus capacitance must at least have the energy E_{DC_min}.

  The following condition must be fulfilled at every point of time t:

$$E_{DC}(t) = E_0 + \int \left(1{,}1 \times P_{DC\_cont} - P_{DC}(t)\right) dt > E_{DC\_min}$$

$E_{DC}(t)$	Energy of DC bus capacitance at point of time t
$P_{DC}(t)$	DC bus power at point of time t
P_{DC_cont}	DC bus continuous power of HMV0x.1R
E_0	Initial energy
E_{DC_min}	Minimum allowed DC bus energy

Fig.2-7: Energy of the DC Bus Capacitance for $P_{DC}(t) \geq 0$ and $U_{DC}(t) \leq U_{DC\_nom}$

☞ The upper limit of the integrator is the energy E_{DC_nom}, because further energy absorption by the DC bus capacitance is impossible due to the control of the DC bus voltage.

Regenerative Operation, Feeding

HMV0x.1R feeds energy, DC bus gains energy:

- Condition:
  - $P_{DC}(t) < 0$
  - $U_{DC}(t) < U_{DC\_nom}$
- The **maximum** DC bus voltage corresponds to the nominal DC bus voltage
- This operating status always follows the operating status "motive operation, feeding", when the DC bus voltage is below the nominal value when entering the regenerative operation.
- DC bus energy:

$$E_{DC}(t) = E_0 + \int \left(1{,}1 \times P_{DC\_cont} - P_{DC}(t)\right) dt$$

$E_{DC}(t)$	Energy of DC bus capacitance at point of time t
$P_{DC}(t)$	DC bus power at point of time t
P_{DC_cont}	DC bus continuous power of HMV0x.1R
E_0	Initial energy

Fig.2-8: Energy of the DC Bus Capacitance for $P_{DC}(t) < 0$ and $U_{DC}(t) < U_{DC\_nom}$

☞ The upper limit of the integrator is the energy E_{DC_nom}, because further energy absorption by the DC bus capacitance is impossible due to the control of the DC bus voltage.

Regenerative Operation, Regenerative

HMV0x.1R regenerates energy, DC bus gains energy:

- Condition:
  - $P_{DC}(t) < 0$
  - $U_{DC}(t) \geq U_{DC\_nom}$
- The **minimum** DC bus voltage corresponds to the nominal DC bus voltage

Supply Units with Smart Energy Mode

- If $P_{DC}(t) < -1.1 \times P_{DC\_cont}$, the DC bus capacitance must absorb the additional regenerative power
- The DC bus voltage must not increase up to the braking resistor switch-on threshold. This means that the DC bus capacitance may at maximum have the energy E_{DC_max}.

  The following condition must be fulfilled at every point of time:

$$E_{DC}(t) = E_0 + \int \left(-1{,}1 \times P_{DC\_cont} - P_{DC}(t)\right) dt < E_{DC\_max}$$

$E_{DC}(t)$	Energy of DC bus capacitance at point of time t
$P_{DC}(t)$	DC bus power at point of time t
P_{DC_cont}	DC bus continuous power of HMV0x.1R
E_0	Initial energy
E_{DC_max}	Maximum allowed DC bus energy

Fig.2-9: Energy of the DC Bus Capacitance for $P_{DC}(t) < 0$ und $U_{DC}(t) \geq U_{DC\_nom}$

☞ The lower limit of the integrator is the energy E_{DC_nom}, because further decrease in energy of the DC bus capacitance is impossible due to the control of the DC bus voltage.

Motive Operation, Regenerative

HMV0x.1R regenerates energy, DC bus loses energy:

- Condition:
  - $P_{DC}(t) \geq 0$
  - $U_{DC}(t) > U_{DC\_nom}$
- The **minimum** DC bus voltage corresponds to the nominal DC bus voltage
- This operating status only exists for a short time during dynamic motion activities with a rapid change between regenerative operation with high regenerative power and motive operation.
- This operating status always follows the operating status "regenerative operation, regenerative", when the DC bus voltage is above the nominal value when entering the motive operation.
- DC bus energy:

$$E_{DC}(t) = E_0 + \int \left(-1{,}1 \times P_{DC\_cont} - P_{DC}(t)\right) dt$$

$E_{DC}(t)$	Energy of DC bus capacitance at point of time t
$P_{DC}(t)$	DC bus power at point of time t
P_{DC_cont}	DC bus continuous power of HMV0x.1R
E_0	Initial energy

Fig.2-10: Energy of the DC Bus Capacitance for $P_{DC}(t) \geq 0$ and $U_{DC}(t) > U_{DC\_nom}$

☞ The lower limit of the integrator is the energy E_{DC_nom}, because further decrease in energy of the DC bus capacitance is impossible due to the control of the DC bus voltage.

2.4 Troubleshooting

Malfunction	Remedy
Device current is not limited to the 1.1-fold nominal current	Use HMV0x.1R with SEM (check type code) Check DC bus voltage and, if necessary, increase DC bus capacitance or adjust load profile
Braking resistor loaded	Increase DC bus capacitance or adjust load profile
HMV0x.1R signals error F8057 and switches power off	Use bigger supply unit

Tab.2-3: Troubleshooting

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