# FUNCTION DESCRIPTION

## Integrated Motor Drive
## IMD 100



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Document no.: 4189360013 Rev.: G
Date: 2020-09-25
Language: EN-GB

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# Contents

# 1. Introduction

This document describes the functions of the IMD 100 series. The IMD 100 is a heavy-duty motor driver that targets mainly pitch systems in wind turbines. This document describes how the IMD 100 can be used in a pitch system and which functions are available when integrating it in the system. This document is intended for anyone who needs an in-depth understanding of the functions of the IMD. It is not intended to be used for the actual integration of the IMD in a pitch system though knowledge acquired from reading it will be helpful for that task.

This version describes the functions of the IMD with the latest firmware and hardware version available at the time of publication. Newer versions might be available, with functions not described in this manual. Typically, these functions will be minor functions or bug fixes, as the manual will be updated for major releases.

## 1.1 Conventions

The following conventions are used in this document:

| Used in document | Description |
|---|---|
| ␣ ↵ | Used to illustrate a space and Enter characters |
|  | A yellow symbol illustrates hazard type (this symbol is an example for general hazard). There are different types such as electrical, chemical and so on. |
| Danger! | A signal word used to indicate an imminently hazardous situation, which if not avoided, will result in death or serious injury. (ISO 3864) |
| Warning! | A signal word used to indicate an imminently hazardous situation, which if not avoided, could result in death or serious injury. (ISO 3864) |
| Caution! | A signal word used to indicate a potentially hazardous situation, which if not avoided, could result in minor or moderate injury. (ISO 3864) |
|  | A blue symbol illustrates a need for mandatory action. In this example read instructions. Other types of blue symbols exist and always indicate mandatory action. |
|  | A symbol used to draw attention to extra information or an action that is not mandatory |
| Current | When “current” is used it always means electrical current. When a reference to time is made “present” or “ongoing” are used. |
| IMD | When the IMD is mentioned, it means the IMD 100 series |
| Safety-chain relay | The term “Safety-chain relay” is used for the IMD safety-chain relays (SCR 1 and SCR 2), and must not be exchanged with the turbine’s safety chain relay. |

# 2. Product overview

The IMD is designed to operate in harsh environments based on DEIF's experience with offshore and marine products.

The IMD-100 is a robust motor drive ideal for use as pitch servo drive for wind turbines from kW to MW range. The servo drive has cold climate (from -30º C to +70 º C) and High altitude operation (up to 4000 m) specifications, making it suitable for any wind turbine pitch system, in almost any location.

## 2.1 Integration in a pitch system

The IMD has many built-in functions that makes the integration of the IMD easy, and makes many external components superfluous. At the same time, it saves costs and space in the often-crammed locations in the hub by allowing for smaller cabinets.

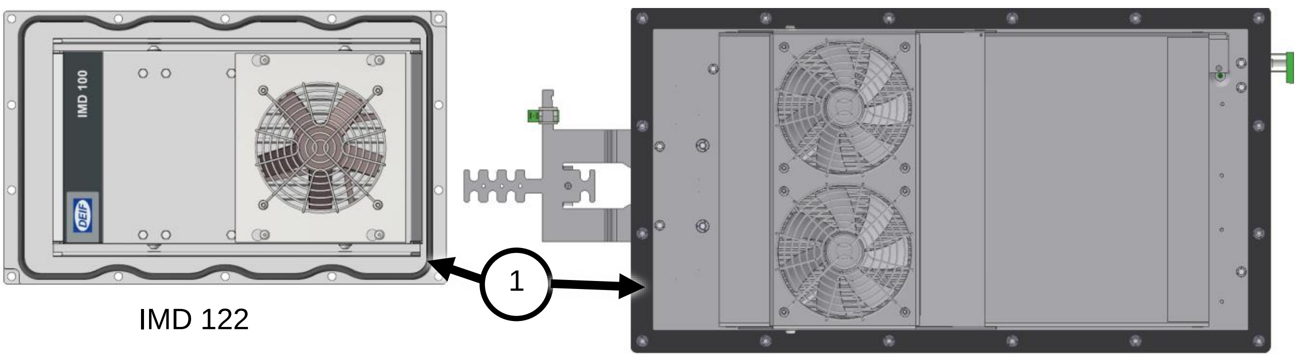
### 2.1.1 Built-in functions

The following functions are integrated in the IMD:

- 24 V DC power supply for powering the IMD and other external components (variant depended).
- Charger for Safe Energy (SE, variant depended).
- EMC filter for Mains.
- Digital inputs and outputs.
- Inputs for temperature sensors.
- Ballast resistor to dissipate inducted energy from the motor (option for IMD 122 C). Ballast resistor is always needed. Either built-in or external.
- Synchronous Serial Interface (SSI) for multi-turn or single-turn encoder.

### 2.1.2 Mechanical and electrical integration

The IMD is mounted from the inside of the cabinet. A gasket seal at the back of the IMD ensures tight assembly (IP 54) as shown in the following figure at pos. 1.




IMD 122

IMD 135

**Figure 1** Gasket seal at the back of the IMD

All the electrical connections are placed on two sides only (three sides for IMD 135 C – top as well), making it easy to locate the IMD anywhere in the cabinet:


In order to withstand vibrations, no screw terminals are used. With the exception of the PE (ground) terminal, all connectors are either spring loaded connectors or D-sub connectors for standard components (Resolver, SSI encoder, and CAN/CANopen communication).

All control connectors are implemented with removable female connectors with locking mechanism:

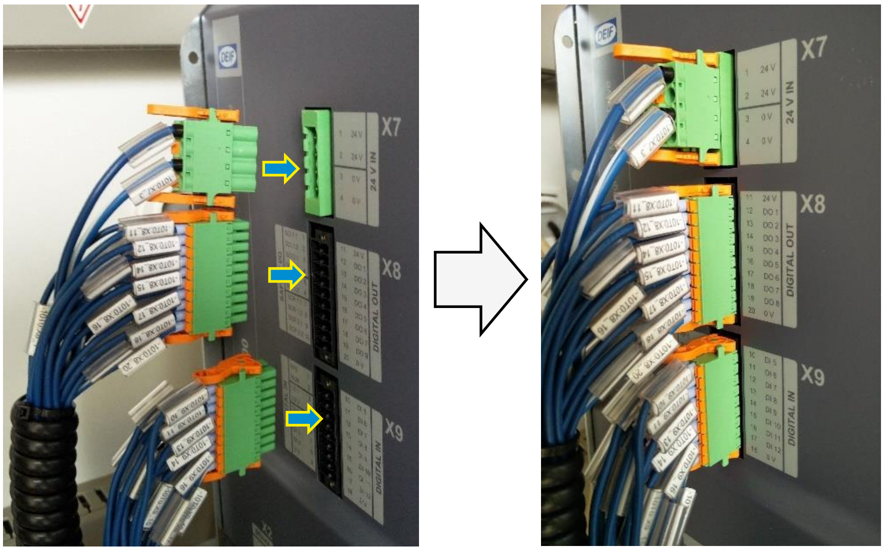



**Figure 2** Male-female connectors

Power connectors do not have removable connector. The shield connector is spring loaded as well (pos.1 in Figure 3 on page 9).

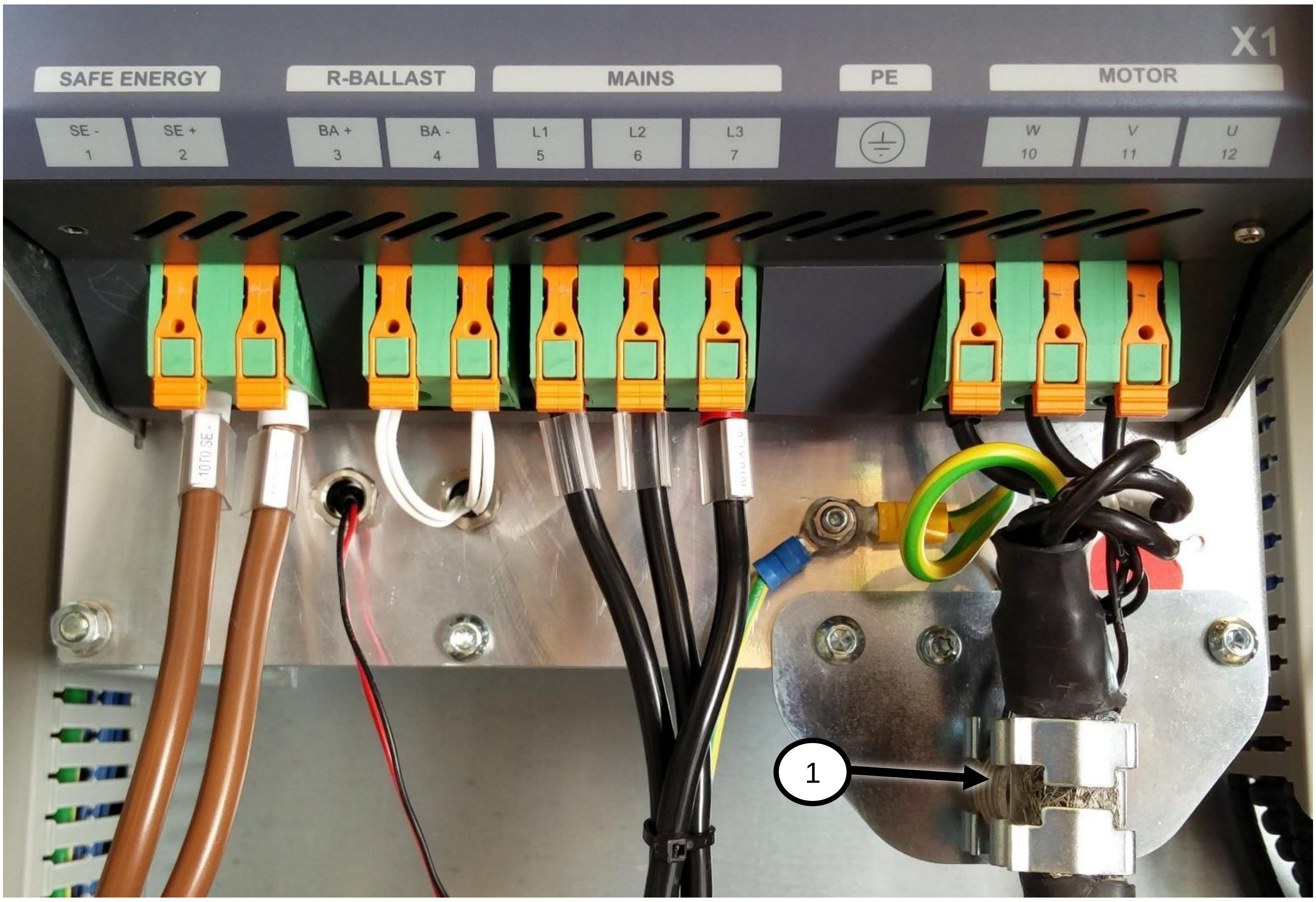
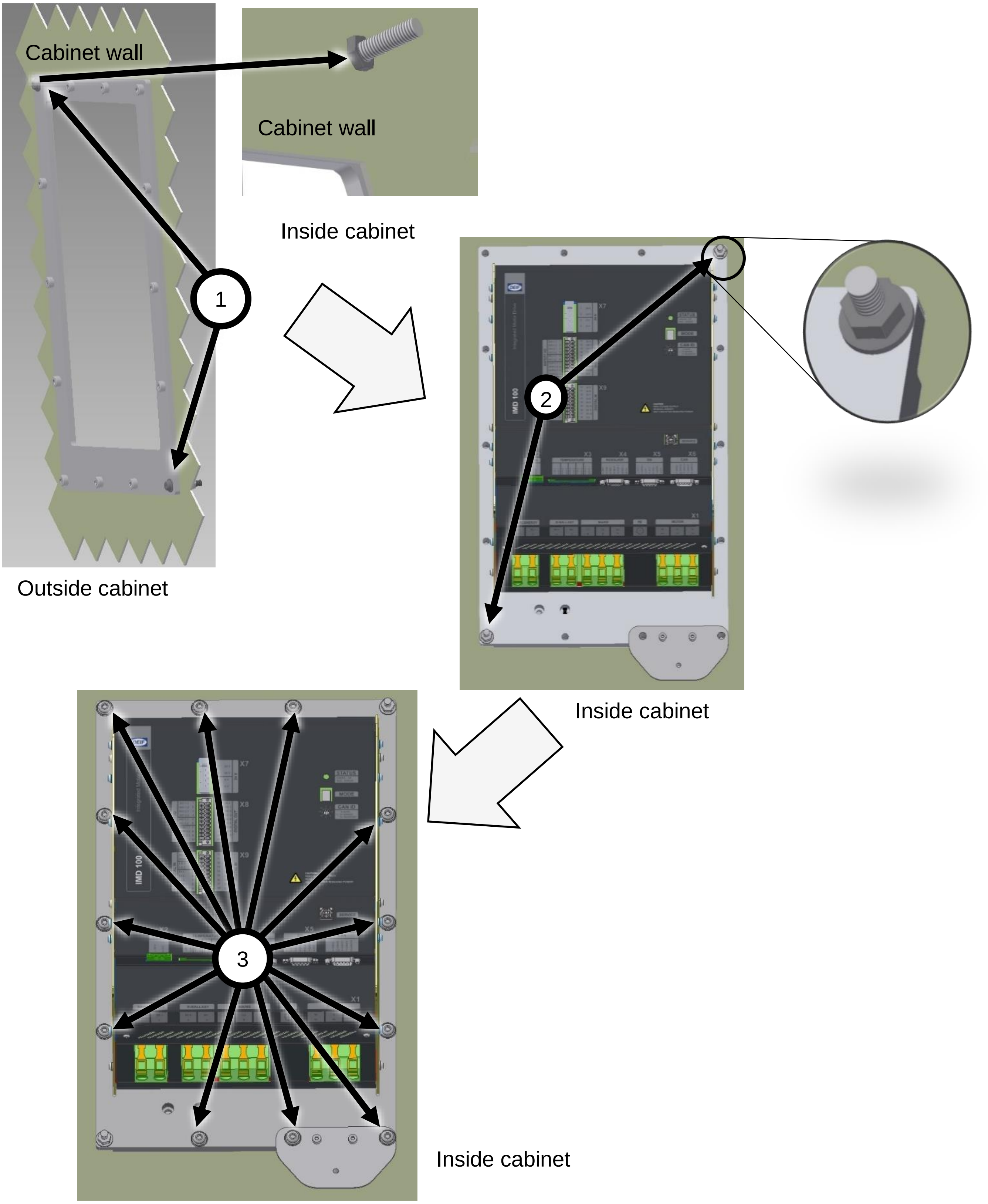



**Figure 3** Power connectors

## 2.2 Installation, service and replacement

Due to the spring loaded and removable connectors, connecting the wires can be done quickly and reliably. The same applies if the IMD needs to be replaced, ensuring as little turbine downtime as possible. Service tasks are kept at minimum with only one moving part (fan).

If the optional mounting frame kit is used, the IMD can be easily mounted by a single person from inside the cabinet:




Other optional mounting frames are also available.

# 3. IMD main function and role in a pitch system

The IMD controls one motor in a pitch system. The IMD main functions are:

1. Convert a controller command into movement of the pitch motor, ensuring that it is done according to pre-configured properties and conditions.
2. Variety of safety functions regarding the turbine and personnel safety.

The following figure illustrates the main components in the pitch system (simplified):

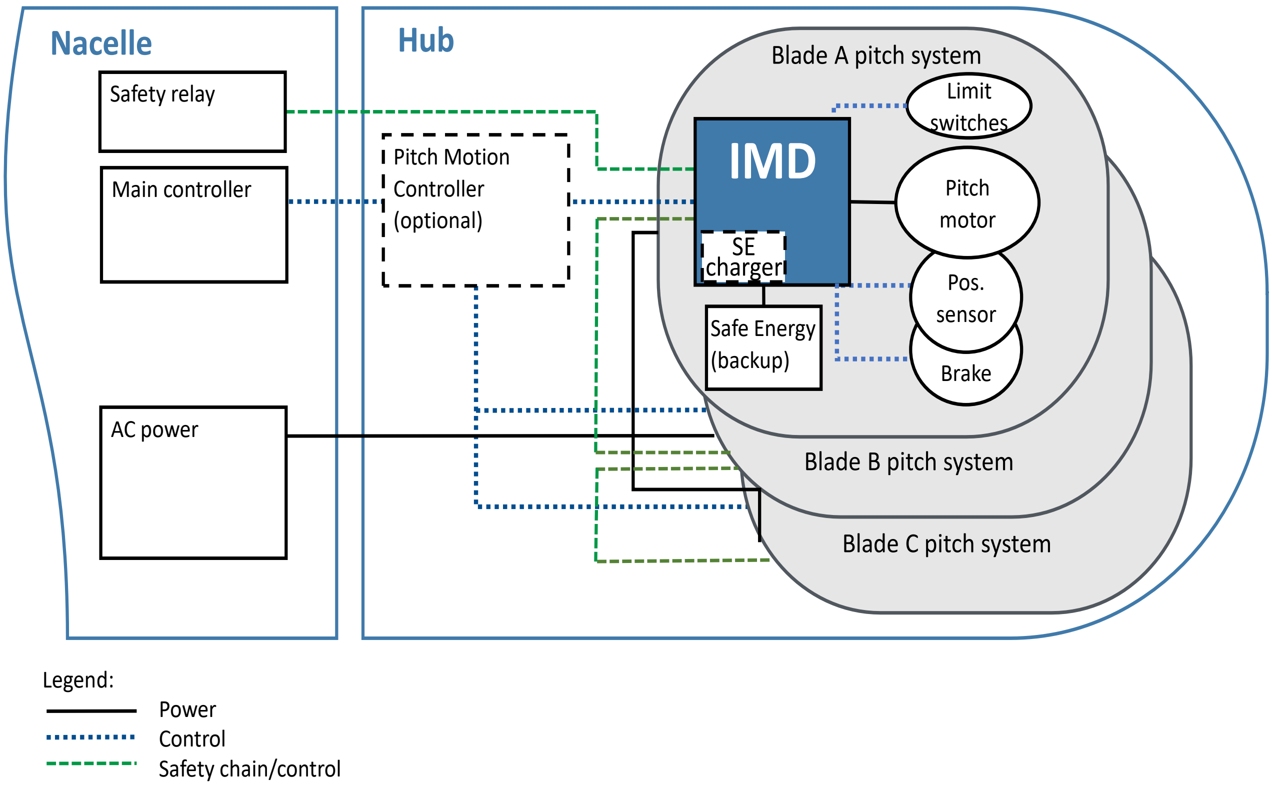



**Figure 4** IMD in a pitch system

### Power:

The IMD is supplied with power from the nacelle (typically 3 x 400 V AC) as well as from a DC energy backup pack (batteries or ultra-capacitors). The energy backup is a safety measure (Safe energy) that ensures that the blade can always be pitched to stop position. IMD 122 also has a built-in power ballast (option), used to dissipate power generated from the motor during deceleration or when the motor is driven by an outside force. For IMD 135 C or if the built-in option is not used in IMD 122, an external ballast resistor must be used.

It is also possible to order the IMD with a charger, thereby enabling direct charging the safe energy source, connected to it (no need for external charger, or special circuitry).

### Safety:

The IMD can be integrated in a safety chain as well as act on a safety chain trip. When the safety chain inputs trip (for any external reason), the blade will always be pitched to stop position.

When an IMD has an error, it will trip the safety chain, thus causing the other IMDs in the hub to pitch to stop position and stop the turbine. Depending on the error, the IMD with error will also try to pitch the blade to stop position if it is possible.

Personnel safety is ensured with a hardware (HW) emergency stop input that stops any motion immediately.

**Control:**

In normal operation, the IMD operates on commands from the outside. Any change from the static state (like change of blade motor position, change of output and so on) is done according to commands from the application SW, residing in DEIF's Pitch Motion Controller (PMC, an optional component) or the main controller. There are two ways in which the controller can request a blade motor movement:

- By giving a desired blade motor position and maximum speed - the IMD will move the blade motor until the desired position is reached
- By giving a speed and direction (plus or minus) - the IMD will move the blade motor until a stop commend is received

The IMD is pre-configures with an acceleration and deceleration ramps (how fast it may accelerate or decelerate to the desired speed). It will use these values to reach the desired speed.

There are typically two (redundant) limit switches in the blade pitch system that are used to ensure that the blade does not pitches higher than 90º (typically at 89º and 91º), see following figure. The IMD will decelerate to a halt according to the defined deceleration ramp, if a limit switch is activated.

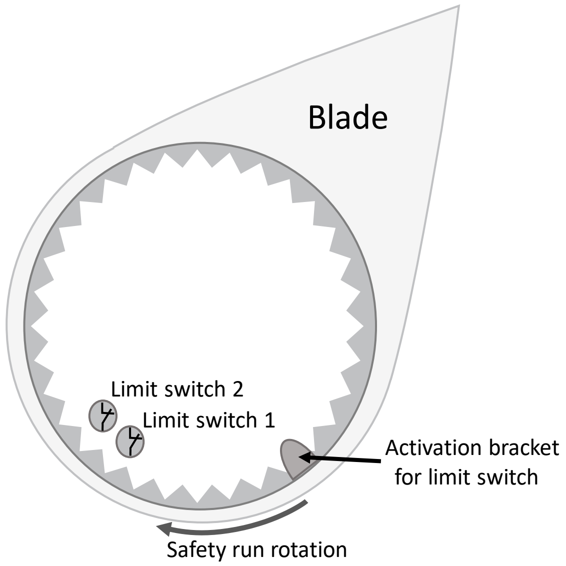



**Figure 5** Limit switches in the blade pitch system

Virtual Limit Switches (VLMS, positions based on resolver values), can be used as a safety precaution, in case the physical limit switches fail. One Virtual limit switch at each end can be used. The use of virtual limit switches requires zero point calibration of the resolver. Se section 6.2.3 on page 40 for more information about VLMS.

The IMD monitors the temperature and current of the motor as well as protects the whole system from overload and potential damage. Monitored data (including other data such as position, load and so on) is available for the application SW.

# 4. Safety functions

The following functions are considered as safety functions with regards to the IMD:

1. Personal protection: Stop the movement of the blade motor immediately as a result of emergency stop activation.
2. Machine protection: Bring the blade to a safe (stop – also called feather) position, if an error is detected in any vital components (internal or external). This action is called a “safety run”.

## 4.1 Personal protection (Emergency stop)

The emergency stop is connected to a digital input that stops the IMD immediately. There are two options (inputs) for the emergency stop:

- **RFE** (rotational field enabled): When this input is set to low, the motor driver is immediately disabled (done by HW disabling of the output module). At the same time the IMD SW cuts the supply to the brake, thus stopping the blade motor with the brake, as well as tripping the safety-chain relay, and generate an error. This function has highest priority. When the RFE goes high again, and the error is cleared, the IMD will perform a safety run.
- **RUN**: When this input goes low, the IMD will decelerate the blade motor and engage the brake at standstill (the brake will be engaged after approximately 0.9 s even if standstill is not reached). This action will not generate an error, will not trip the safety chain and will not start a safety run when the input goes high again. Using RUN input will typically stop the blade faster than RFE, and protect the brake, since it will be engaged when the blade is not moving anymore.

The following table lists the difference between using RUN and RFE:

**Table 1** Functions of RFE and RUN inputs

| | RUN | RFE |
|---|---|---|
| Disabling output | SW disable | HW disable |
| Stopping the blade motor | Stopping *with* modulation (speed zero), and then engaging the brake. | Stopping *the* modulation and engaging the brake |
| Generate error | No | Yes |
| Start safety run when input is high again (for RFE the error must be cleared as well) | No | Yes |

**Info**
If both RFE and RUN are used (in parallel), RUN will have no affect since RFE has the highest priority.

## 4.2 Machine protection and safety run

The IMD behaves differently depending on whether a detected error is internal or external. External errors are errors in other components in the turbine tripping the safety chain. In any case, the IMD will try to perform a safety run if it can.

