ENGINEERING
TOMORROW

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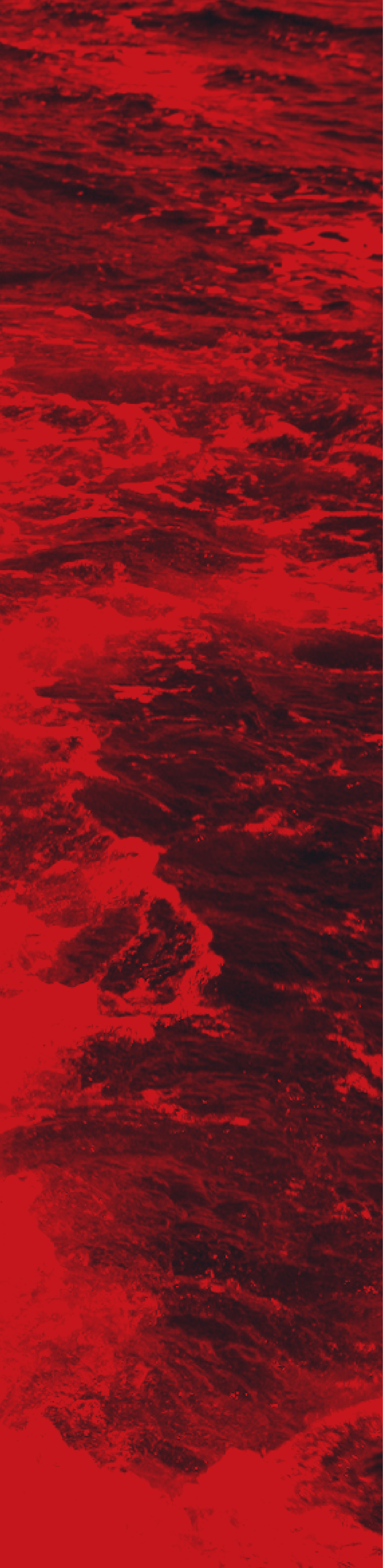
Application Paper

SynchStarter solution
A **synchronised by-pass motor starter** for variable pitch thrusters

Reduce starting current

for variable pitch thrusters using VLT® drives with synchronised bypass



Abstract

This paper describes the SynchStarter control solution, which involves a specific installation of frequency converter and synchroniser combined with a specific control method to start up a variable pitch thruster. This solution reduces the generator power required, and promotes longer equipment life due to less wear and tear.

The SynchStarter solution also applies to similar applications:

- Refrigeration compressors running at full nominal capacity – but where the compressor can be started with no load.
- Hydraulic power packs which can be started with no load.

Contents

SynchStarter solution

A synchronised by-pass motor starter for variable pitch thrusters, using the VLT® AutomationDrive FC 302 frequency converter and DEIF FAS-113DG synchroniser.

1. Introduction

An azimuth thruster is a marine propeller placed in a pod that can be rotated to any horizontal angle (azimuth), making a rudder unnecessary. This give ships better maneuverability than a fixed propeller and rudder system.

Azimuth thrusters driven by fixed speed electrical motors and with variable pitch control to control the speed of vessels are commonly used as propulsion systems for tugs, ferries and fishing vessels.

During startup the thruster draws a high current. The generator must be sized to manage the momentarily high startup current, up to eight times the nominal value, without severe voltage dips or generator trips.

Using SynchStarter - a strategic control solution using a frequency converter and synchroniser - a smaller generator can deliver the required starting current, by comparison to a motor with soft starter.

2. Application key requirements

The electrical motors driving the azimuth thruster are powered from the ship's generators which must be able to deliver the starting current when the motor is switched on. A conventional soft starter has a starting current which is approximately 3 or 4 times the nominal motor current lasting a few seconds. The high starting current may cause voltage dips or tripping generators onboard ships with weak electrical grids.