### 4.2.1 Safety run

The safety run is the main machine safety function of the IMD. The safety run brings the turbine to a stop by feathering the blades to approximately 90º (stop position), thus ensuring that no further damage is caused. Many of the IMD functions and configurations are therefore related to the safety run.

A safety run is considered completed when a limit switch is activated.

There are two safety run modes (though they both take the blade to stop position):

- Safety run
- Blind safety run

In case of no feedback from the resolver, the IMD immediately initiates a blind safety-run. This safety-run is named “blind” since the resolver feedback is part of the motor control loop, which is missing. When the feedback is missing, an error (FEEDBACK error) is generated. This error is temporarily cancelled during the blind safety-run, and set again when the safety-run is completed.

When performing a blind safety run, constant current is used (motor nominal current or application effective continues current, whichever is lowest). Because of the missing feedback there is no torque regulation and the expected achievable speed is approximately 30% of max speed. Exceeding the corresponding maximum torque will cause the motor to stall. The IMD itself cannot detect the stall condition, in which case, only a restart by disable/enable the drive can restart the motor. The blind safety run has its own acceleration rump, in order to be able to set it to long time, thus preventing high torque.

When a blind safety-run is completed, the IMD reloads all parameters from start-up configuration (zero) in the EEPROM. As a consequence of losing the feedback, the position cannot be updated correctly, and a pre-set position is likely to be invalid.

**Attention**
Do not disable drive (through CANopen or USB) during a safety run. This will cause the safety run to briefly stop and start again.

#### *4.2.1.1 Safety run with speed profile*

The safety run can be executed either with one speed until the limit switch is reached, or following a configurable position/speed profile with 5 steps. Before a profile can be used the following conditions must be fulfilled:

- The profile steps must be configured
- Speed profile in safety run must be enabled
- Zero position for the blade motor must be calibrated (resolver no. of revolutions is 0 at blade zero position)

Configuring the profile steps is done by defining the position (absolute number of revolutions) in which the step will be entered to, and the speed that will be used for the step.

The speed profile will always start at step zero, and change to the appropriate step when the position is reached. Step zero has the same properties as a safety run without profile.

The following figure illustrates two safety runs:

- The top run is started when the drive is in zero position, and therefore shows all the five steps.
- The bottom run is started when the drive is past the position for step one. It starts in step 0 and as soon as it registers that the position for step 2 is reached, it jumps to step 2, omitting step one.
- At the bottom left, is the configured speed profile used for the examples

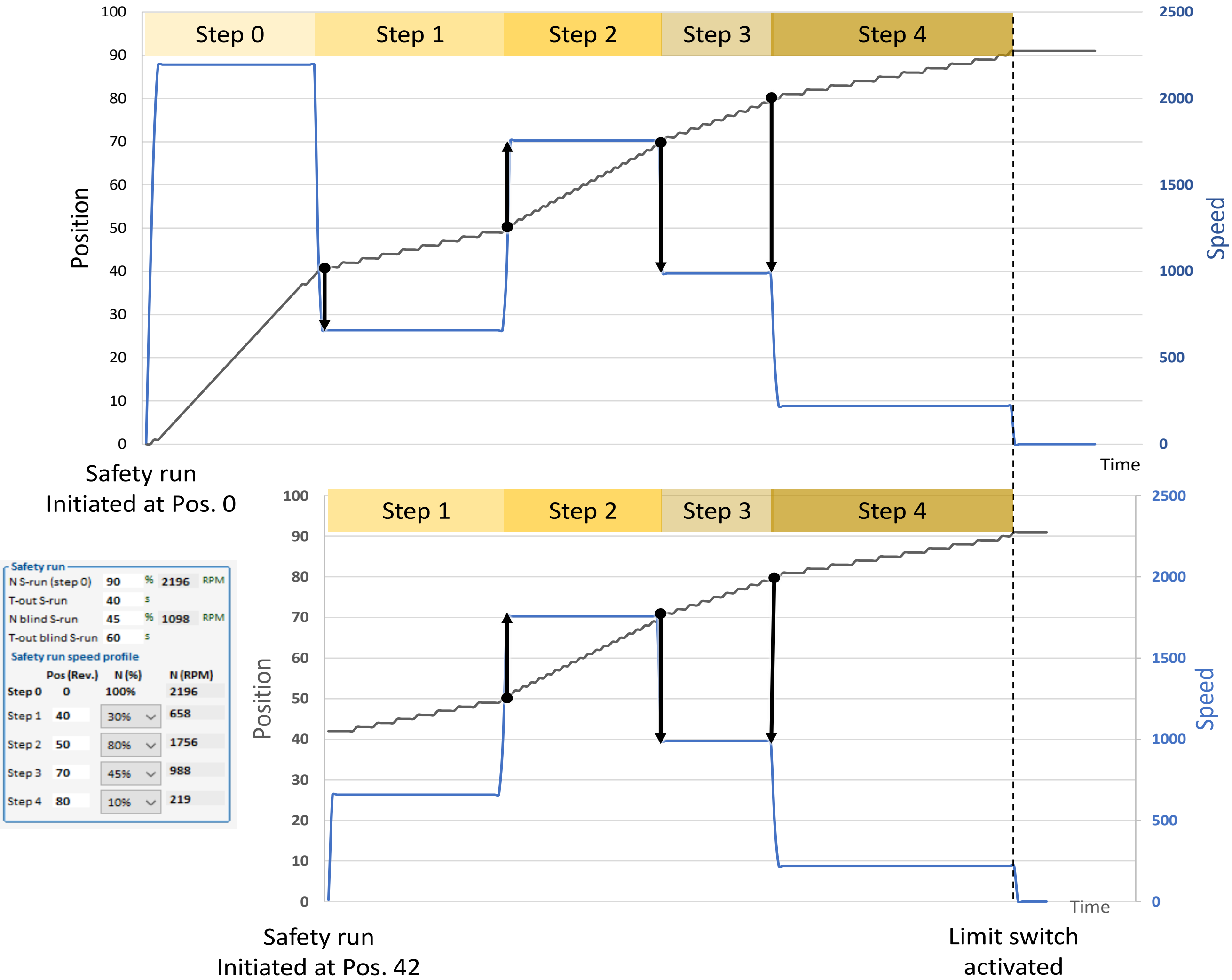



**Figure 6** Safety run with speed profile

**Info**
Speed profile cannot be executed in blind safety run.

### *4.2.1.2 Safety run configuration*

The following table lists the safety run related properties / functions are configured as parameters in the IMD:

**Table 2** Safety run properties

| Parameter | Description |
|---|---|
| Timeout | The time after which the IMD stops the safety run and reports a timeout. There are different values for each safety run mode. |

| Parameter | Description |
|---|---|
| Speed | The speed that will be used for the safety run.<br>There are different values for each safety run mode.<br>The motor will run the other way if negative values are used. |
| Speed profile enable | Enable speed profile when a safety run is executed. Has no effect on blind safety run |
| Speed profile | A set of four steps, each containing a position and a speed |
| Acceleration | The same acceleration time used for any speed increase is used (no specific safety run acceleration time).<br>Blind safety run has a special acceleration parameter. |
| Deceleration | The deceleration time (ramp) defined for any speed decrease, and after a limit switch is activated.<br>There are two deceleration parameters, one global deceleration that is used for any deceleration, and one that is used for fast decelerations. The parameter with shortest value of the two is used after a limit switch activation. |
| Auto safety run @ start | Enabled: If no limit switch is activated upon IMD start, the IMD will perform a safety run as soon as RFE and RUN inputs are high.<br>Disabled: If no limit switch is activated upon IMD start, device enable state must also be present apart from high RFE and RUN inputs before the IMD will perform safety run. |
| Safety run restart @ limit switch 1 off | Enabled: If limit switch 1 is activated and then deactivated in a safety run, the IMD will restart the safety run.<br>Disabled: The safety run will not restart, even if limit switch is deactivated after being activated.<br>This function is only available for limit switch 1. |
| Safety restart @ mains return | Enabled: If the mains power (and there is no safe energy) disappears during a safety run, the IMD will restart the safety run automatically when the power returns.<br>Disabled: The safety run will not restart automatically, when the mains power returns. |

**Attention**
Safety run should not be used to stop the turbine under normal circumstances.
The motor will turn at the predefined speed until the limit switch is activated after which, it will stop very aggressively. This will put a lot of strain on the turbine.
Normal turbine stop should be done with speed or position commands.

#### *4.2.1.3 Safety run while on safe energy*

There are several reasons that the IMD will run on safe energy:

- The pitch controller determined that the mains should not be used and sent “Mains disconnect” command to the IMD
- The mains input is too low, and the IMD disconnected the mains from the DC-link
- The IMD determined that the DC-link voltage is too high and disconnected the mains from the DC-link

While on safe energy, the DC-link voltage might be lower, which can affect the speed used for the safety run. To ensure that the blade will get to stop position fast enough, it is possible to use the field weakening feature. For more details see section 6.4.3 on page 47.

If the DC-link voltage level reaches DC-link Vlow, the IMD will try to reconnect the mains automatically, and make use of any energy source available to complete the safety run.

### 4.2.2 Intended use of the safety-chain mechanism

The safety-chain mechanism is intended to ensure machine safety. The chain includes different parts of the turbine and the purpose of it is to ensure that the turbine is brought to a safe state if any of the vital component fails and cannot execute its designated task. The SCR outputs in the IMD are part of the chain. If the chain is broken for any reason, all IMDs that are capable of doing so will drive the motor to pitch their blades to stop (safe) position. The following illustration depicts the basic principle of the safety-chain (only one channel of the safety-chain is depicted for simplicity):

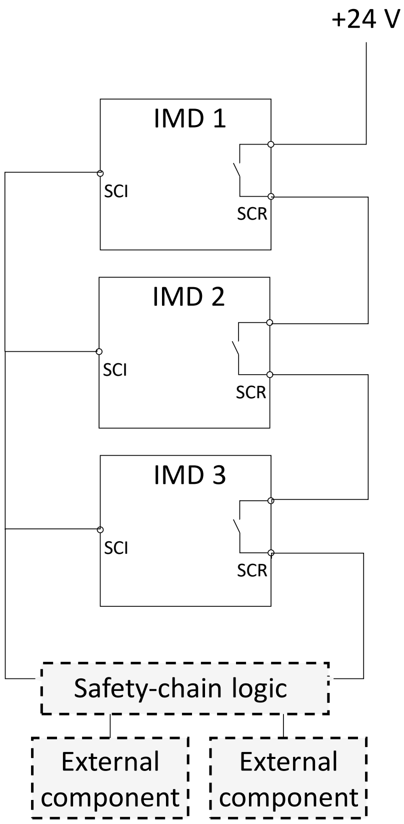



**Figure 7** Safety-chain principle

### 4.2.3 Actions on external safety-chain trip

There are two double inputs for monitoring of both channels of a safety chain. If either input is missing or any of the errors listed in section 4.2.4.1 on page 18 are encountered, the IMD will (if it can) pitch the blade to stop position with a configured speed for this situation and apply the brake (see section 7.7 on page 58). Both inputs must be go low at the same time before going high again in order to return to normal operation mode.

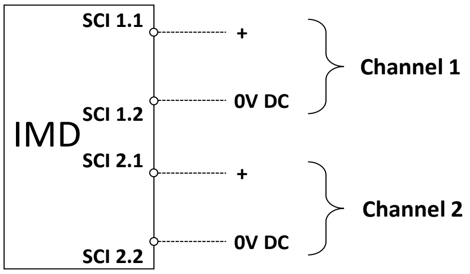



**Figure 8** Safety-chain supply input

**Info**

If a safety chain is not utilised, both SCI channels must be connected to +24 V DC (through the safety-chain relay) and 0 V DC, in order to allow the IMD to enter operational state. The safety-chain relay is needed to reset the safety-chain function in the IMD if an error occurs.

### 4.2.4 Actions on errors detected by the IMD

When internal (inside the IMD) errors are detected, the IMD will do the following:

1. Trip the safety-chain relays
2. Pitch the blade to stop position (if possible)
3. Show error on the front panel display and status LED

**Info**

The term "Safety-chain relay" is used for the safety-chain relays (SCR 1 and SCR 2), and must not be exchanged with the turbine's safety chain relay.

In the following section the safety-chain relay and their behaviour at specific errors is described.

#### *4.2.4.1 Notification of errors - Safety-chain relays*

The IMD has two N.O. relay outputs (SCR). Their purpose is to "inform" other components in the turbine that something is wrong with the IMD. These relays are envisioned to be used to create a chain together with other components in the turbine for both wires of the supply. The relays are closed as long as the IMD is ready for operation and no error is registered. Once an error is registered the relays open and will remain open until the error is cleared and the IMD is ready for operation.

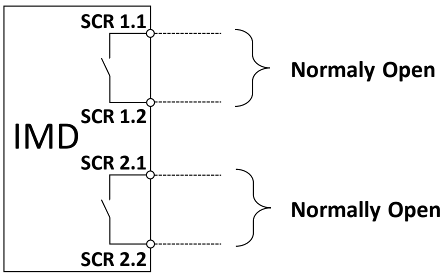



**Figure 9** Safety-chain relays output

The safety-chain relays in the IMD are tripped (open) when an error occurs. For more information about the specific errors, see section 9.1 on page 63.

**Info**

It is also possible to reset (on-off-on cycle) the safety-chain relays manually or through CAN.

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# 5. IMD power: supply and loads

This section describes the power supply, output and ballast resistor of the IMD.

The following figure depicts a simplified power block diagram of the IMD.

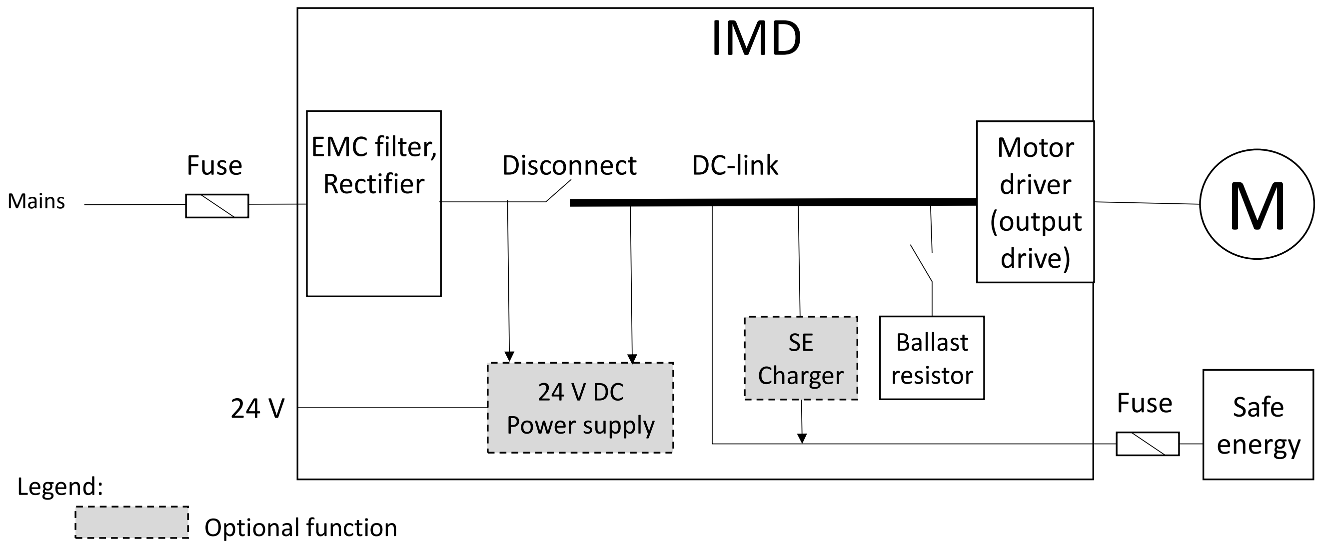



**Figure 10** IMD power block diagram (simplified)

Each of the depicted blocks are explained in the following subsections.

Note that the 24 V power supply and the SE charger are options that are added when the IMD is ordered.

The ballast resistor may be located externally.

## 5.1 Mains supply and motor output

The IMD is powered by 3 x 400 V AC, as well as an optional 400 V DC (safe energy). These voltages are the nominal voltages, see data sheet for full specification. The IMD has built-in EMC filter, which eliminates the need for any external filters. The AC voltage is rectified and fed to the DC-link. The voltages of both Safe energy and DC-link are constantly monitored.

The IMD has a disconnect function that internally disconnects the AC supply from the DC-link. The AC supply is automatically disconnected from the DC-link if the AC voltage monitor reports that no AC voltage is available. It is also possible to disconnect the AC supply using a command through any of the communication channels (IMD manager, CAN, CANopen).

In order limit in-rush current when the power is connected, a pre-charge circuit ensures that the DC-link capacitors are pre-charged. The power connections must always be protected against overcurrent. Mains circuit breaker is optional. However, local regulations must always be followed.

The following figure illustrates the basics of the power supply and output in the IMD:

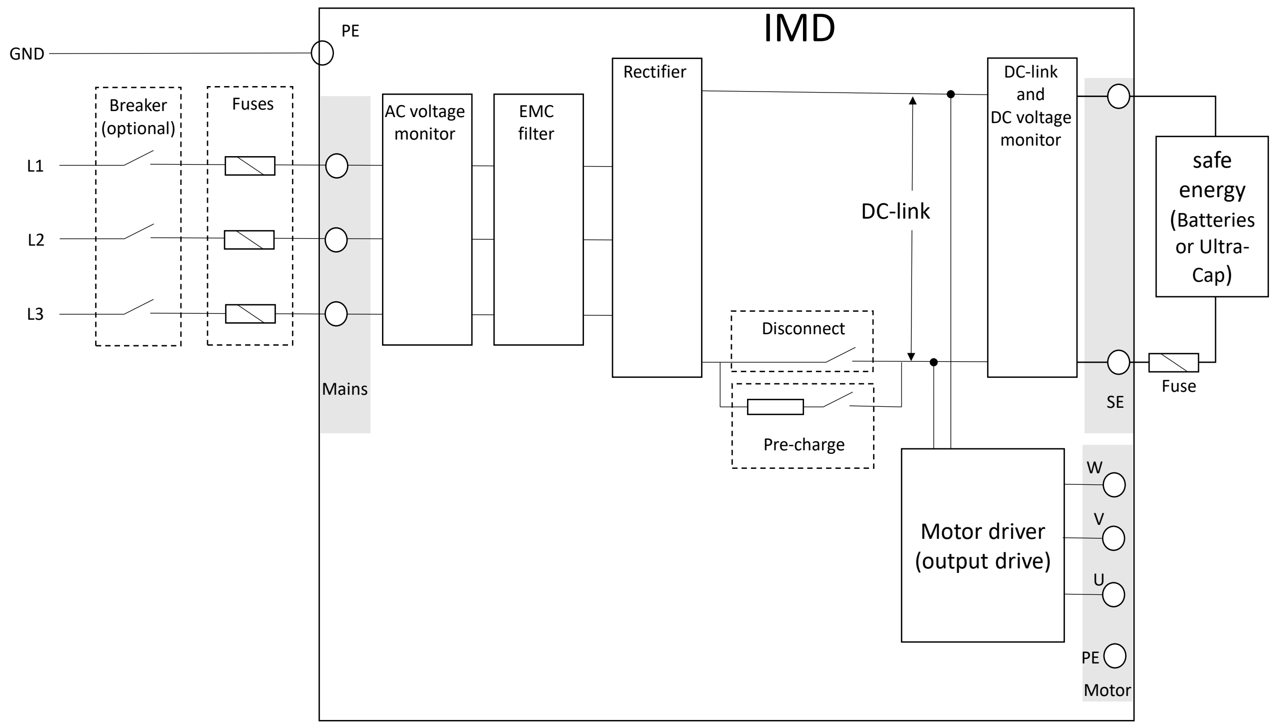



**Figure 11** IMD power supply and motor output

### 5.1.1 Mains line choke

The environment or grid conditions may generate high Total Harmonic Distortion (THD) In the mains. Even though the IMD has a built-in EMC filter, too high THD, may cause the IMD give an overvoltage alarm.

If found needed to use an external grid choke in the specific system implementation use case, it must be limited to maximum 0,68 mH.

## 5.2 DC-link function overview

The DC-link is the midpoint of power supply and consumption. The following figure illustrates the main components that either draw or supply the DC-link with power:

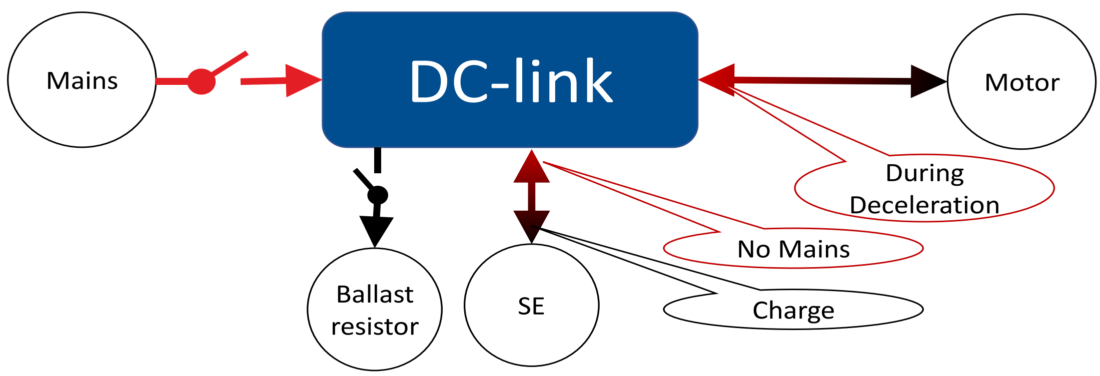



**Figure 12** DC-link power input and output

The inputs to the DC-link are:

- Mains

- Safe energy (SE)
- Motor (during deceleration)

The outputs from the DC-link are:

- Motor
- Ballast resistor
- SE charger (if included)

There are several thresholds (settings, errors and warnings) which are related the voltages on the DC-link and safe energy. These are depicted in the following figure:

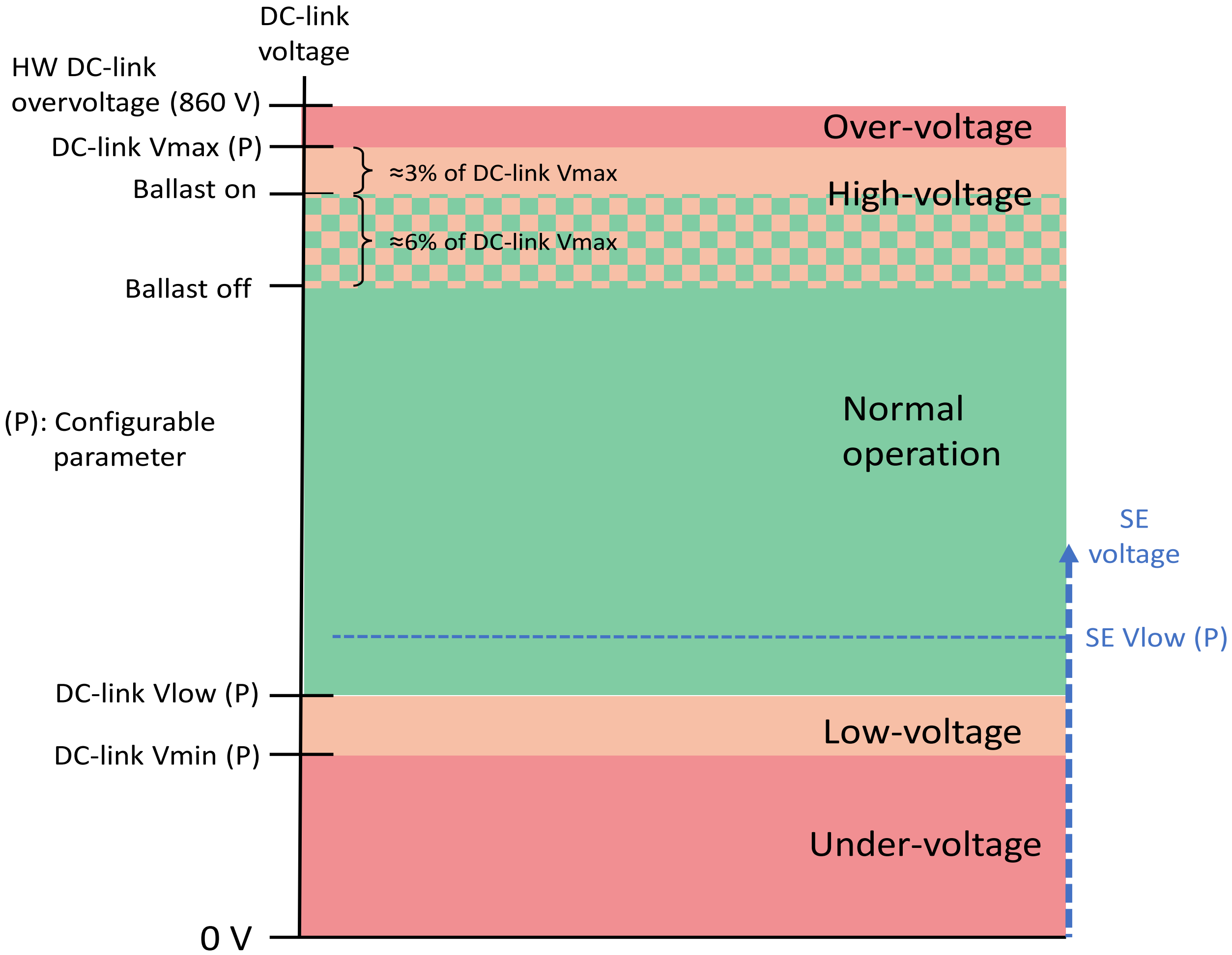



**Figure 13** Voltages thresholds

The behaviour of the IMD with regards to these thresholds is:

- HW DC-link overvoltage: Automatically disables the output drive, disconnects Mains from the DC-link, trips safety chain, and generates OVERVOLTAGE error.
- DC-link Vmax: Disconnects Mains from the DC-link, trips safety chain, performs a safety run, and generates OVERVOLTAGE error. This is a configurable parameter.
- Ballast on: Connects the ballast resistor to the DC-link, at ≈3% of DC-link Vmax, bellow DC-link Vmax.
- Ballast off: Disconnects the ballast resistor from the DC-link, at ≈3% of DC-link Vmax bellow ballast on threshold. The area between Ballast off and DC-link Vmax is defined as High voltage area (the area between Ballast OFF and Ballast on is considered High voltage only after the ballast is turned on). A special function High Voltage Ride Through (HVRT) is triggered in this area (see section 5.2.1 on page 23).

- SE Vlow: Generates POWERVOLTAGE warning. it is not possible to disconnect AC mains from the DC-link, unless SE Vlow is set to zero (SE Vlow disabled).
- DC-link Vlow: Generates UNDERVOLTAGE error, trips safety chain and performs a safety run. If Mains is disconnected from the DC-link, the IMD will attempt to reconnect the Mains. This is a configurable parameter.
- DC-link Vmin: Disables the drive and engages the brake. This is a configurable parameter.

The following figure shows a typical configuration for the IMD with 400 V AC mains, and different values when batteries (288 V nominal) or ultra-caps (450 V nominal) are used as safe energy:

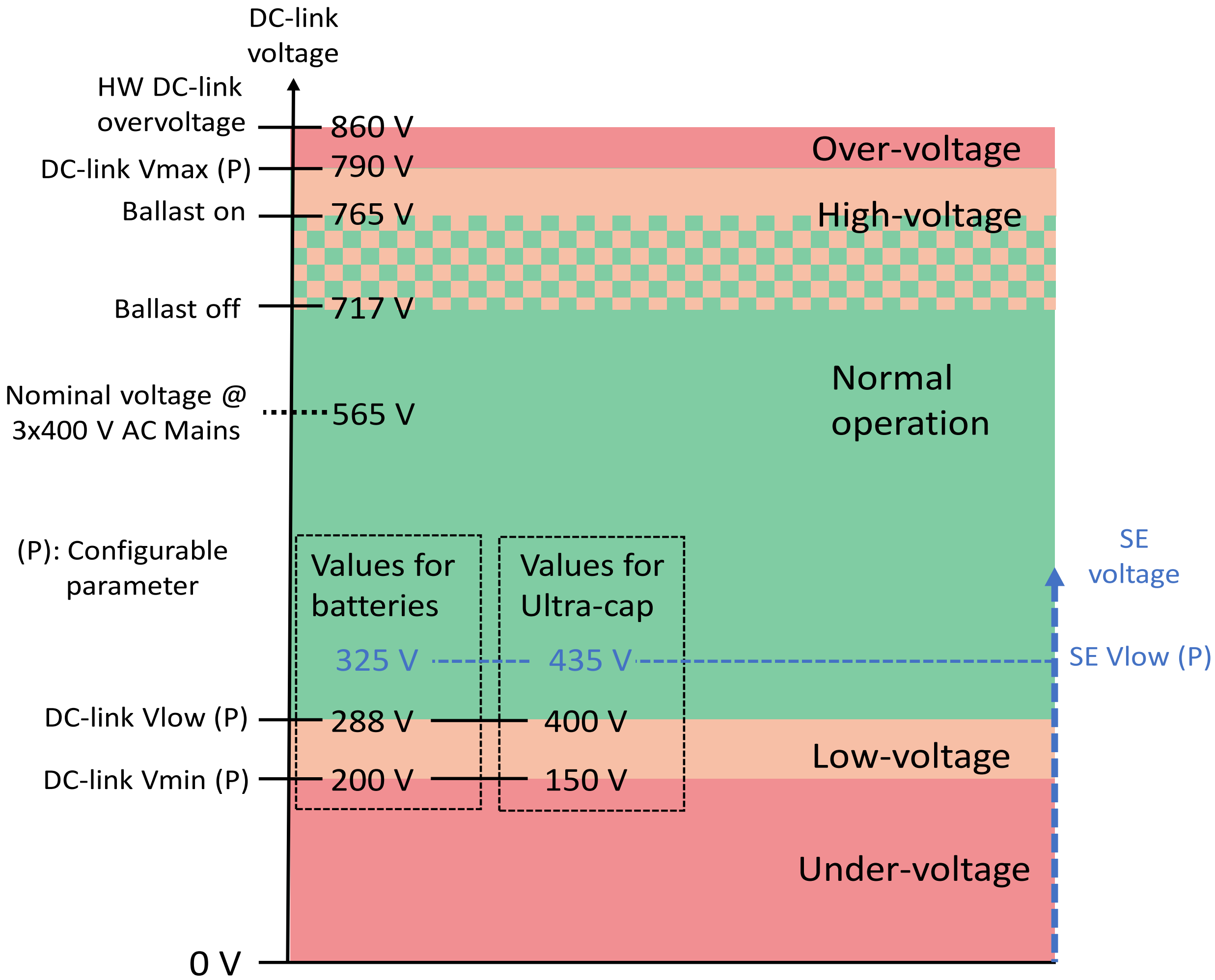



**Figure 14** Voltages thresholds – typical values example

### 5.2.1 Fault Ride Through (FRT)

Wind turbines are required to stay connected when short periods of high or low grid voltage occur (known as FRT). These functions are named as High Voltage Ride Through (HVRT) and Low Voltage Ride Through (LVRT). For the IMD that means that the IMD must not trip the safety chain (and thereby stop the turbine) for at least the specified times by the grid operator.

The IMD has mechanisms that enables it to function during these conditions. The main feature that enables the IMD to function while the mains is disconnected is the safe energy.

The following figure illustrates the flow of the FRT mechanism:

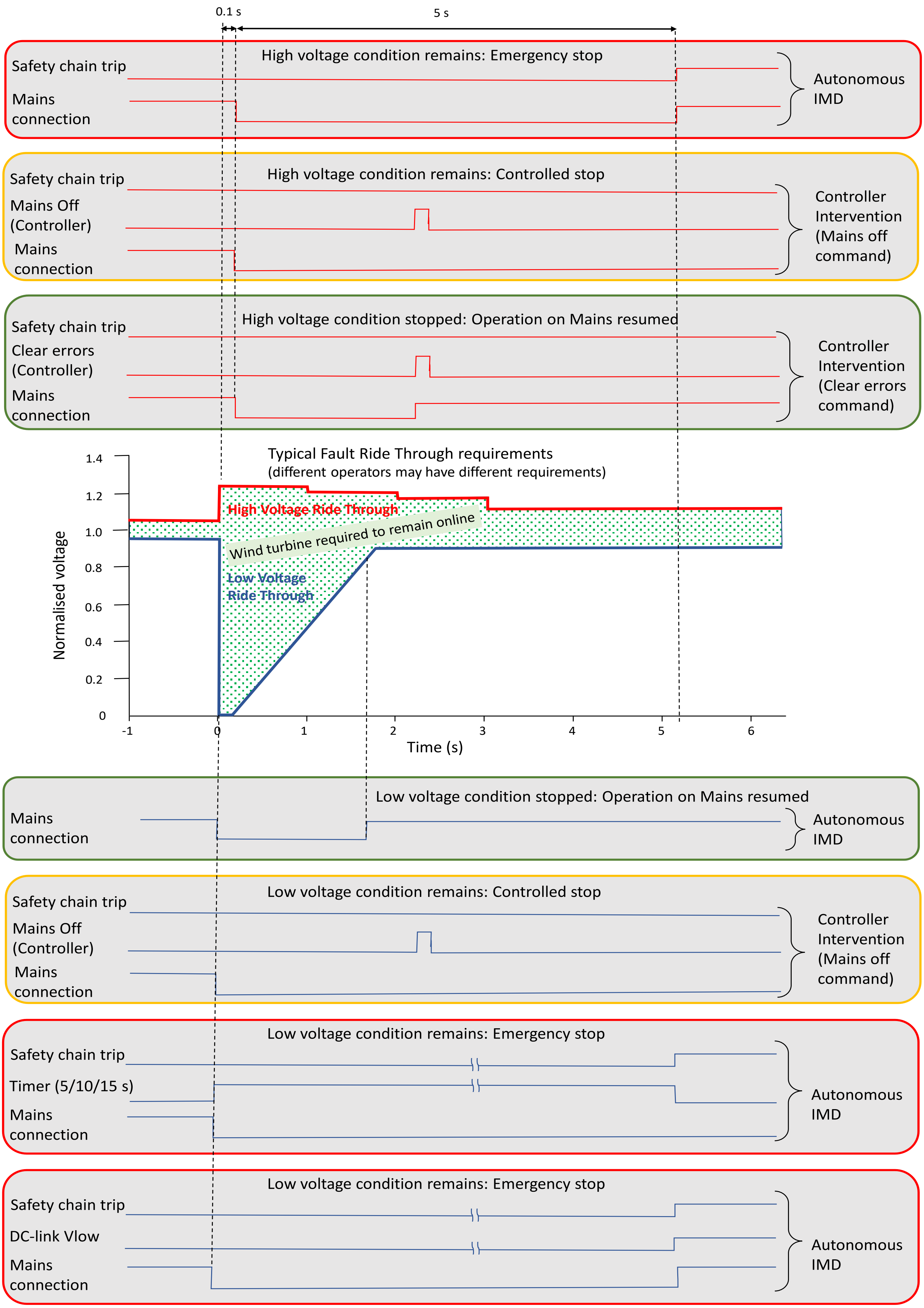



**Figure 15** FRT functions

NOTE After “Mains Off” command is sent, the IMD will not reconnect the mains automatically, unless a safety run on safe energy is performed and the DC-link voltage is lower than DC-link Vlow.

#### *5.2.1.1 High Voltage Ride Through (HVRT)*

High voltage detection (HVD) is triggered when the ballast resistor is turned on (while Mains is ON) for more than 100 ms. A “HIGHVOLTAGE Ballast on too long” warning is generated, and the IMD disconnects the mains from the DC-link. There are three scenarios following the disconnection of the mains:

- **High voltage condition stopped, operation on mains resumed:**
  If the warning is cleared by clear errors command within five seconds from the HVD, the mains is reconnected and the IMD stays in normal operation. This option can be used by the pitch controller after confirming that the high voltage condition is stopped.
- **High voltage condition remains, controlled turbine stop:**
  If a “Mains off” command is sent within five seconds from the HVD, the warning is cleared, and the DC-link remains disconnected from the Mains. If the high voltage condition persists, the turbine can be stopped (controlled stop) and avoid a safety run (emergency stop).
- **High voltage condition remains, emergency turbine stop:**
  If five seconds elapsed after the HVD without further action from the pitch controller or a person with IMD manager, a “HIGHVOLTAGE Ballast on too long” error is generated and the IMD trips the safety chain and performs a safety run.

#### *5.2.1.2 Low Voltage Ride Through (LVRT)*

The IMD has a configurable timer that defines how it will react in a Low voltage (no Mains) Condition:

| | |
|---|---|
| Timer is set to zero | No safety run is performed when there is no Mains. The IMD will use the safe energy until the DC-link voltage is bellow DC-link Vlow, when safety run is performed. |
| Timer is set to 5, 10, or 15 seconds | The timer starts when the Mains is not OK. After the timer runs its configured value, the safety chain is tripped, and a safety run is automatically performed.<br>If a “Mains Off” special command is sent to the IMD before the timer has timed out, the timer is cancelled. |

When Mains not OK is detected, the IMD automatically disconnects the Mains and connects the safe energy to the DC-link. There are four scenarios following the disconnection of the mains:

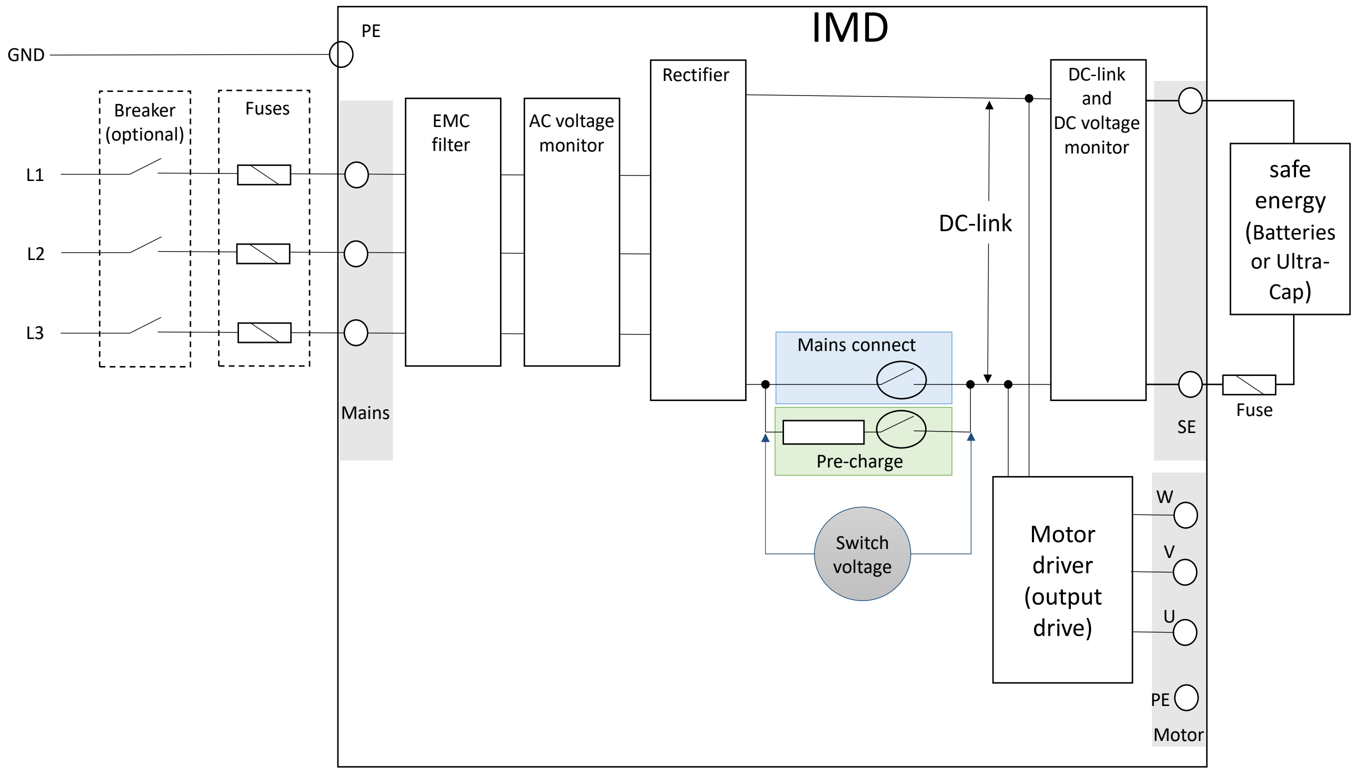
- **Low voltage condition stopped, operation on mains resumed:**
  If the low voltage condition is stopped before the timer runs out or DC-link Vlow is reached, the IMD reconnects the mains and stays in normal operation.
- **Low voltage condition remains, controlled turbine stop:**
  If a “Mains off” command is sent before the timer runs out or DC-link Vlow is reached, the timer is cancelled. If the low voltage condition persists, the turbine can be stopped (controlled stop) and avoid a safety run (emergency stop).
- **Low voltage condition remains, emergency turbine stop (timer):**
  The timer is configured to 5, 10 or 15 seconds. If the low voltage condition lasts longer than the configured value, the IMD trips the safety chain and perform a safety run after the timer run out.
- **Low voltage condition remains, emergency turbine stop (DC-link Vlow):**
  The timer is configured to 0 seconds (disabled). the IMD continues operating until the DC-link voltage drops below DC-link Vlow configured value. The IMD trips the safety chain and perform a safety run. The IMD will also try to reconnect the Mains automatically. This might be needed to ensure that any energy source available, will contribute to the completion of the safety run.

**Info**
If the DC-link voltage decreases below DC-link Vlow at any point, the IMD will trip the safety chain and perform a safety run. See also “Safety run while on safe energy” in section 4.2.1.3 on page 16.

### 5.2.2 Pre-charge

The pre-charge circuit purpose is to prevent excessive inrush current when the mains is connected to the IMD.

The following figure shows a simplified block diagram of the IMD power and the pre-charge circuit:




The “Mains connect” switch is controlled both automatically by the IMD controller and manually from the IMD manager or CAN. The “Pre-charge” switch is controlled automatically by the IMD controller only. At start-up the “Mains connect” switch is always off.

Whenever the “Mains connect” switch is being switched on, the “Pre-charge” switch is turned on first. Normal pre-charge duration is expected to be approximately 30 ms. When the “Switch voltage” (The difference between the rectifier voltage and the DC-link voltage) is < 20 V, the pre-charge is completed, the “Mains connect” switch is switched on, and the “Pre-charge” switch is switched off.

When the IMD is running on safe energy and returning to Mains, a brief (< 50 ms) output-current limitation is expected due to the pre-charge function.

**NOTE** During pre-charge, a lot of energy is dissipated in the pre-charge resistor. Typical pre-charge time (@ 3x400 VAC and 0 VDC on the DC-link) of 30 ms, will require approximately 40 s of resistor cooling time before next pre-charge. The recommended time between pre-charges is 60 s.

## 5.3 24 V DC supply

24 V DC is used to power the IMD itself as well as supply power to the brake. The IMD can be ordered with or without a built-in 24 V DC power supply. The built-in power supply is an option that cannot be

mounted if the IMD was ordered without it. Depending on whether there is or isn't a built-in power supply, X7 connector is used as input or output:

- IMD has built-in power supply: X7 acts as output, input, or in and out (use of X7 is optional)
- IMD has no built-in power supply: X7 acts as input (use of X7 is mandatory)

The following figure illustrates some application examples:

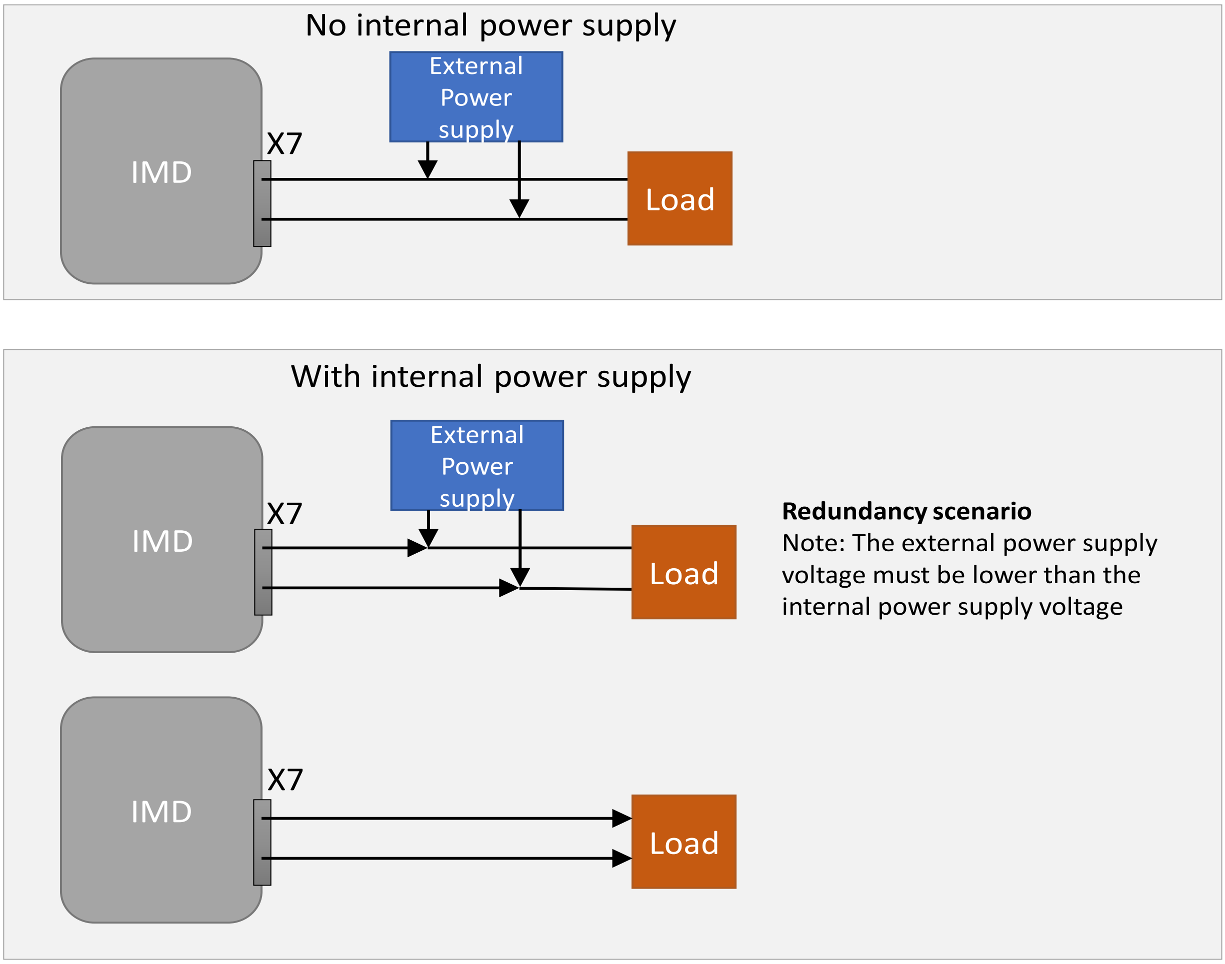
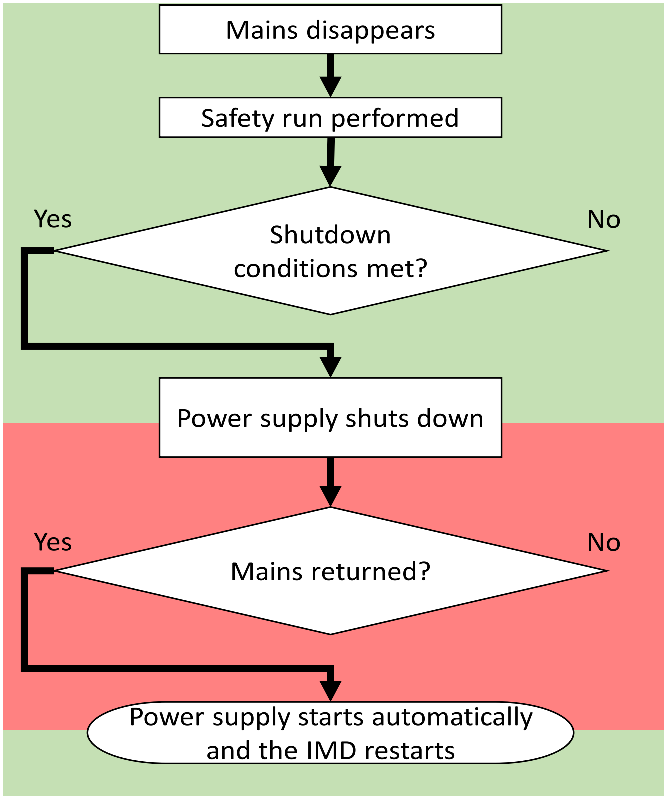



**Figure 16** Typical applications

When equipped with internal power supply, the internal power supply acts as a UPS, ensuring that there is always control power to the IMD, by using the SE as energy source if the Mains disappears. It is also possible to have an additional backup by connecting an external power supply to X7.

In a situation when there is no Mains, the power supply will at some point shutdown in order to prevent depletion of the safe energy source. Once the power supply is shutdown, it will start automatically when the mains returns. It is not possible to restart through SW command. The sequence of the shutdown is as follows:




Shutdown conditions:
Blade is at “parked” position AND at least one of the following is true:

- Timeout passed
- Shutdown command received

**Figure 17** Missing Mains sequence

**Info**

After the power supply shuts down, the IMD is turned off, and it is not possible to use the distributed input/outputs, temperature sensors and so on.

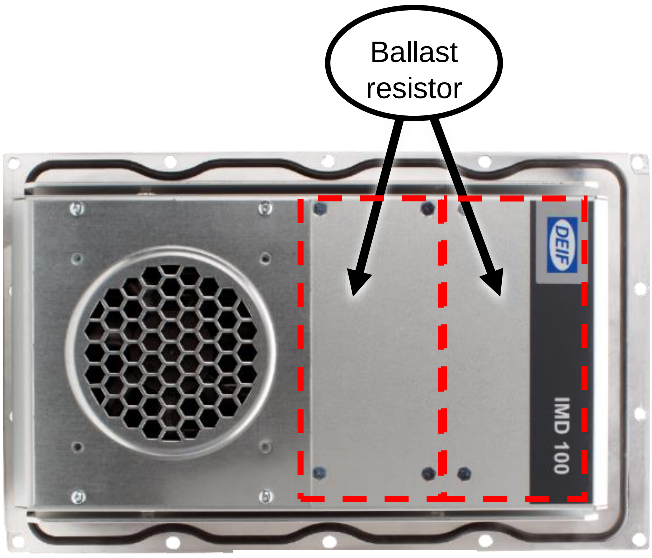
The built-in power supply is protected by a current limiter (approximately 6 A) to protect it from overload through X7.

## 5.4 Ballast resistor

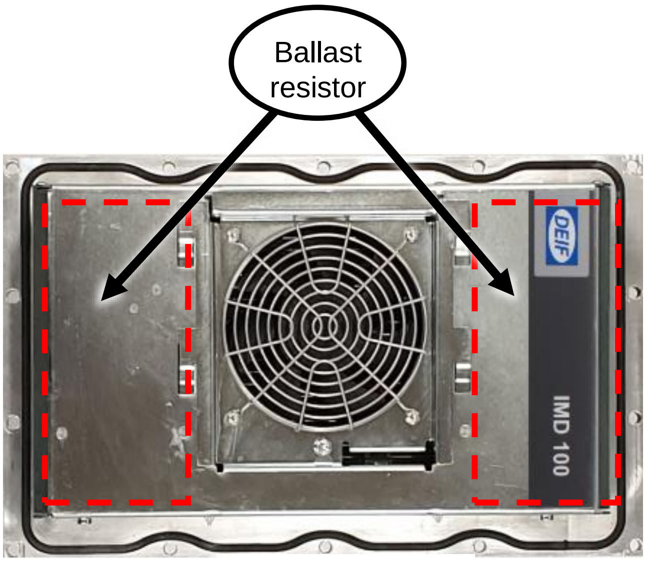
During deceleration, the motor acts as a generator and generates power back into the drive. A ballast resistor is used to convert this power into heat.

IMD 122 C has an option of a built-in resistor (Internal ballast option). If this option is not selected for the IMD 122 C, or when using IMD 135 C, an external ballast resistor (not supplied with the IMD) must be connected to the IMD.

The following picture shows the location of the built-in ballast resistor in IMD 122 C.




IMD 122 B




IMD 122 C

**Info**
The fan guard look may vary

The ballast resistor output is overload protected. When the load on the ballast resistor exceeds 50% of maximum load a warning will be generated.

Additionally, the output is overcurrent protected. If either overload or overcurrent protections are activated, error F will be active (see section 9.1 on page 63 for details).

During deceleration, the motor acts as a generator and generates power back into the DC-link of the IMD. The IMD has a built-in ballast resistor that converts this power into heat. The ballast resistor (20 Ω / 300 W) is suitable for most applications where the IMD is used.

The ballast resistor is connected and disconnected automatically when needed, depending on the configured DC-link Vmax (see section 5.2 on page 21).

**NOTE** The ballast resistor cannot be activated if RFE input is low.

## 5.5 Safe energy

Pitch systems typically have a safe energy (SE) source to enable pitching out of the wind in situations when there is no grid (no Mains).

Three functions in the IMD are designed for the safe energy:

1. Monitoring the safe energy source
2. Ensuring that the safe energy source is adequate by periodically testing the source
3. Charging the safe energy source (this is an option)

### 5.5.1 Monitoring the safe energy source

The IMD monitors the SE source voltage continuously.

A warning (POWERVOLTAGE Source(s) < min) is issued if the SE voltage is lower than a parameter set value.

IMD 122 C has an extra connector for mid-point voltage. It can be connected to a mid-point in the safe energy source, enabling to check that both parts of the SE are symmetrical (subject to the number of elements). No warning or configuration are associated with this function, and the IMD does not take any action or evaluation. Evaluating the value and taking actions is done by external controller.

Ultra-capacitors only: When equipped with the SE charger option, the IMD is capable of measuring the capacity and resistance of the capacitor bank. See section 5.5.3 on page 30.

### 5.5.2 SE test

When the IMD is used together with safe energy, it is also possible to use the ballast resistor for safe energy test. The test itself is done and evaluated by an external controller, and it must be ensured that the power on the resistor does not exceed the rated power of the resistor.

### 5.5.3 Safe energy charging (option)

When equipped with a built-in charger, the IMD is capable of charging the connected safe energy (SE) source. If the IMD was ordered without the built-in charger, the charger cannot be added to the IMD later.

The charger starts charging automatically with the saved configuration, when the DC-link voltage is adequate. The IMD generates a warning in case of a charger error. The IMD will not perform a safety run or change state in case of a charger error.

The following energy source types are supported:

- Lead acid batteries (temperature compensated)
- Lithium Ion batteries
- Ultra-capacitors

The charger is an advanced multistage programmable charger, capable of optimised charging for different types of supported energy sources. If the charger configuration is done according to the safe energy source manufacturer recommendations, the energy source is kept at maximum performance and prolonged lifetime. Charging is done in stages where the charging properties and transition to the next stage are programmable.

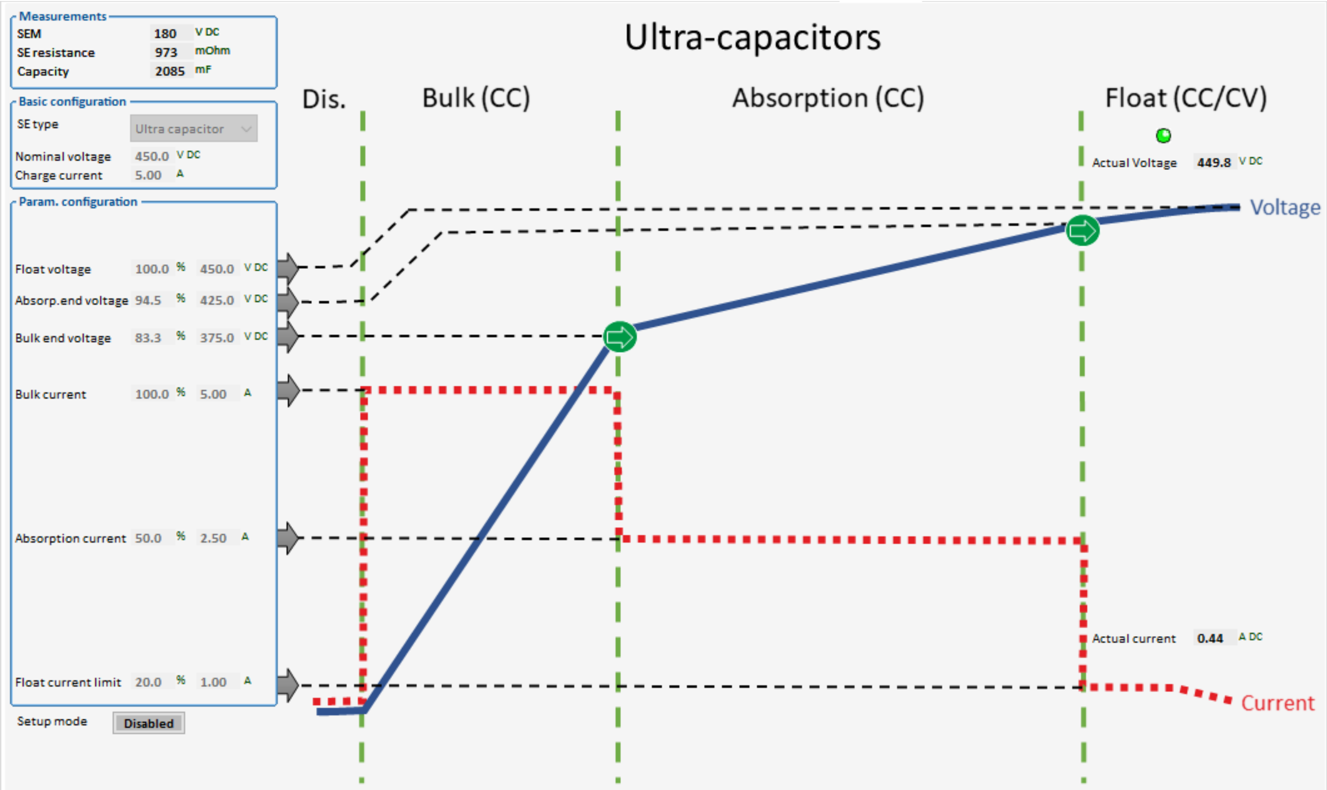
There are two types of parameters:

- Basic configuration (parameters that must always be defined):
  - SE type
  - Nominal voltage of the SE
  - Charge current
- Parameter configuration (parameters that have default values but can be changed):
  - Voltage and/or current for each charging stage in percentage of the basic configuration values
  - Values of voltage or current that cause transition to the next stage in percentage of the basic configuration values

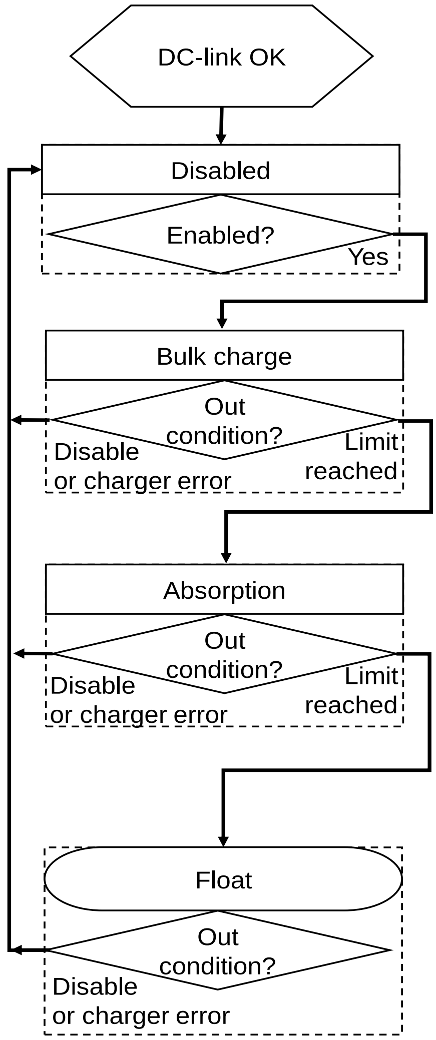
The default values of the parameters (factory defaults) in the parameter configuration can always be applied either before or after changing the parameter's values manually. All configurable parameters are part of the IMD configuration file that also contain the standard IMD parameters. See description of the configuration management in section 7.7 on page 58.

**NOTE** The factory defaults values are different depending on the SE type selected. They are not optimised for any specific batteries or ultra-capacitors. These values define a charging curve that would fit most units of the selected SE type. It is recommended to check values and optimise them according to the specific manufacturer recommendations.

The following figure is an example of Ultra-capacitor charging, illustrating the charging curve, measurements, and the applicable programable parameters:




The following figure depicts the charging process after the IMD is configured for charging:




DC-link OK is when:
DC-link voltage > 120 V DC AND
DC-link voltage > SE voltage + 15 V DC

The charger is automatically enabled when there are no errors and when not in setup mode.
After being disabled or if an error occurred, the charging process always start at this stage.

Main charge stage, using high Constant Current (CC).
This state continues until an end voltage limit is reached.
DC-link not OK generates a charger error.

*Topping (or equalisation) stage.*

- *Lead Acid* and *Lithium Ion* are charged with Constant Voltage (CV). Charging is continued until the charging current drops below a current limit.
- *Ultra capacitors* equalise their charge using low CC. This state is continued until the SE voltage is above a voltage limit.

DC-link not OK generates a charger error.

Maintenance charge (final stage).

- *Lead Acid*: constant charge with low current.
- *Lithium Ion*: Repetitive CV charging that starts when SE voltage is below a voltage limit, and stops when current is below a low limit .
- *Ultra capacitors*: Constant charge with a low current limit, until the float voltage is reached, and the charge is changed to CV.

DC-link not OK generates a charger error.

**Figure 18** Charging process

### 5.5.3.1 *Charger measurements (ultra-capacitors)*

The charger is capable of measuring capacity and resistance of the connected safe energy source. These measurements values are intended as guiding values that show the changes of the capacitor over time. They can be used as an indication of the ultra-capacitor's state with regards to when it is time to replace the capacitors. The IMD does not take any action or evaluation of the measured values. Evaluating and taking actions is done by external controller.

The capacity and resistance measurement are done by charging the capacitor's voltage at a known current for a known period of time, measuring the voltage across the capacitor and calculating the results:

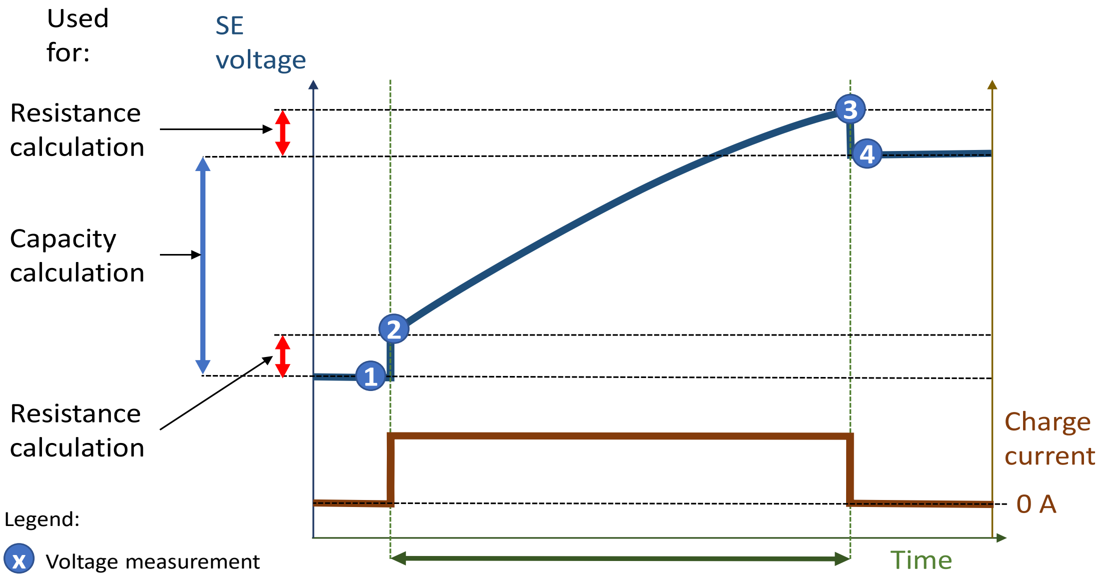



**Figure 19** Measurements principle

The capacity is calculated based on voltage measurements 1 and 4, where the internal and external resistance has no influence because the current is zero.

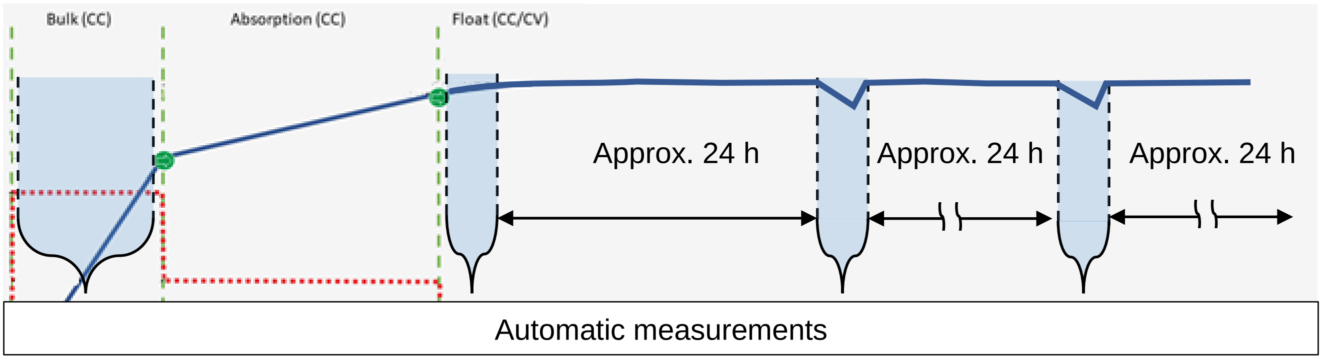
The resistance is calculated from the voltage rise (voltage measurements 1 and 2) and voltage fall (voltage measurements 3 and 4), which are governed by the resistance. The resulting resistance is the average of the two results.

The resistance result is the total resistance as seen by the IMD (sum of the following):

- Wires from the IMD to the SE bank
- Wires connecting the capacitors in the SE bank
- Total ESR (Equivalent Series Resistor) of all capacitors in the SE bank.

When in float stage, the measurement cycle starts by waiting for the capacitor's voltage to drop (5 -10 V), and then charge with higher current than the normal float charge.

The measurements are done automatically during charging according to the following scheme:



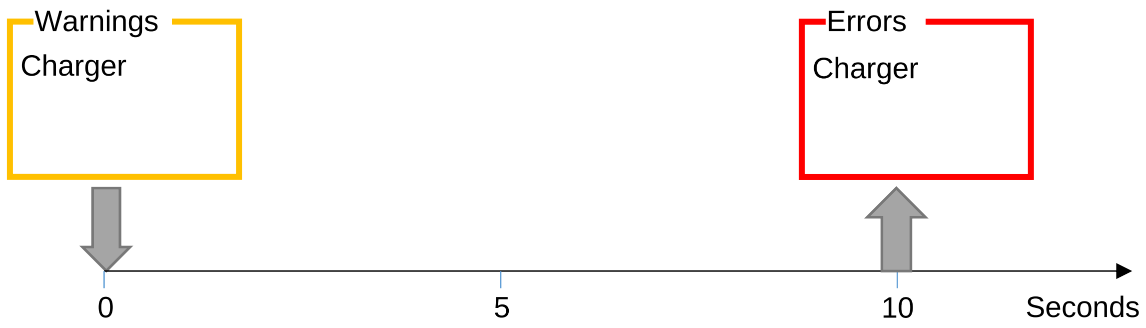
### 5.5.3.2 Charger Error handling

The charger has errors and warnings in two different map registers. The errors and warnings are propagated and are indicated as a single error (warning B**,** “CHARGER Error or warning”) in the IMD error and warnings map. Communication error with the charger is indicated as BUSTIMEOUT warning.

The charger always attempts to start charging again, even if there is an active error. If there is a temporary error, the charger set the error in its error map, and start charging again when the error disappears, even though the error is still shown as active in the error map. Only a “Clear errors” command to the IMD or restarting the IMD can clear charger errors.

Per default, a charger error will not cause any action from the IMD other then have an active warning. A configuration parameter (reg. 0x01. bit 11) determines how the IMD behaves when charger error occur:

- 0x01. Bit 11 = 0: Charger errors are never escalated to errors and remain as warnings.
- 0x01. Bit 11 = 1: If a communication error with the charger or any other charger error occurs, the IMD waits for 10 s, then generates an error and performs a safety run. The automatic safety run can be avoided if the turbine controller (or the IMD Manager) sends a “Clear error” command within 10 s, when the 10 seconds timer before generating an error is restarted.




The different situations are depicted in the following figure. Note that the depicted charger warning states and the charger error states are the same as depicted in the figure above. That is, the IMD “CHARGER” errors and warning.

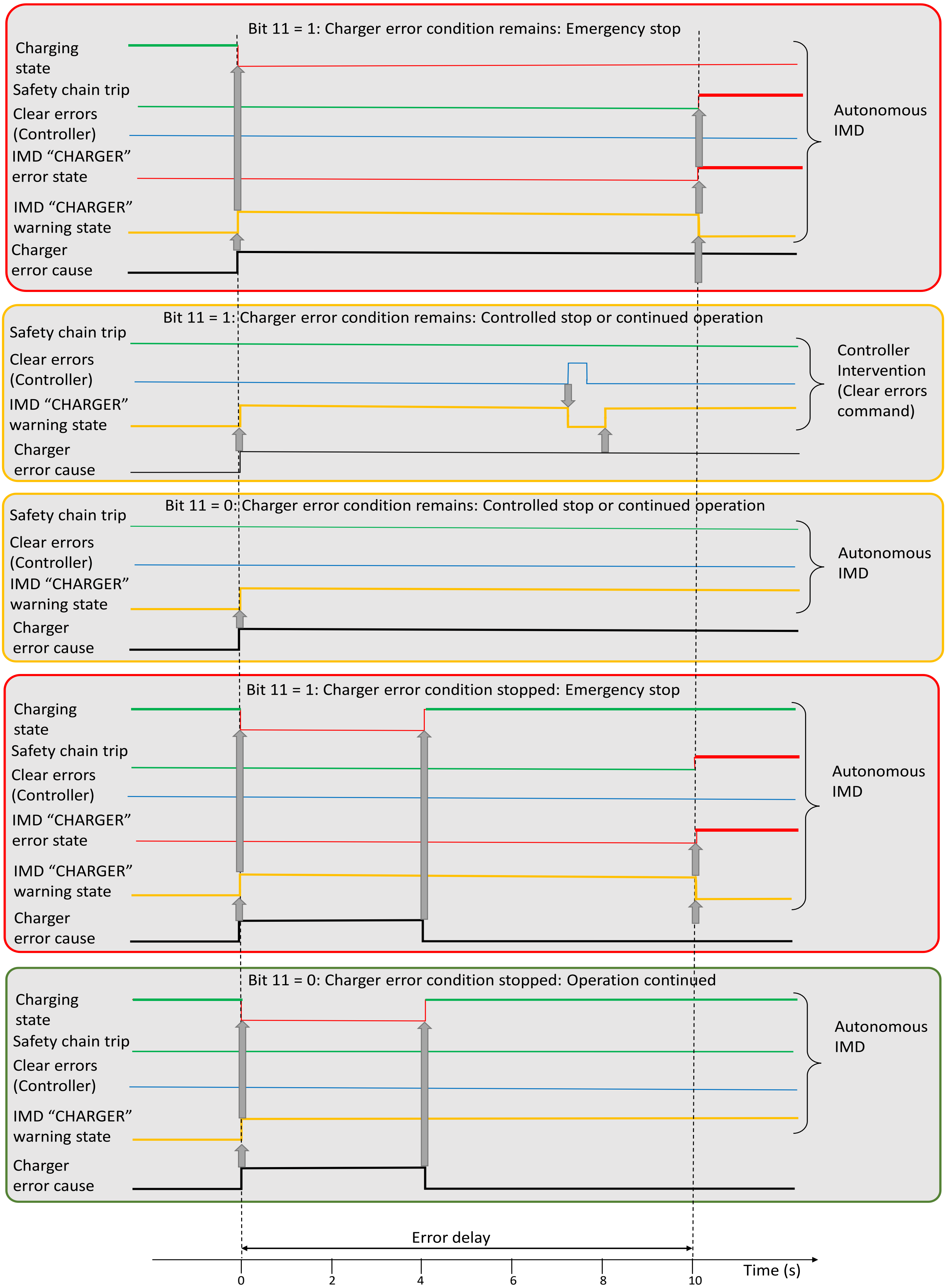



**Figure 20** IMD handling of charger errors

Charger error detection (CED) is triggered when a charger communication timeout or a charger error is detected, and a 10 s timer is started. There are three scenarios following the disconnection of the mains:

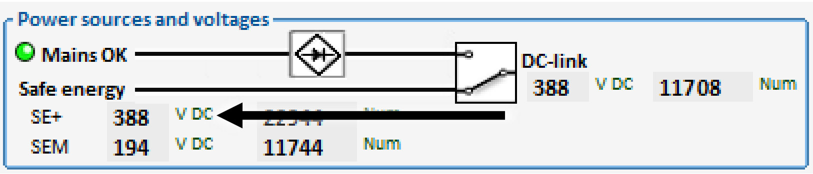
- **Bit 11 = 0: Charger error condition stopped, operation continued (green):**
  Normal operation is continued. If the error condition is stopped, charging is resumed and the warning is cleared.
- **Bit 11 = 1: Charger error condition stopped, emergency stop (red):**
  After ten seconds an error is generated, the warning is cleared, and a safety run is performed. If the error condition is stopped, charging is resumed.
- **Bit 11 = 0: Charger error condition remains: Controlled stop or continued operation (yellow):**
  Normal operation is continued.
- **Bit 11 = 1: Charger error condition remains: Controlled stop or continued operation (yellow):**
  If a “Clear errors” command is sent within 10 s from the CED, normal operation continues. If the charger error condition persists, the turbine can be stopped (controlled stop) and avoid a safety run (emergency stop).
  NOTE: If the error condition persists, a new warning will be generated after the clear errors is received.
- **Bit 11 = 1: Charger error condition remains, emergency turbine stop (red):**
  If 10 s elapsed after the CED without further action from the turbine controller or a person with IMD manager, an error is generated, the IMD trips the safety chain, and performs a safety run.

### 5.5.4 Safe energy (ultra-capacitors only) discharging

It is possible to discharge ultra-capacitors for service purposes. Discharging is done using the ballast resistor to discharge the capacitors.

Discharge can be initiated from one of the following sates (see Figure 31 on page 54 ): Safety-chain relay (SCR) tripped, Parked tripped, Parked ready, Safety run timeout, Manual operation (not depicted in figure). The discharge operation does not change the IMD state.

When starting the discharge, the IMD disconnect the mains from the DC-link (“Grid off”), and turn the fan on. The Actual SE voltage can be monitored continuously in the IMD manger:




Discharging fully loaded capacitors can take some time. To calculate the approximate time full discharge will take use the following formula:

| | |
|---|---|
| Formula: $t = \frac{0.5*C*U^2}{Pb*0.75}$ | t: Total approximate discharge time (to zero) in s<br>C: Total SE capacity in F<br>U: DC-link/SE voltage in V<br>Pb: Ballast resistor rated power in W |
| Example: $t = \frac{0.5*2*450^2}{300*0.75} = 900s$ | C: 2 F<br>U: 450 V<br>Pb: 300 W |

**Stopping the discharge:**

The discharge is deactivated by executing a special command, or if the there is no 24 VDC.

The remaining voltage on the capacitors depends on the way the discharge stopped:

- If the mains supply is missing and there is no redundant 24 V the voltage across the ultra-cap can not be discharged lower than approximately 100 V DC.
- If the discharged is stopped by a command (“Idle”) the remaining voltage across the ultra-capacitors depends on the capacity and charge level of the ultra-capacitors, discharge time, and the ballast resistor.

# 6. Motor control

This section describes how the motor is controlled and monitored. It describes the basic principles of the control and how the control is done in practice. It does not describe each parameter that needs to be configured.

## 6.1 Basics of the IMD motor control

As described in section 2 on page 7, the IMD converts a controller command into movement of the pitch motor. In general, there are three control elements in the IMD that are used:

1. Position
2. Speed
3. Current

Depending on whether there is a PMC (Pitch Motion Controller) in the system or not, two or three of these elements are used.

The following figure illustrates the basics of the IMD motor control:

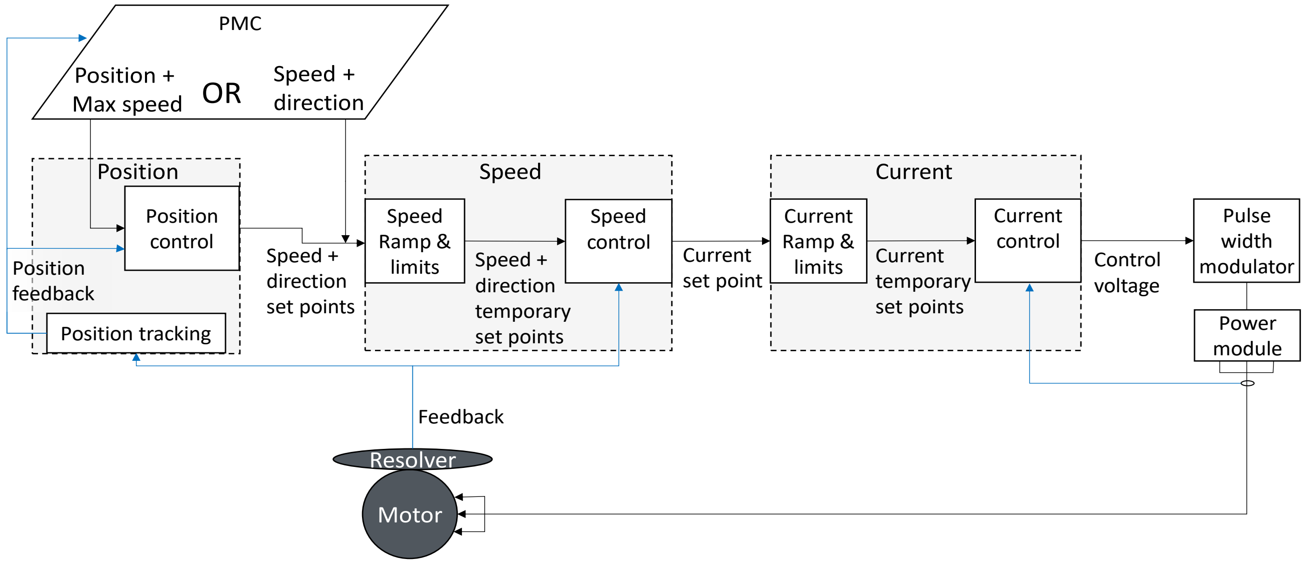



**Figure 21** Basic control of the IMD

Both speed and current stages have internal control loops, which regulate the output from the stage.

### 6.1.1 Position control stage

The position control receives an absolute blade motor position and maximum speed request from the PMC. A position tracking function continuously calculates the actual motor position based on the resolver feedback.

Based on the present position of the blade motor, the position control determines the direction of the movement and sends a speed and direction command to the speed stage.

**Info**

If the position control is enabled (during configuration), it will cause the IMD to hold the motor and blade in position also when speed control is used and the speed is zero, thus preventing drift of the motor axle.

### 6.1.2 Speed control stage

The speed control stage receives the desired direction and speed from either the position stage or the PMC. The first function of the stage is to apply ramp and maximum speed limits.

- Ramp: The ramp defines the acceleration or deceleration of the motor to reach the maximum speed (acceleration) or to zero (deceleration). It is defined in the time (ms) that it will take the motor to reach maximum speed (100%) from zero or to zero from maximum speed. The same ramp rate will be used no matter what the desired speed set point is. If for example the motor is at zero RPM and the desired set point is 70 %, it will take 70 % of the Ramp time to reach this speed.

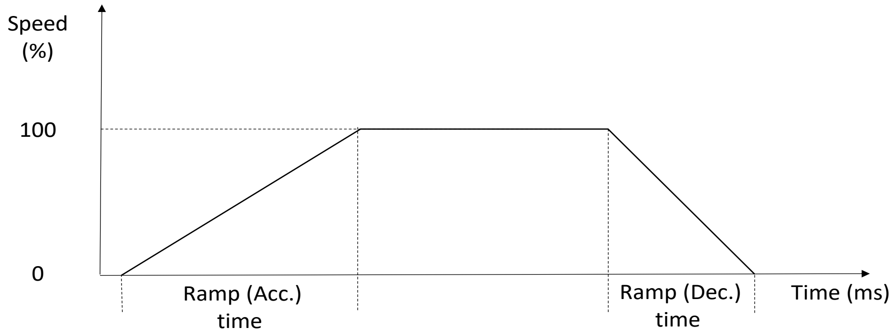



**Figure 22** Acceleration and deceleration ramps

- Limits: Three limits for maximum speed can be defined (the lowest limit will be applied):
  - Global speed limit, which apply to all movement
  - Positive direction limit (N-Lim +)
  - Negative direction limit (N-Lim -)

  The above-mentioned limits must also be enabled (can be enabled individually) in order to be applied. The direction definition (positive or negative) depends on the connections to the motor. Positive is not necessarily motion towards 90º.

In practice, the first function (speed ramp & limit) will continuously send temporary speed set points to the second function (speed control) that will ensure that the acceleration/deceleration will be correct.

### 6.1.3 Current control stage

The current control stage works very similar to the speed control stage, and applies current limits (see section 6.4.1 on page 44) according to the configuration. The resulting current set point are then converted to output voltage that controls the output module (Pulse Width Modulator).

## 6.2 Position control

The IMD uses a resolver to monitor the position of the pitch motor and blade. The following figure illustrates the setup of the physical pitch system (size not proportional).

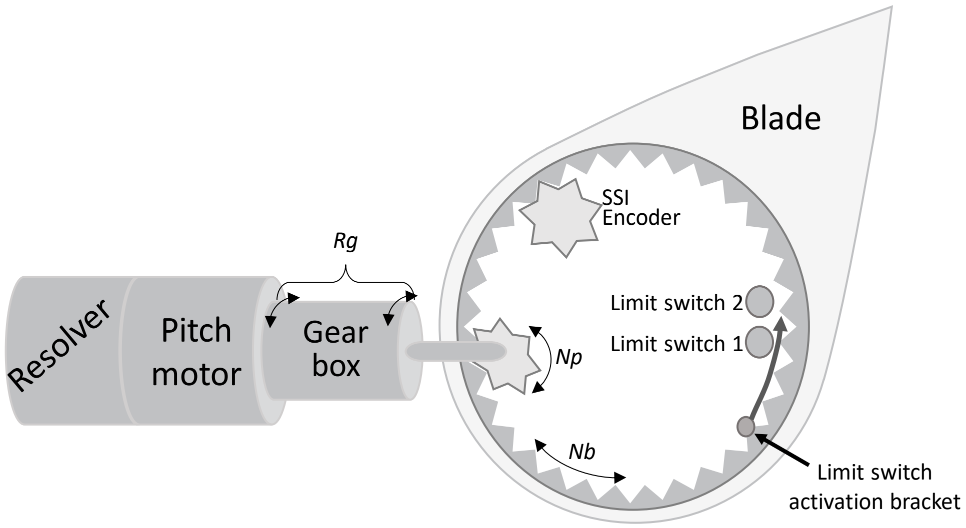



**Figure 23** Position control components

The resolver measures the position of the motor axis at all time. In order to be able to tell exactly how many rounds the motor has turned, the IMD counts the number of whole rounds the motor has taken, and adds to it the present position of the motor axis. By knowing the ratio of motor rounds to blade ring distance, it is thus possible to calculate how many degrees the blade has pitched.
The formula for calculation the ratio is:

| | |
|---|---|
| $\frac{Nb}{Np}Rg = Rtotal$ | *Rtotal* = the total ratio of motor axis to blade rotation<br>*Nb* = number of teeth on the blade<br>*Np* = number of teeth on the pinion<br>*Rg* = gear box in/out ratio |
| Example:<br>$\frac{133}{17}230 = 1800$ (rounded) | *Nb* = 133<br>*Np* = 17<br>*Rg* = 230 |

To calculate the needed movement of the motor in order to achieve specific blade movement in degrees:

| | |
|---|---|
| $\frac{\text{Rtotal} * \text{NB}°}{360°} = \text{Motor revolutions}$ | *Rtotal* = the total ratio of motor axis to blade rotation<br>*NB°* = Desired relative movement of the blade in degrees |
| Example:<br>$\frac{1800 * 2°}{360°} = 10$ | *Rtotal* = 1800<br>*NB°* = 2 |

The position of the blade is calibrated by configuring position 0° (see section 6.2.2 on page 40)and calculating the ratio of the motor rounds/position and the blade rotation in degrees.

The position of the blade can also be monitored by an absolute position encoder with a Synchronous Serial Interface (SSI) that measures directly the position of the blade. The SSI position value does not have any direct control function and is not used by the IMD. It is a measurement that can be retrieved from the IMD by the main controller and can be used for example to ensure that the blade actually moves.

It is possible to configure the IMD to automatically pitch the blade to stop position (limit switch activated) when the IMD is powered up.

While the IMD is active, it controls the position of the motor by modulating the supply to the motor. The IMD is able to maintain the blade motor position without moving it.

### 6.2.1 Automatic position storing

When the drive is enabled, the drive keeps the blade in place by keeping the motor in the same position. If the drive is disabled, only the brake keeps the blade motor in place. If the blade drifts while the device is disabled and the IMD restarts, the last position of the blade motor might not be known. Therefore, when the drive is disabled, the IMD automatically checks the position of the resolver every two minutes, and if the value has changed from the last stored value, the IMD stores the new value in the non-volatile memory (EEPROM).

During manual operation the position is stored by the IMD every time the motor and brake outputs are deactivated.

### 6.2.2 Position pre-set

The position value comprises of two components: one for the position within one revolution, and one for the number of full revolutions. The resolver only measures the position within one revolution. The IMD counts the number of revolutions, based on the readings from the resolver.

It is possible to change the value of the component that indicates the number of whole revolutions to any value. Changing the actual position value can be done no matter whether the position control is enabled or not. This function is used for zero calibration of the blade, typically performed during commissioning.

### 6.2.3 Virtual limit switches

The Virtual Limit Switch (VLMS) function is introduced to ensure the following:

- The IMD will stop the motor if the physical limit switches fail for any reason
- To stop the motor in manual operation mode if the motor gets outside a specific area (the physical limit switches has no influence in manual mode)

The purpose of the VLMS is to define a larger pitching span so that the IMD ensures that the blade will never pitch beyond these limits.

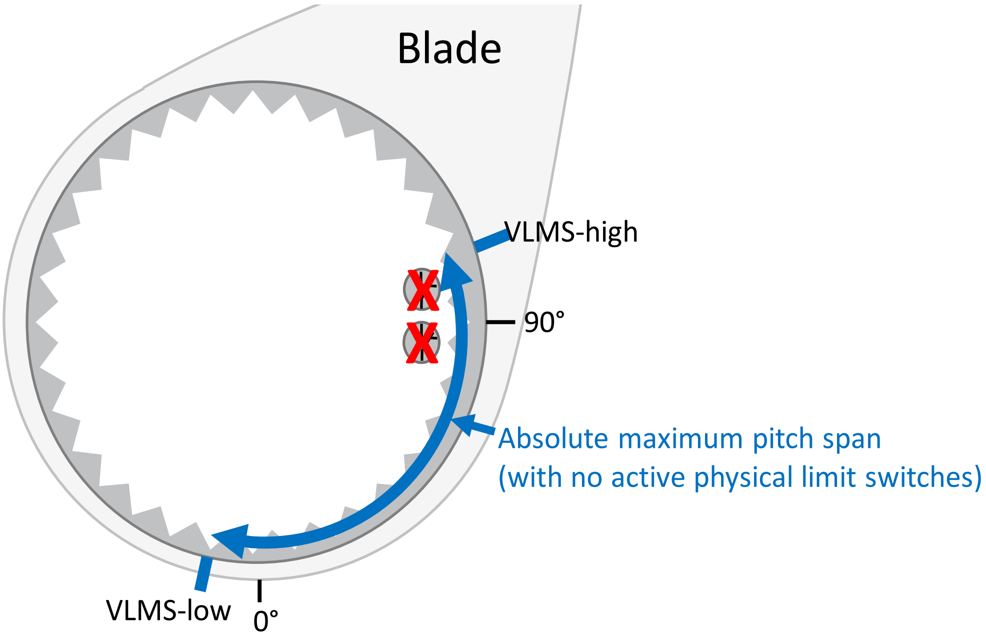



Figure 24 Maximum pitch span with VLMS

#### 6.2.3.1 VLMS function

The VLMS are always functioning unless they are configured to be disabled:

| Operation mode | Functioning mode | Disable possibility |
|---|---|---|
| Normal operation | VLMS functioning | Can be disabled |
| Manual operation | VLMS functioning | |
| Manual operation 360 | VLMS not functioning | Always disabled |

The “Manual operation 360” is a special mode of the manual operation where the VLMS is always disabled.

When a VLMS is activated, the IMD does the following:

- Stop the blade with normal stop ramp.
- It is only possible to start the motor again in the direction that will move it back into the allowed area.

**NOTE:** The motor will stop after the VLMS depending on the defined stop ramp and the speed of the motor at the time when the VLMS is reached. A safety run is also stopped if the VLMS is reached.

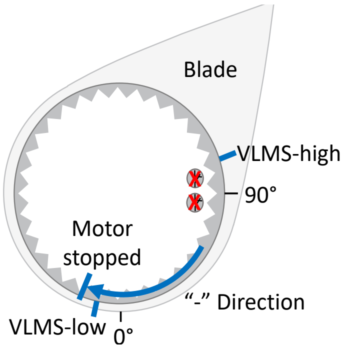
Accuracy of VLMS position: Only the number of revolutions is used for the VLMS function.

### 6.2.3.2 *VLMS operation*

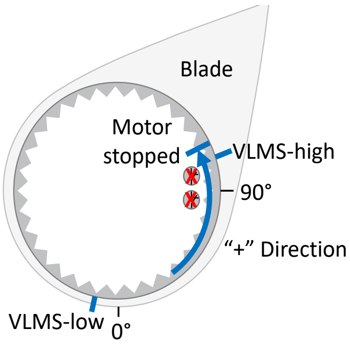
This section describes the operation of a pitch system with VLMS in different scenarios. In the following scenarios it is assumed that VLMS-low is configured to "-5", and VLMS is configured to "1000"

**Normal operation:**

- The blade is turning past zero, and the motor reaches position -5 revolutions. The motor stops and can only be moved in the "+" direction.




- The blade is turning past 90º, and the motor reaches position 1000 revolutions. The motor stops and can only be moved in the "-" direction.

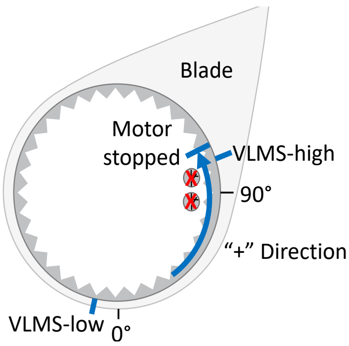



**Safety run:**

If the motor reaches position 1000 before a physical limit switch is activated the motor stops and can only be moved in the "-" direction.

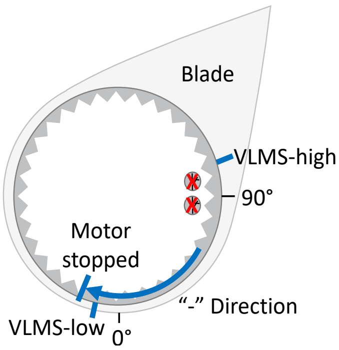
After safety run timeout (from the safety run start) the IMD state will change to state 18 (Safety run timeout). From this state it will only be possible to proceed with manual operation. Initiating a new safety run will not move the motor since only movement towards zero is allowed.

**NOTE** This is also the case if the VLMS-high is configured too low (before the blade reached the physical limit switch).



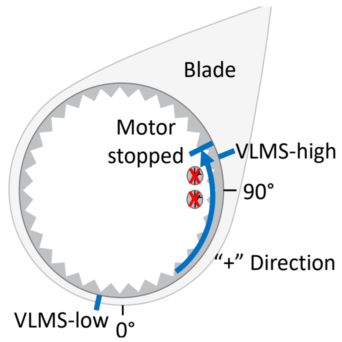

**Manual operation mode:**

The IMD is in manual operation mode, and the movement of the blade is controlled by switches connected to DI 12, DI 11 and DI10.



- The blade is turning past zero, and the motor reaches position -5 revolutions. The motor stops and can only be moved in the "+" direction.

- The blade is turning past 90º, and the motor reaches position 1000 revolutions. The motor stops and can only be moved in the "-" direction.

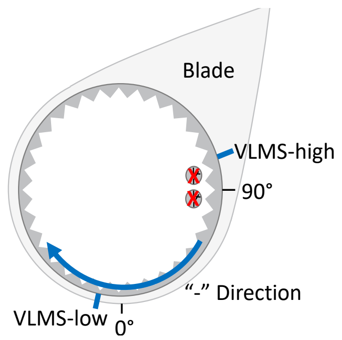



**Manual operation 360 mode:**

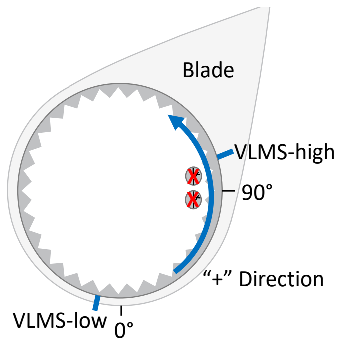
The IMD is configured to "Use of manual operation 360" enabled.

The IMD is in manual operation mode, and the movement of the blade is controlled by switches connected to DI 12, DI 11 and DI10. D 9 is set ON (high). In this operation mode the IMD ignores the VLMS.

- The blade is turning past zero, and the motor reaches position -5 revolutions.
  The motor does **not** stop when moving past the VLMS.




- The blade is turning past 90º, and the motor reaches position 1000 revolutions.
  The motor does **not** stop when moving past the VLMS.




- Exit from "Manual operation 360": DI 9 is set to low. The IMD goes to "Manual operation" (assuming DI 12 is still high)

- If DI 12 is set low while in "Manual operation 360", the IMD goes back to normal operation.

# 6.3 Speed control

See section 6.1.2 on page 38.

# 6.4 Current control

This section describes the current limitation and current control aspects.

## 6.4.1 Current limitation

The output current to the motor is constantly monitored, and the current is limited if certain conditions are present.

The following values (configurable) are used for current control:

- *I-nom* – (I nominal) the maximum continuous current. The depicted *I*-nom is a combination of motor nominal current and application I con eff (continuous effective current), whichever is lowest. This value is given in RMS.
- *I-max* – the maximum peak current value. This value is given as Peak to Peak. The IMD will always limit the current to this value.
- *T-peak* – the maximum time that the current is allowed to be at *I-max*. After the output current was limited due to overload energy, and is under I nom, a duration of 2 x *T-peak* must elapse before the IMD will allow the current to exceed *I-nom* again.

**Info**

In practice, I nominal and I maximum are defined in two sets of parameters: one based on the motor specification and one based on the application specification. At any time, the lowest value will be used no matter whether it comes from the motor or application definition.

When defining these values, a specific amount of overload energy that is allowed (shaded area) is actually defined. As the area increases in size, the overload energy integral increases, and when it reaches 100% (corresponds to *I-max* for a duration of *T-peak*) the current is limited to *I-nom*, as depicted in the following figure:

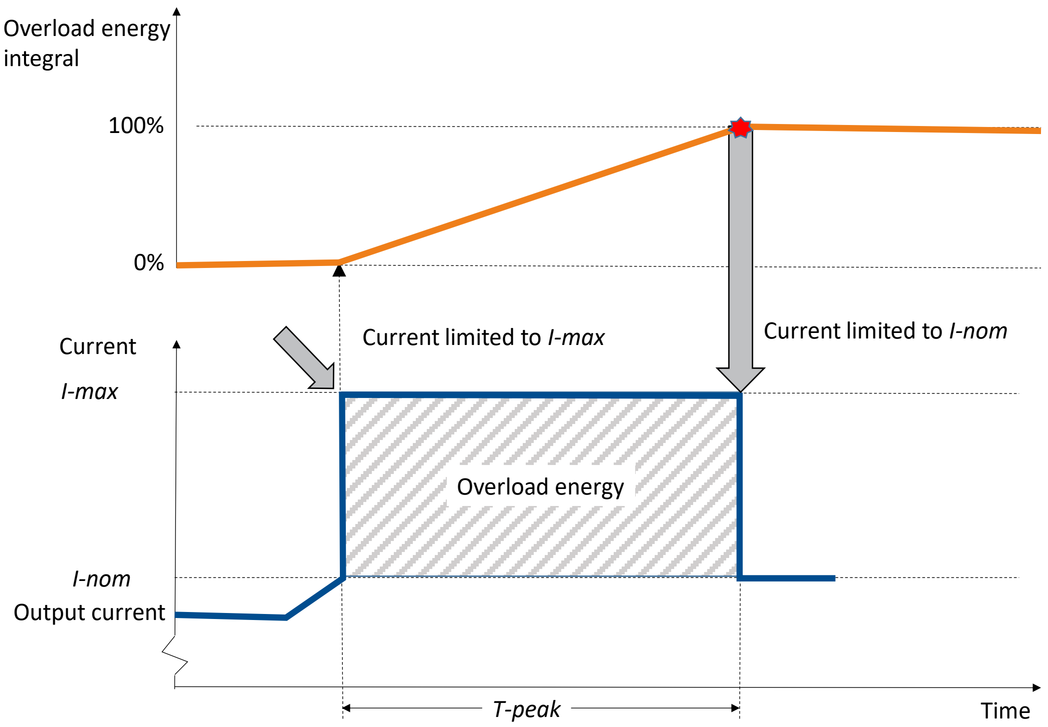



**Figure 25** Maximum overload energy and current limitation

The overload energy is constantly calculated, and when the accumulated energy equals the allowed overload energy, the IMD will limit the current to *I-nom*. Therefore, if the output current is above *I-nom* but bellow *I-max*, the time until the IMD will limit the current to *I-nom* will be longer than *T-peak* as illustrated in Figure 26 on page 45 (assuming the same energy overload was defined).

**Info**

*T-peak* in Figure 26 on page 45 and Figure 27 on page 46 is the same as in Figure 25 on page 45. The difference is when the IMD actually limits the current to *I-nom*.

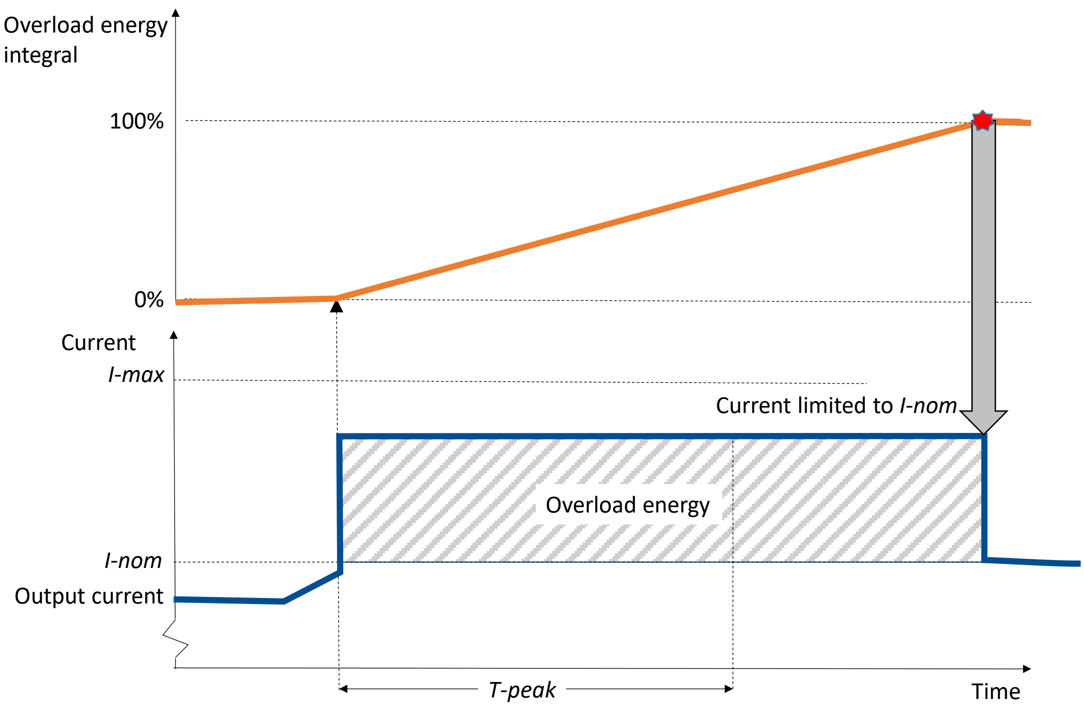



**Figure 26** Current limitation when the current is above *I-nom* and below *I-max*

If the current consumption is not stable but increases or decreases during the overload situation, the overload energy is calculated differently depending whether the current is above or under *I-nom*. If the actual current is under *I-nom* after it has been above *I-nom*, the overload energy integral will decrease with half the rate (depicted with dashed line) of when it increases. The impact is that the time until the current is limited to *I-nom* is shorter than it would have been without this double time factor in the calculation as depicted in the following figure:

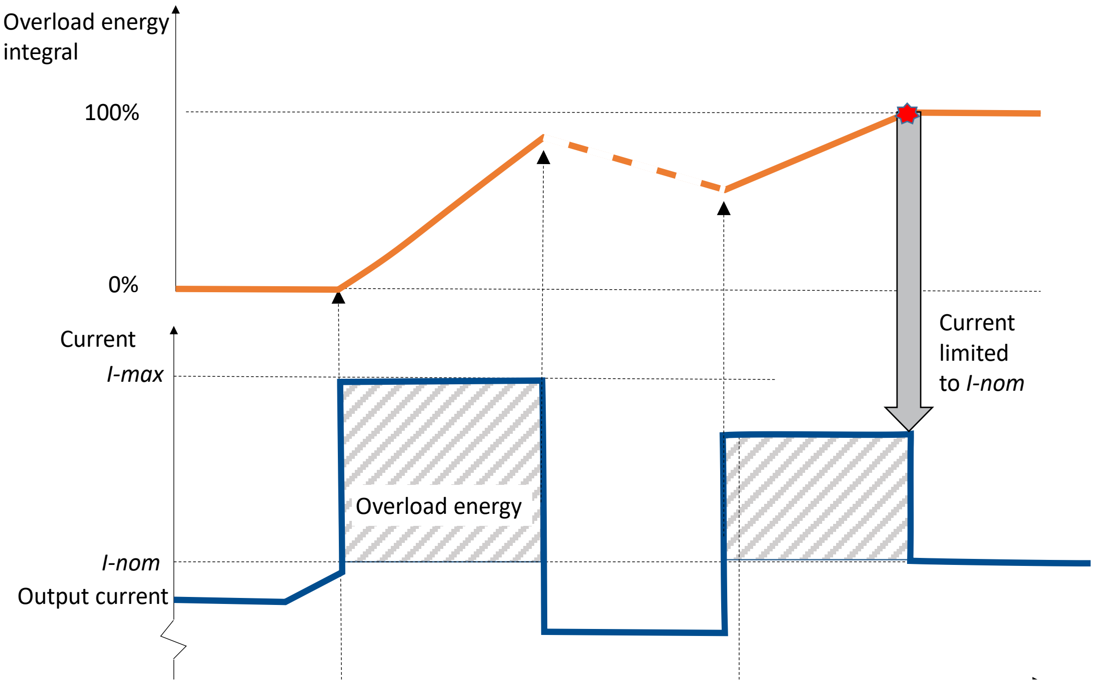



**Figure 27** Current limitation when the current is above and below *I-nom* (unstable current)

Note the different slopes in the different stages in Figure 27 on page 46 depending on how high the current is. When the current equals *I-nom,* the overload energy integral stays the same.

### 6.4.2 Current control

The current control defines how the motor will be controlled with regards to current. There are three parameters defining the control loop for the current:

- *I-Kp* – a factor that defines the proportional amplification (how fast the control will react to changes). Too low value will result in slow response when maximum torque is not reached. Too high value will result in overshoot, noisy operation of the motor, which will vibrate as well.
- *I-Ti* – Integration time for the current controller. Should be kept as low as possible, while still optimizing the response to the desired effect. The longer integration time, the longer it will take the motor to change its movement, and will result in low frequency oscillation.
- *I*-TiM – Maximum value of the integral memory. Should be kept as low as possible, while still optimizing the response to the desired effect. Too high value will result in low frequency oscillation.

The following figure shows examples of control where the control parameters were used to optimize the control loop.

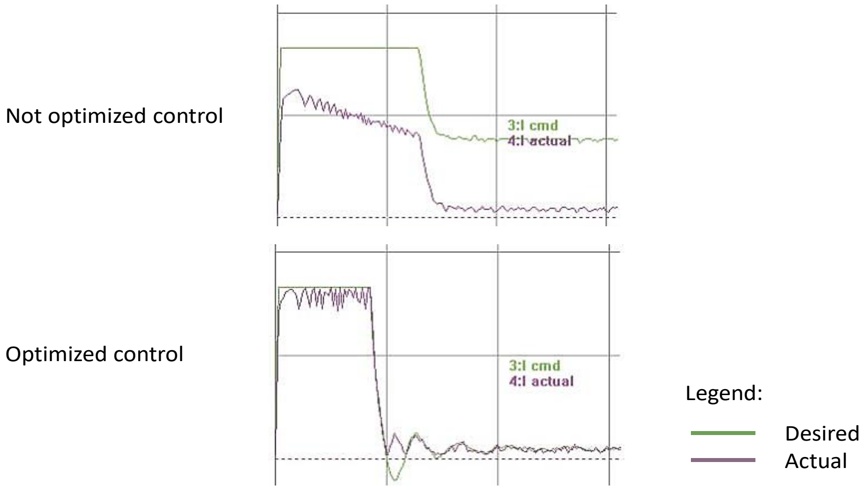



**Figure 28** Examples of control optimization

**Attention**

Only experienced and qualified personnel should adjust the control parameters.

### 6.4.3 Field weakening

In an electric motor the maximum achievable speed will always depend (among other parameters) on the voltage that can be supplied to the motor.

| | |
|---|---|
| $\frac{V}{Mfield} = RPM$ | *V* = Available voltage<br>*Mfield* = Magnetization parameters (these can be different parameters depending on motor type)<br>*RPM* = Motor speed |

In situations where the grid is not available and the turbine needs to perform a safety run, achieving the desired speed for the safety run might not be possible due to a lower DC-link voltage. As can be seen in the formula above, lowering the voltage will automatically lower the speed, unless the *Mfield* is lowered as well. This can be achieved by field weakening. Depending on the motor type, different ways of field weakening are implemented:

**Table 3** Field weakening implementation

| Motor type | Control implementation |
|---|---|
| Permanent magnets | A magnetic field, with opposite direction to the permanent magnets direction is created with reactive current. |
| Windings | The reactive current that magnetizes the winding is reduced. |

No matter which method is used, the result is a lower *Mfield* that enables higher speed. There are three side effects of using field weakening:

1. Using field weakening requires in total more current (active and reactive) than otherwise, even more so with permanent magnets
2. Overall, more power is needed to move the blade to stop position than when field weakening is not used (must be considered when designing the safe energy source).
3. The available torque is reduced proportionally to the speed addition.

The higher speed effect that can be achieved depends on the motor construction, even for the same motor type. In general, the effect that can be achieved in synchronous motor with permanent magnets, is less than with asynchronous motors.

If the field weakening parameters are configured, the function will automatically be activated when needed (though only during safety run while running on safe energy).

# 6.5 Motor monitoring and protection

The IMD monitors the temperature of the motor, the connections, and is also able to pre-heat the motor in severe cold temperature.

## 6.5.1 Motor connection monitoring

The IMD monitors the connection to the motor by monitoring the symmetry of the current of the phases. Asymmetry indicates a loss of a phase.

Monitoring the current symmetry requires motor motion as well as some load (not idle). If a phase is missing when the motor is still, an error will appear when the motor starts running again.

## 6.5.2 Temperature monitoring

The IMD monitors the temperature of the motor using Pt100 (Pt4), KTY84, or PTC sensors which are typically built in the motors. For cabling flexibility purpose, there are inputs for these sensors in both X3 and X4 connectors. The mounted sensor is configured as active in the IMD. If KTY or PTC are used in the motor, Pt4 can be used by the control system (main controller or PMC) as a distributed temperature sensor. There is no redundancy function for the motor sensor.

A switch off motor temperature is configured in the IMD (*M-Temp*). The temperature configured depends on the motor and sensor used. When the temperature of the motor is above *M-Temp*, the blade is pitched to stop position and the safety-chain relays are tripped, and a MOTORTEMP error will be sent.

When the actual motor temperature is above 87.5% of *M-Temp*, a MOTORTEMP warning is shown in the display and sent to the controller. The warning is only applicable for linear sensors (Pt100 and KTY 84). If a PTC sensor is used, the warning will practically be sent at the same time as the MOTORTEMP error.

The actual motor temperature can be retrieved from the IMD anytime. The value retrieved is an integer count that depends on the sensor type (Pt100 or KTY 84), and needs to be converted to degrees. The temperature reading is not applicable for PTC sensor.

## 6.5.3 Pre-heating the motor

In extreme cold temperature conditions when the motor was not operating, it is possible to pre-heat the motor before operation. This is done by sending current to the motor while maintaining its position. It is possible to use up to *I-nom* (in steps of 1/8 *I-nom*) to preheat the motor. In spite of the relatively high current, due to the size of the motor (and depending on the ambient temperature) pre-heating the motor can take many hours. Start and stop of the pre-heating function is done by the application SW.

# 6.6 Manual operation

It is possible to control the motor manually using digital inputs 10, 11, and 12 for service purposes. These inputs are intended to be connected to three switches in the pitch cabinet. If a Bus timeout error is active when manual operation starts, the error is reset.

### 6.6.1 Manual operation without VLMS, or with VLMS active

The digital inputs have the following designations:

| Digital input | Function designation |
|---|---|
| DI 12 | Manual operation “Manual enable” |
| DI 11 | Activate motor clockwise (“+” direction) |
| DI 10 | Activate motor counter-clockwise (“-“ direction) |

The IMD must be in manual operation mode (state 59) in order to be able to operate the motor manually with the above-mentioned inputs.

If any of these inputs are activated when not in manual operation mode a HW warning will be generated.

Manual operation is configured to operate in either of the two modes:

- Manual operation can only be performed when SCI inputs are OK (safety chain OK)
- Manual operation can only be performed when SCI inputs are not OK (safety chain tripped)

Both modes applies to both manual operation and manual operation 360 (see section 6.6.2 on page 50).

**Info**
Safety run will not be executed while in manual operation mode.

#### *6.6.1.1 IMD configured to manual operation when SCI inputs are OK*

The IMD is brought into manual operation mode by activating DI 12 following by either DI 11 or DI 10.

Once in manual operation mode, activating DI 11 or DI 10 will start the motor with a preconfigured speed and acceleration in the defined direction for as long as the input is activated, though no longer than the predefined maximum operation time. No special deceleration time is defined for the manual operation (standard operation deceleration is used). When in this mode the brake is engaged after a predefined manual operation delay elapsed from the time the motor is deactivated.

Taking the IMD out of manual operation mode is done by deactivating DI 12. Upon exit from manual operation mode, the IMD always returns to Normal operation state (state 1).

#### *6.6.1.2 IMD configured to manual operation when SCI inputs are Not OK*

The IMD is brought into manual operation mode by activating DI 12 (high). Any motor motion is stopped.

Once in manual operation mode, the manual operation behaves in the same way as when the SCI inputs are OK (section 6.6.1.1 on page 49). In this mode however, it is also possible to disable DI 10 and DI 11 through CAN (so it is not possible to move the motor).

If the CAN connection is not active, DI 10 and DI 11 are always enabled, DI 12 always stops the motor, and manual operation 360 is automatically enabled if DI 9 is high.

Taking the IMD out of manual operation mode is done by deactivating DI 12. Upon exit from manual operation mode, the IMD always performs a safety run.

### 6.6.2 Manual operation 360

If virtual limit switches are used it is not possible to pitch the blade past a virtual limit switch in manual mode, unless the IMD is put in “Manual operation 360” mode. In this mode the virtual switches are ignored.

To put the IMD in Manual operation 360 the IMD must be configured to enable the use of this mode. When in manual mode, high on DI 9 puts the IMD in Manual operation 360.

# 7. General functions

## 7.1 Brake control

The brake system is an integrated part of the pitch system. The brake is a negative brake, which means, that it is spring activated and brakes the blade motor whenever there is no power applied to the brake. The brakes are powered directly from the IMD (24 V DC). The brake is automatically activated/deactivated when either the drive enable (RUN) digital input is changes, or an Enable command OFF/ON is sent to the IMD.

A configurable brake delay ensures that the IMD stops the motor and holds it in the same position before the brake is engaged/disengaged. This function prolongs the lifetime of the brake.

## 7.2 Communication

There are two ways to communicate with the IMD: CAN (Controller Area Network) and USB (Universal Serial Bus).

### 7.2.1 CAN bus communication

The main communication channel to the IMD in a pitch system is through the CAN bus (the IMD acts as a slave). The IMD supports a proprietary CAN protocol and CANopen protocol. At startup, the IMD ignores any errors/timeout in the CAN communication as long as the communication is not started from the CAN master.

Once the IMD receives massages from the CAN master, a time out in the communication will cause an error (CAN BUS TIMEOUT) to be generated. The error can be cleared either from the IMD manager (USB) or through the CAN bus (if it is working again). If the error is cleared from the IMD manager while there is still no CAN bus connection, no further timeout errors will be generated, until it receives communication with the CAN master is restored.

The IMD has an address switch that can offset the programmed address of IMD.
The address can be offset by 1 to 14 (zero and 15 are reserved). The switch is located on the IMD front panel.


### 7.2.2 USB communication

The IMD has one USB connector located on the front panel. It is mainly used for communication with a PC for configuration and service purposes. The protocol used is Serial over USB (also called virtual comport).

## 7.3 Inputs and outputs (I/O)

The IMD offers a variety of inputs and outputs that can be used as desired by the application SW (PMC or main controller):

- One KTY 84 temperature sensors input (intended for motor temperature sensor if in use)
- Four Pt100 temperature sensors inputs (Pt4 can be used for motor temperature sensor instead of KTY)
- Eight digital outputs
- 12 digital inputs (of which four are reserved for manual operation)
- Potential free relay (RO) that can be used to reset a safety relay for example. The function of the relay is controlled by the application SW (Pitch motion controller or Main controller).

### 7.3.1 Input and output logical functions

Some of the digital inputs and outputs can be configured with logical functions in order to execute independent actions, which are not dependent on the application sw.

#### *7.3.1.1 Input logic*

In general, digital inputs are passive, and their state can be read in a register. However, four of the inputs are programmable and can have special functions assigned to them, which can be defined in the “Input logic” group.

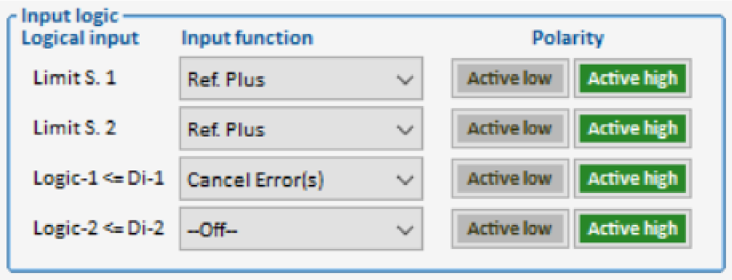



**Figure 29** Logical inputs

There are four inputs that can be defined: Limit S.1, Limit S.2, Logic-1, and Logic-2. For each of these inputs it is possible to define a function, and polarity (whether the action will be activated on high or low state of the input).

At least one limit switch input is required to be defined (see section 4.2.1 on page 14). Without this function, the IMD will consider them as other digital inputs and a safety run will never be concluded.

In the example in Figure 29 on page 52, Limit1 and Limit2 are defined as reference switches and Logic-1 is defined with “cancel error(s)” function. They are all active high.

Defining Limit1 and Limit2 as Ref. Plus, tells the IMD that these inputs are used as reference switches.

Defining Logic-1 as “Cancel error” function means that when the connection on Digital input 1 goes high, the IMD will cancel errors (the errors will be cancelled if the error causes are not valid anymore).

#### *7.3.1.2 Output logic*

The nine digital outputs (eight DOs and one Safety RO) can be set On and Off by bit mapping in register 0x98. However, four of these outputs (DO 5 to DO 8) can be programmed to perform different functions in the IMD Manager. The following example configures DO 8 for fan control (see also section 7.6 on page 57):

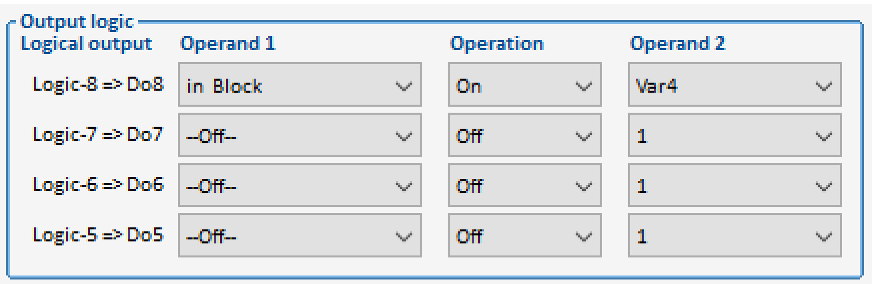



**Figure 30** Logical outputs

The four outputs that can be defined in the Logical outputs group, are mapped to the following digital outputs:

- Logic-8 is mapped to DO 8 (IMD 122 B: It is recommended to use Logic 8 for fan control)
- Logic-7 is mapped to DO 7
- Logic-6 is mapped to DO 6

- Logic-5 is mapped to DO 5

**Info**
When configuring digital outputs, it is important to distinguish between the terms Logic-x and DO x. DO x is the actual physical output, while Logic-x is the logical mapping of a function to a specific output.

Programming the outputs is done as a Boolean function with two operands and an operation. If the result of the function is true, the output will be set to High. If the result of the function is false, the output will be set to Low.

## 7.4 Power-on and operation States

When the IMD starts, it goes through a sequence that ensures correct start and operation of the drive.

The operation of the IMD from start up until and during operation can be monitored by reading a "user state" register in the IMD.

The following figure illustrates the main steps/states that the IMD executes. Not all states are illustrated to enhance simplicity and the names of the states are not the same as shown in the IMD manager in order to ease the understanding of the processes. Safety run means pitching the blade to stop position (90 º) due to an error or another safety situation.

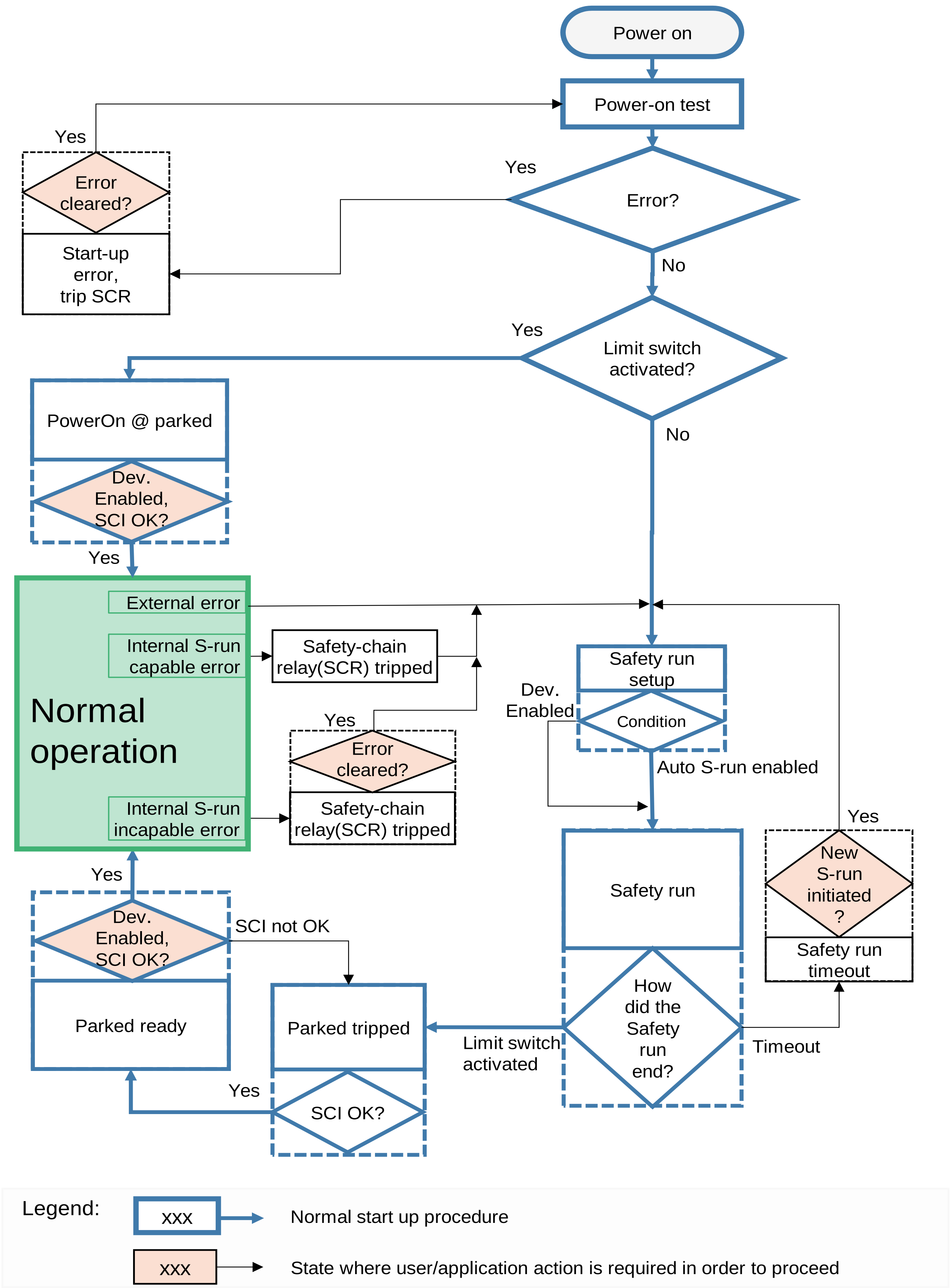



**Figure 31** Start up and operation states

The following scenarios are illustrated in Figure 31 on page 54:

- Power-on
- Errors occurred during normal operation, either internal or external

### 7.4.1 Power-on

Following is a description of the power on sequence:

1. When the IMD is powered on, it will start with a Power-on test that includes some self-tests as well as some external conditions (for example resolver connection). Fatal errors discovered at this stage will put the IMD in “Start-up error” state and will cause it to trip the safety-chain relays. If there are errors, the IMD will remain in “Start-up” error” until the error is fixed and cleared.
2. When the Power-on test is successfully completed the IMD checks the state of the limit switch:
   - If any limit switch is activated, the IMD waits for a device enabled state (Enable device command, and RUN digital input high), and the safety-chain inputs OK (both inputs are going high simultaneously).
   - If no limit switch is activated the IMD will change to “Safety run setup” state and execute the following sequence:
     i. Wait for device enabled, or if the Auto S-run (“auto safety run” function) is enabled, go directly to “Safety run”.
     ii. At safety run, the blade is pitched to stop position. When the safety run is concluded, the IMD checks how it was concluded. If there was a timeout, it will wait for initiation of a new Safety run. If the safety run ended with the activation of a limit switch, it will change to “Parked tripped” state.
     iii. At “Parked tripped” state the IMD checks/waits for the safety-chain inputs OK (both inputs are going high simultaneously), and changes to the “Parked ready” state
3. When device enabled state (Enable device command, and RUN digital input high), and the safety-chain inputs OK (both inputs are going high simultaneously) are present, the IMD will go to “Normal operation” state.

### 7.4.2 Errors during normal operation

When an error occurs during normal operation the IMD reaction depends on whether it external or internal error and if it is internal error, whether it is possible to perform a safety run or not. The safety-chain relays are always tripped when an internal error occurs.

Depending on the error, different paths are used.

#### *7.4.2.1 External errors*

External errors are errors in other part of the turbine that result in a turbine safety chain trip. In this case, the IMD will not trip the safety-chain relays and change to “Safety run setup” in order to perform a safety run immediately.

#### *7.4.2.2 Internal S-run capable error*

This path is used if an internal error is encountered in the IMD during normal operation and the IMD is capable of performing a safety run. The safety-chain relays are tripped and the IMD will change to “Safety run setup” in order to perform a safety run immediately.

The following errors causes this path:

| IMD display | IMD manager Error(s) field | Error description |
|---|---|---|
| None | None | Safety-chain input is missing (one or both inputs) |
| 3 | BUS TIMEOUT | Timeout has occurred on the CAN-bus. Timeout period defined in ms in register CAN_TIMEOUT (0xd0). This timeout period is active after the CAN-bus has reached operational state. |
| 4 | FEEDBACK | Bad or no feedback signal. The resolver circuit detects a fault. |
| 5 | UNDERVOLTAGE | The DC-link voltage is below DC-link Vlow, and above DC-link Vmin |
| 6 | MOTORTEMP | Motor temperature too high. Motor-temperature reached the limit specified in *M-temp.* |
| 7 | DEVICETEMP | Device temperature too high. The IMD temperature has exceeded 82 ºC. |
| B | CHARGER | Error in the charger (option). This error is generated automatically after warning B has been active during the Charger timeout period and not cleared Warning to error escalation is configurable. |
| C | HIGHVOLTAGE | Ballast resistor on for longer than 5 seconds. |
| F | BALLAST | Ballast circuit overload or current too high. The ballast resistor load has exceeded the configured value (overload), or the maximum current limit. |

#### *7.4.2.3 Internal S-run incapable error*

This path is used when there is no possibility to pitch the blade to stop position. The following errors causes this path:

| IMD display | IMD manager Error(s) field | Error description |
|---|---|---|
| 0 | BADPARAS | Parameter error. Specific parameters have unreasonable values. This error can only be reset by a power-cycle (Off-On) of the IMD. |
| 1 | POWER FAULT | A fault condition related to the IGBT module is detected. |
| 2 | RFE open | RFE-Switch off. RFE (Rotational Field Enable) input is in low state. |
| 8 | OVERVOLTAGE | DC-link voltage limit exceeded. Overvoltage condition is detected on the DC-link. |
| 9 | I _PEAK | Peak current excessive. The current to the motor exceeded the peak current limit for more than 8 ms. This error can be reset. |
| A | MOTOR OUTPUT | Speed uncontrollable. The IMD is not able to control the speed of the motor. |

| IMD display | IMD manager Error(s) field | Error description |
|---|---|---|
| E | HW-ERROR | Hardware component failure. Any of the following conditions has occurred:<br>• An internal supply voltage has failed<br>• Internal communication to power-module has timed out<br>• The controller has detected a power-module error-condition<br>• The internal current measurement has failed |

After the safety-chain relays are tripped, the error must be cleared before the IMD will continue. When the error is cleared, the IMD will continue and attempt to pitch the blade to stop position, and wait for safety-chain reset before going to normal operation again.

## 7.5 Hardware protection functions

The IMD has hardware (HW) protection functions which ensures that the output module is shut down when fatal errors occur, even if the processor is not running. The following errors trigger the HW protection:

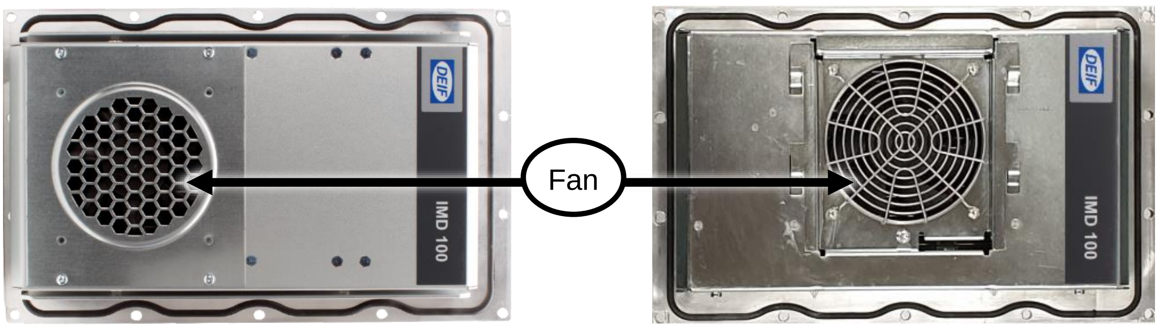
- Output module error including short-circuit (error 1)
- Output module temperature too high (error 7)
- DC-link voltage too high (error 8)
- Internal control circuit supply voltage failure (5 V DC or 15 V DC, error E)
- Ballast circuit short-circuit (error F)
- 24 V DC too low

When the HW protection is triggered the HW circuit in IMD will immediately shutdown the output module, no matter whether the processor is active or not.

## 7.6 Forced cooling with fan

The heat sink cover has a fan built in. It has two purposes:

1. Force cooling of the heat sink when the power module (IGBT) is too hot
2. Force cooling of the built-in ballast resistors (option)




IMD 122 B IMD 122 C

The IMD has a fan mounted at the back of the heat sink that forces extra air flow.

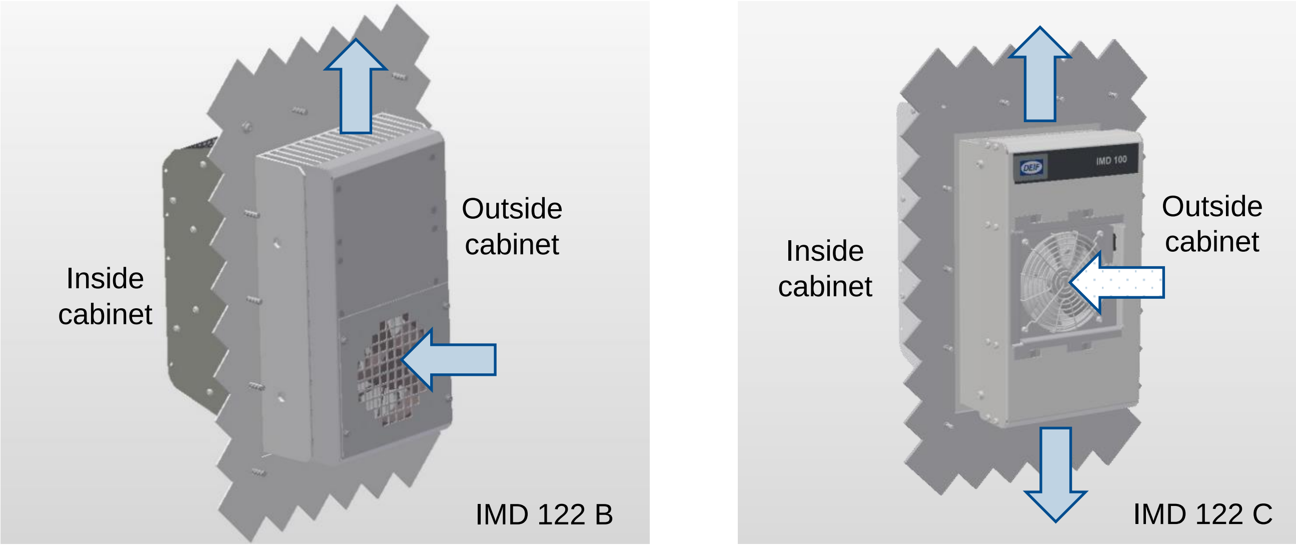



**Figure 32** Forced cooling with fan

**Fan control and connection**

IMD 122 C: The fan is internally connected and automatically controlled by the IMD.

IMD 122 B: The fan is connected to a digital output (DO 8 is recommended). Activating the output and thereby the fan, is done by the application SW or configuration. Both reason for start and values for start/stop can be configured.

## 7.7 Configuration and control

Due to the important safety functions of the IMD, it must be able to operate independently at all times. The IMD is controlled for the most part by acting on configured parameters, and to some extent on special commands. The configuration of the parameters is divided into two parts:

1. Parameter configuration, which is done through the IMD Manager. This is the major part of the configuration and contains all the parameters which are not changed dynamically during operation. Examples for these parameters are maximum current levels, PID control parameters, safety run timeout and speed and so on. All these parameters are saved in a configuration file, which is loaded by the IMD upon start.
2. Control during operation, which is done through the communication channel (CAN/CANopen) by the pitch application SW. An example for a typical parameter set by the pitch application SW, is when a new position for the blade motor is sent through the communication channel.

### 7.7.1 Configuration management

The IMD has multiple areas in its non-volatile memory (EEPROM) in which it is possible to store configurations. As illustrated in the following figure, all configuration management is performed through the IMD volatile memory (RAM), which holds the running configuration.

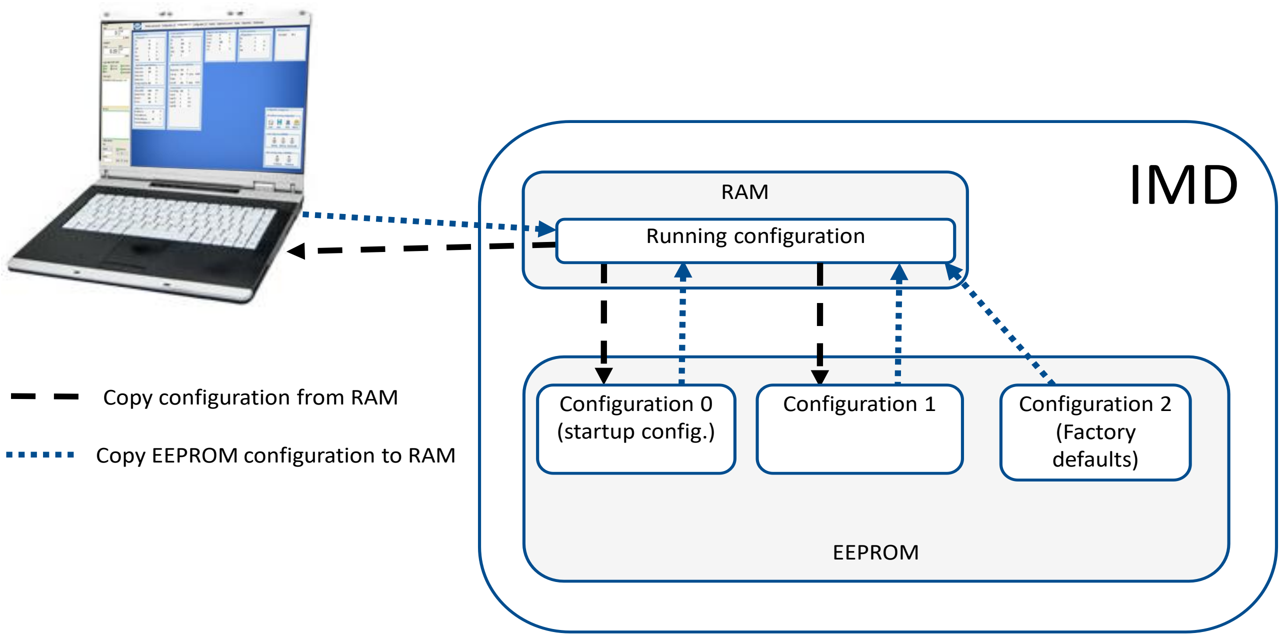



**Figure 33** Configuration management

As illustrated, there are three configurations that can be saved in the EEPROM (only two can be save by the user):

- Configuration 0 is the default configuration that the IMD loads to the RAM at startup. For IMD with built-in charger the configuration also contains charger parameters.
  This configuration is used as the running configuration.
- Configuration 1 can be used as a backup (charger parameters are not included).
- Configuration 2 is factory defaults (charger parameters are not included). These parameters cannot be changed.

It is possible to load another configuration using the IMD Manager. It can be any of the configurations stored in the EEPROM of the IMD, or another configuration stored on the PC or network drive.

When parameters are changed (either from the IMD Manager or using the CAN/CANopen interface), they are changed in the running configuration. The running configuration must be saved for the changes to be used the next time the IMD starts, or be retrievable from a saved configuration.

### *7.7.1.1 Charger option configuration*

The charger configuration is done separately, either manually or using a configuration script. The principle of running configuration and startup configuration in EEPROM is the same as for the IMD configuration, however, there is only one saved configuration for the charger.

## 7.8 Firmware update

There are two ways to update the IMD firmware (FW, application SW of the IMD):

1. **Update through the "Service" USB connector:** mainly used in production, service and lab.
2. **Update through CANopen:** mainly used in cases when updating remotely, thus eliminating the need for physical presence in the hub.

Using CANopen update method, requires development and implementation (by the customer) of update SW in the Pitch Motion Controller or the turbine's Main Controller.

.

# 8. IMD display description

The IMD display indicates the status of the IMD. The display contains a seven-segment display and a multicolour LED. Interpretation of the information is a combination of both display and LED.

NOTE In boot mode (firmware upgrade) the display and LED state are totally random, and may even be turned off. This is normal behaviour and does not indicate any error or faulty condition.

## 8.1 Status LED

The LED on the front panel of the IMD indicates the status of errors, warnings and safety chain inputs,


**Table 4 Status LED states**

| LED state | Active error | Active warning | Safety chain inputs |
|---|---|---|---|
| Off | None | None | Not OK |
| Green continuous | None | None | OK |
| Orange*/green flashing alternately<br>The display alternates between warning and operational state:<br>Orange (1/4 of cycle): the display shows warning number<br>Green (3/4 of cycle): the display shows operational state | None | Active warning.<br>Display shows<br>warning no. | OK |
| Red flashing | None | Active warning.<br>Display shows<br>warning no | Not OK |
| Red continuous | Active error. Display shows error no. | Don’t care | Not OK |
| Orange* continuous | Active error. Display shows error no. | Don’t care | OK |

* Orange may look like red or yellow depending on the angle of viewing.

## 8.2 MODE seven segment display

The seven-segment display shows the state of the IMD as well as which error or warning are active. See Status LED states table on page 60 for information about the relations between the LED and display.

### 8.2.1 The seven-segment display in normal state operation

The following table shows how to interpret the display information for normal state (LED green or off while flashing):

**Table 5 Display of operational state**

| MODE display | Dot / Line | Description |
|---|---|---|
|  | Flashing<br>Off | Normal operation – IMD is active.<br>IMD is not operating. Missing Voltage or hardware failure |
|  | Flashing<br>On<br>Off | The IMD is starting after a reset.<br>Drive enabled<br>Drive is disabled |
|  | on | The IMD is holding the blade motor in position (speed is zero) |
|  | on | The drive is turning in positive direction |
|  | on | The drive is turning in negative direction |
|  | Flashing<br>On<br>Off | The current is limited to *I-nom*<br>The current is limited to *I-max*<br>Normal operation, the current is equal to or bellow *I-nom* |
|  | On for 0.1 s | A new command was received through the CAN bus or the USB. |

The display will show any combination of the operational states. For example, when the motor turns in the positive direction:

| | |
|---|---|
| Example:<br> | Normal operation – IMD is active (dot flashing).<br>The drive is enabled (Bottom line on)<br>The motor is now turning in positive direction (right lower line) |

### 8.2.2 The seven-segment display when a warning is active

When a warning is active the display switches between showing the warning number/letter as described in the Warning list and description table on page 66 (when the LED is flashing orange and in on state), and the operational state as described in the Display of operational state table on page 61 (when the LED is in off state). The dot will be flashing as well.

The LED and display cycle is as follows:

| Dot | Status LED | 7 Segment display |
|---|---|---|
| ON | Orange | Warning number |
| OFF | Green | Operational state number |
| ON | Green | Operational state number |
| OFF | Green | Operational state number |

### 8.2.3 The seven-segment display when an error is active

When an error is active the display shows the error number/letter as described in the Error list and description table on page 63. The dot will be flashing as well.

# 9. Errors and warnings

The IMD has two ways to report faults: Errors and warnings:

| | Cause and action | Reset |
|---|---|---|
| Warning | Normal parameter limits are beginning to be crossed. No immediate action.<br>If not addressed, some warnings might escalate to errors after a timeout. | Automatically reset when the cause is removed. |
| Error | Severe violation of limits, causing a safety chain trip, and either an immediate motor stop or initiating a safety run. | Reset is done either from the controller, another USB device, or using the IMD Manager tool.<br>From the application SW or another USB device, writing any value to register 0x8E resets errors.<br>Reset is not possible if the cause is not removed. |

Both errors and warnings are displayed on the IMD display and the IMD Manager tool.

## 9.1 Error list

When an error is active it is displayed in the IMD Manager tool in the “Error(s)” field. Following is a list of errors:

**Table 6** Error list and description

| IMD display / Error bit no. | IMD Manager Error(s) field | Safety run performed | Error description |
|---|---|---|---|
| 0 | BADPARAS | No | Checksum (CRC) error when reading parameters from EEPROM. This error can only be reset by a power-cycle (OFF-ON) of the IMD. |
| 1 | POWER FAULT | No | A fault condition related to the IGBT module is detected. |
| 2 | RFE open | No | RFE (Rotational Field Enable) input is in low state. |
| 3 | BUS TIMEOUT | Yes | This error can be caused by three reasons:<br>• Timeout has occurred on the CAN-bus. Timeout period defined in ms in register CAN_TIMEOUT (0xd0). The bus time out error is enabled after the CAN bus has reached operational state.<br>• Communication error with the built-in charger (after the communication was initialised at start-up).<br>• Communication error with the built-in charger (option). When resulting from this reason, the error is generated automatically after warning 3 has been active during the Charger timeout period and not cleared. |

| IMD display / Error bit no. | IMD Manager Error(s) field | Safety run performed | Error description |
|---|---|---|---|
| 4 | FEEDBACK | Yes | Bad or no motor feedback signal. The resolver circuit detects a fault. |
| 5 | UNDERVOLTAGE | No | DC link voltage is lower than DC-link Vlow or DC-link Vmin. |
| 6 | MOTORTEMP | Yes | Motor temperature too high. Motor-temperature reached the limit specified in *M-temp.*<br>This error can be reset after the motor had cooled down. |
| 7 | DEVICETEMP | Yes | IMD temperature too high.<br>This error can be reset after the IMD had cooled down. |
| 8 | OVERVOLTAGE | Yes/No | DC-link voltage upper limits (HW DC-link overvoltage or DC-link Vmax) exceeded. |
| 9 | I_PEAK | No | The current to the motor exceeded the peak current limit for more than 8 ms. |
| A | MOTOR OUTPUT | No | The motor speed and direction cannot be controlled. The motor either races at full speed or cannot move. This error can be caused by four reasons:<br>• Non coherent parameter configuration.<br>• Mismatch between the direction from the drive and direction from the motor feedback.<br>• The phase sequence (W, V, U) is wrong.<br>• At least one of the phases from the IMD to the motor is disconnected. |
| B | CHARGER | | Error in the charger (option). This error is generated automatically after warning B has been active during the Charger timeout period and not cleared.<br>There are a number of charger errors that caused the warning that was escalated to the error. Possible errors are listed in section 9.1.1 on page 65. The active errors can be determined by reading the charger error register. |
| C | HIGHVOLTAGE | Yes | HIGHVOLTAGE warning was on more than approximately five seconds. |
| D | PRE_CHARGE | Yes | Pre-charge circuit failure. Mains power cannot be connected to DC link. |

| IMD display / Error bit no. | IMD Manager Error(s) field | Safety run performed | Error description |
|---|---|---|---|
| E | HW-ERROR | No | Hardware component failure. Multiple reasons can cause this error. For example:<br>• An internal supply voltage has failed<br>• Internal communication to power-module has timed out<br>• The controller has detected a power-module error-condition<br>• The internal current measurement has failed<br>Determination of the precise reason can only be done by experts, possibly also using the errors log. |
| F | BALLAST | Yes | This error can be caused by two reasons:<br>• Ballast resistor overload. The ballast resistor load has exceeded the configured value (Ballast-P). This error can be reset after a timeout has elapsed.<br>• Hardware failure in the ballast circuit or resistor |

### 9.1.1 Charger (option) errors

If the built-in charger option is mounted in the IMD, the following errors can be read from the charger warnings register:

| Error bit no. | Error text | Error description |
|---|---|---|
| 0 | OPENCIRCUIT | The charger detected open circuit. No safe energy source is connected, or a wire is broken. |
| 1 | SHORTCIRCUIT | The SE output is short-circuited.<br>For lead acid this error is raised when the SE voltage is less than 20% of nominal while charging. |
| 2 | CHARGERTEMP | The internal temperature of the charger is too high. |

## 9.2 Warning list

When a warning is active it is displayed in the IMD Manager tool in the “Warning(s)” field. Following is a list of warnings:

**Table 7** Warning list and description

| Warning bit no. | IMD Manager Warning(s) field | Warning description |
|---|---|---|
| 0 | BADPARA | Parameter error. This warning can be caused by the following reasons:<br>• Deceleration ramp too long when “Run” signal is deactivated<br>• Calculation of motor-parameters gives an unlikely result |
| 1 | Warning 1 | Not used |
| 2 | Warning 2 | Not used |
| 3 | COMCHARGER | Communication error with the built-in charger (option).<br>If this warning persists for the Charger timeout period, and the IMD is configured to escalate charger warnings to error, error 3 will be generated.<br>Sending “clear errors” every 8 seconds will delay error generation (until clearing errors is stopped) if the warning persists. |
| 4 | FEEDBACK | Unstable resolver signal. This warning is also active during blind safety run. |
| 5 | POWERVOLTAGE | Safe energy voltage is lower than SE Vmin. |
| 6 | MOTORTEMP | --Motor temperature high. Motor-temperature reached 87.5% of the limit specified in *M-temp*. |
| 7 | DEVICETEMP | IMD temperature high.<br>Internal components temperature exceeded 72 ºC. |
| 8 | Warning 8 | Not used |
| 9 | I_PEAK | Digital output driver is overheated |
| A | Warning A | Not used |
| B | CHARGER | Error in the charger (option).<br>There are a number of charger errors that caused the warning that was escalated to the error. These can be determined by reading the charger error register.<br>If this warning persists for the Charger timeout period, and the IMD is configured to escalate charger warnings to error, error 3 will be generated.<br>Sending “clear errors” every 8 seconds will delay error generation (until clearing errors is stopped) if the warning persists. |

| Warning bit no. | IMD Manager Warning(s) field | Warning description |
|---|---|---|
| C | HIGHVOLTAGE | Ballast resistor is on too long (> 100 ms) while the Mains is ON. If the pitch controller does not act for more than 5 seconds, a HIGHVOLTAGE error is generated, and the warning is reset. |
| D | Warning D | Not used |
| E | HW-warning | This warning can be caused by the following reasons:<br>• Current offset too high (too far from zero)<br>• Pt100 measurements are wrong, measured value cannot be trusted<br>• DI 10, 11 or 12 is high when not in manual operation mode (and manual mode is enabled). |
| F | BALLAST | The ballast resistor load is over 50% the configured maximum value. |

### 9.2.1 Charger (option) warnings

If the built-in charger option is mounted in the IMD, the following warnings can be read from the charger warnings register:

| Warning bit no. | Warning text | Description |
|---|---|---|
| 0 | BATTEMP | The battery temperature is more than 10ºC outside charging temperature limits (-20ºC to 50ºC). Lead acid only. |
| 1 | TEMPCHANNEL | The defined temperature sensor channel is not valid. |
| 2 | VinLOW | The input voltage from the DC-link is below 270 V DC. |
| 3 | Vin-VseLOW | The input voltage from the DC-link is not at least 15 V DC higher than the SE voltage. |
| 4 | LOWCURR. | The output current is too low compared to setpoint. |

## 9.3 Errors log

The IMD has an error log containing up to 20 entries. The log is a rolling log using “First In First Out” principle, which means that it always contain the latest 20 errors generated by the IMD, with the latest error at the top. The log entries are available in the IMD Manager and through CAN/CANopen. Each entry contains the following parameter values at the time the error occurred (see description of the register in the Integration manual for details):

| Information | Register | Description |
|---|---|---|
| IMD state | 0x02 | The state of the IMD |
| T-IGBT | 0x4A | The numeric representation of the IGBT temperature |
| N act (filt) | 0xA8 | The filtered actual speed value in units |
| N cmd ramp | 0x32 | Speed command after ramp in units |

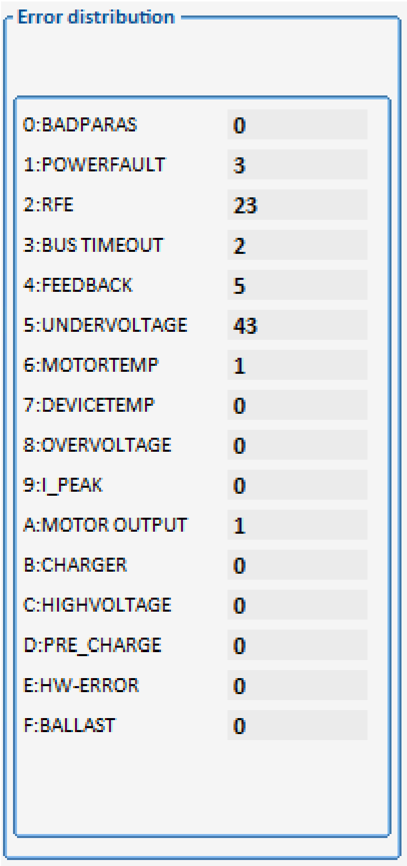
| Information | Register | Description |
|---|---|---|
| I act (filt) | 0x5F | Actual filtered current value in units |
| DC-link voltage | 0xEB | The filtered voltage of the DC-link in units |
| Drive status | 0x40 | Bit map representation of the state of the internal flags |
| Logic in block | 0x9B | Bit map representation of the state of digital inputs and some internal flags |
| Out block | 0x98 | Bit map representation of the state of digital outputs |
| Power board status | 0x63 | Status of the power board |
| Actual current limit | 0x48 | The current limit used at the time |
| Special command | 0x03 | The values of the special commands register. If a command was executed, the register contains the feedback for the command. |
| Error register value | 0x8F | Active errors at the time the error occurred |
| ID | N/A | Special ID information for the error |
| Timestamp 1 (Device enabled) | N/A | A relative time stamp (seconds) for the entry indicating the time elapsed since the last time the device enabled flag was set |
| Timestamp 2 (power) | N/A | A relative time stamp (seconds) for the entry indicating the time elapsed since the last power on of the IMD |
| Timestamp 3 (life) | N/A | A relative time stamp (seconds) for the entry indicating the time elapsed since the IMD was delivered from the factory, or if the IMD is older, since the first time a firmware supporting error history was installed. This time counter only counts time when the IMD 24 V DC supply (external or internal) is on.<br>For IMDs that were delivered with FW older than 1-08-0 (first FW with error log) the life time stamp is relative to the time when the first FW supporting error log was installed on the IMD. |

The last error further contains the following parameter values at the time the error occurred (Extra info):

| Information | Register | Description |
|---|---|---|
| Actual position | 0x6D | The actual position based on the resolver and rounds count |
| Actual position SSI | 0x6F | The actual position based on the SSI encoder count |
| 1st error in power board | 0x94 | First error (code) on power board since last clear error command. |

| Information | Register | Description |
|---|---|---|
| Ballast energy counter (L) and Current overload integral (H) | 0x45 | Values of Ballast energy counter (low 16 bits), Current overload integral (High16 bits), |
| SE voltage | 0x66 | Numeric value of the safe energy voltage |
| SE mid-point voltage | 0x61 | Numeric value of the safe energy mid-point voltage |
| T-air | 0x4B | Numeric value of the air temperature inside the IMD |
| (dbg) *temp | 0x9A | Dynamic pointer register used for debug by DEIF engineers |
| (dbg) *ptr1 | 0xB8 | Dynamic pointer register used for debug by DEIF engineers |
| (dbg) *ptr2 | 0xBA | Dynamic pointer register used for debug by DEIF engineers |
| (dbg)  ptr1 | 0xB7 | Dynamic pointer register used for debug by DEIF engineers |
| (dbg)  ptr2 | 0xB9 | Dynamic pointer register used for debug by DEIF engineers |

The error log also contains a distribution representation of all errors occurred during the “Elapsed time:life” (the time elapsed since the first FW supporting error history was installed), showing how many times each error appears in the log:



# 10. Revision history

Apart from editorial changes the following changes have been made in this revision:

| Date | Revision | Changes |
|---|---|---|
| 2020-09-25 | G | • "Charger (option) warning" in "Warning list" updated<br>• "Firmware update" section added to "General functions" |
| 2020-06-29 | F | • "Mains line choke" section added to "Mains supply and motor output" section<br>• "Charger error handling" section updated<br>• "Fault Ride Through (FRT)" updated<br>• "Safe energy (Ultra-capacitors only) discharging" added to "Safe energy"<br>• "Safety run" section updated (blind safety run, Errors which causes a safety chain trip table, Safety run while on safe energy)<br>• "DC-link monitoring and notifications" renamed to "DC-link function overview"<br>• "Pre-charge" sections added to "DC-link function overview"<br>• "Virtual limit switches" section added to "Position control"<br>• "Position pre-set" section in "Position control" corrected<br>• "Manual operation" section updated<br>• "Ballast resistor" section updated<br>• "Action on internal errors" updated<br>• Some information regarding fan configuration moved from "Forced cooling with fan" to the "Integration manual"<br>• "Error and warning lists" section renamed to "Errors and warnings" and updated with charger and charger related errors and warnings<br>• "Errors and warnings log" section added to "Errors and warnings" section<br>• "Basic of the IMD motor control" and "Position control stage" sections updated<br>• IMD power block diagram in "IMD power supply and loads" updated |
| 2019-09-03 | E | • Error and warning lists updated<br>• "Safety run while on safe energy" section updated<br>• "Fault Ride Through" added to "DC-link monitoring and notifications"<br>• Section "Motor temperature monitoring and protection" changed to "Motor monitoring and protection"<br>• "Motor connection monitoring" section added to "Motor monitoring and protection" section |

| Date | Revision | Changes |
|---|---|---|
| 2019-08-19 | D | • "Built-in functions" section updated with SE charger.<br>• A new section "Safe energy" added, containing "SE test" (previously "Safe energy test"), "Monitoring the safe energy source", and "Safe energy charging".<br>• "IMD main functions and role" updated with SE charger.<br>• "DC-link supply and ballast" section name changed to "IMD power: supply and loads", whole section updated with built-in power supply and SE charger.<br>• "DC-link Vlow" and "DC-link Vmin" updated in "DC-link monitoring and notifications".<br>• PTC sensor added to "Motor temperature" section.<br>• Manual operation added to "Motor control" section.<br>• "Brake control" section moved to the "Integration manual". A short description is added to "General functions" section. |
| 2018-04-06 | C | • Brake control drawings corrected and subsections titles changed<br>• Definition of I-nom corrected<br>• Status LED description updated<br>• DC-link monitoring and notification added<br>• Safety run updated<br>• "Start up and operation states" renamed to "Power-on and operation states"<br>• Error and warning lists updated |
| 2017-05-31 | B | • "Product user documentation" section updated<br>• "Product overview" section added<br>• Error and warning lists updated<br>• New function descriptions added: Pre-heating, Battery test, position pre-set and storage, field weakening, configuration and control, safety run, input/output logic<br>• "Start up and operation states" updated<br>• Display description updated |
| 2016-06-27 | A | This is the first version of the document. |

# 11. Product user documentation

The IMD product has an extensive user documentation, targeted towards different audience and product use stages.

The following documents are part of the user documentation:

**Table 8 IMD user documentation**

| Document | Target audience | Content |
|---|---|---|
| IMD 100 datasheet<br>Document no.: 4921260015 | Buyers and technicians of customers | Describes relevant specifications and give an overview of the IMD functions |
| IMD 100 function description<br>Document no.: 4189360013 | Mainly technicians and engineers of customers. | Describes the functions of the IMD. Gives the reader an understanding of the purpose of the IMD in a system, and which functions can be utilised in a pitch system. The functions are described so that the reader can understand what each function is used for. |
| IMD 100 integration manual<br>Document no.: 4189360015 | Engineers at customer R&D department | Describes how to integrate the IMD in a pitch system. Gives extensive knowledge about:<br>IMD SW (parameters and how to achieve specific functionality)<br>How to create customized parameter file for use in production<br>Requirements for external interfaces/components |
| IMD Manager installation instructions<br>Document no.: 4189360018 | Engineers at customer R&D department, as well as commissioners and service personnel | Describes how to install the IMD Manager. The IMD Manager is an application used to configure and control the IMD using the Service USB connector. |
| IMD Manager user manual<br>Document no.: 4189360019 | Engineers at customer R&D department, as well as commissioners and service personnel | Describes how to use the IMD Manager. The IMD Manager is an application used to configure and control the IMD using the Service USB connector. |
| IMD 100 installation instructions<br>Document no.: 4189360005 | Technicians at production site where the IMD is mounted in the cabinet/hub | Describes how to mount, connect and perform initial start, test, and configuration (using a configuration file) of the IMD at production. |
| IMD 100 initial configuration and verification manual<br>Document no.: 4189360016 | Commissioners or other personnel with similar qualifications, as well as service personnel (for SW upgrade) | Describes how to upgrade the IMD SW, how to load configuration file, and how to verify the IMD installation to the possible extent. |
| IMD 100 service and maintenance manual<br>Document no.: 4189360017 | Service and warehouse personnel | Describes preventive (scheduled) and corrective maintenance of the IMD, as well as storage requirements. |

| Document | Target audience | Content |
|---|---|---|
| IMD 100 installation checklist<br>Document no.: 4189360021 | Technicians at production site where the IMD is mounted in the cabinet/hub | Installation tasks with check boxes to document the tasks done during installation |
| IMD 100 configuration and verification checklist<br>Document no.: 4189360022 | Commissioners or other personnel with similar qualifications, as well as service personnel (for SW upgrade) | configuration and verification tasks with check boxes to document the tasks done during configuration and verification |
| Addendum to installation manual<br>Document no.: 4189360023 | Integration and installation personnel | Describes the how to replace a pitch drive when the IMD is equipped with Retrofit wiring harness var.1 |

The IMD 100 documentation is written anticipating an OEM (original equipment manufacturer) product use-cycle in a wind turbine. The envisioned cycle is described in the following figure. The description also explains the tasks, who is expected to execute the task, the location where the execution takes place and the supporting DEIF documentation for the task. Many details in these tasks depends on the actual implementation, which is why the IMD documentation will never stand alone.

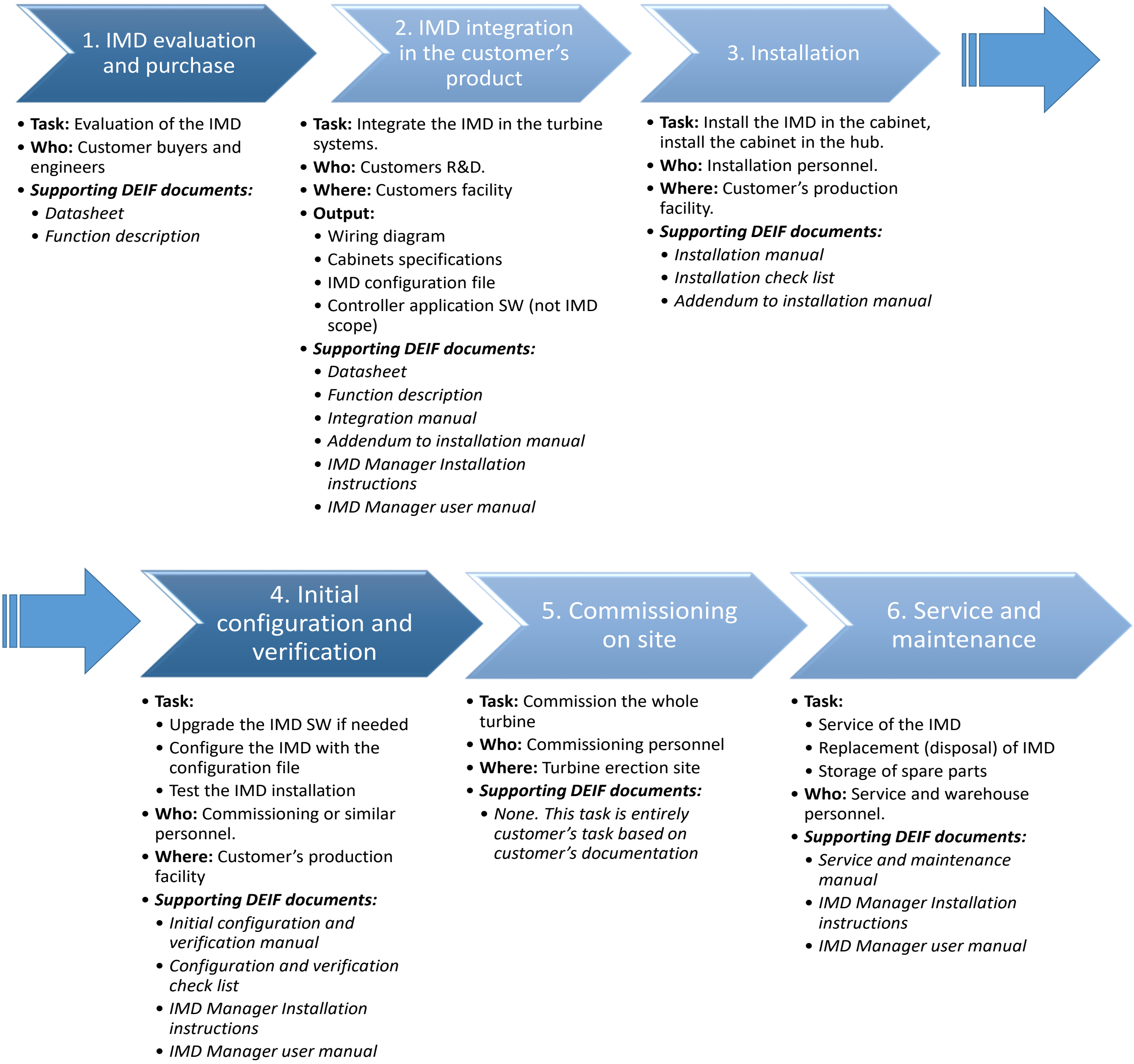



**Figure 34** Tasks and documentation overview

The described product use-cycle might not apply as is for all customers, but the tasks are universal and can therefore be adapted. For example, if the SW upgrade, configuration and verification is done during the turbine commissioning, the applicable documentation can be used at this stage instead of a separate stage at the end of production.

# 12. Glossary

## 12.1 Terms and abbreviations

| | |
|---|---|
| CAN | Controller Area Network (communication protocol) |
| EEPROM | Electrically Erasable Programmable Read-Only-Memory. Non-volatile memory |
| ESR | Equivalent Series Resistor |
| HVD | High Voltage Detection (Ballast resistor is ON) |
| HVRT | High Voltage Ride through (mechanism to ignore short period mains high voltage situation). |
| HW | Hardware |
| IGBT | Insulated-Gate Bipolar Transistor (used in the output module) |
| IMD | Integrated Motor Drive |
| LED | Light Emitting Diode |
| PMC | Pitch Motor Controller – a unit that controls the pitch of all blades' motors |
| RAM | Random Access Memory. Volatile memory |
| RFE | Rotational Field Enabled – enable IMD for operation |
| Safety run | The act of pitching a blade to a stop position due to an error or another safety related situation. |
| SCI | Safety-Chain Input |
| SCR | Safety-Chain Relay (output) |
| SE | Safe Energy (batteries or ultra-cap) |
| SSI | Synchronous Serial Interface |
| Stop position | The blades are placed out of the wind, thus bringing the rotor to a stop |
| SW | Software |
| UPS | Uninterrupted Power Supply used for power backup. |
| USB | Universal Serial Bus |
| VLMS | Virtual Limit Switch – Limit switches based on resolver position instead of a physical switch |

## 12.2 Units

| Unit | Unit Name | Quantity name | US unit | US name | Conversion | Alternative units |
|---|---|---|---|---|---|---|
| A | ampere | Current | | | | |
| ºC | degrees Celsius | Temperature | ºF | Fahrenheit | $T[ºC] = \frac{(T[ºF] - 32\,º) \times 5}{9}$ | |
| g | gram | Weight | oz | ounce | 1 g = 0.03527 oz | |
| Hz | hertz | Frequency (cycles per second) | | | | |
| kg | kilogram | Weight | lb | pound | 1 kg = 2.205 lb | |
| m | metre | length | ft | foot (or feet) | 1 m = 3.28 ft | |
| mA | milliampere | Current | | | | |
| mH | millihenry | Inductance | | | | |
| mm | millimetre | Length | in | inch | 1 mm = 0.0394 in | |
| ms | millisecond | Time | | | | |
| RPM | revolutions per minute | Frequency of rotation (rotational speed) | | | | |
| s | second | Time | | | | |
| V | volt | Voltage | | | | |
| V AC | volt (alternating current) | Voltage (alternating current) | | | | |
| V DC | volt (direct current) | Voltage (direct current) | | | | |
| W | watt | Power | | | | |
| Ω | ohm | Resistance | | | | |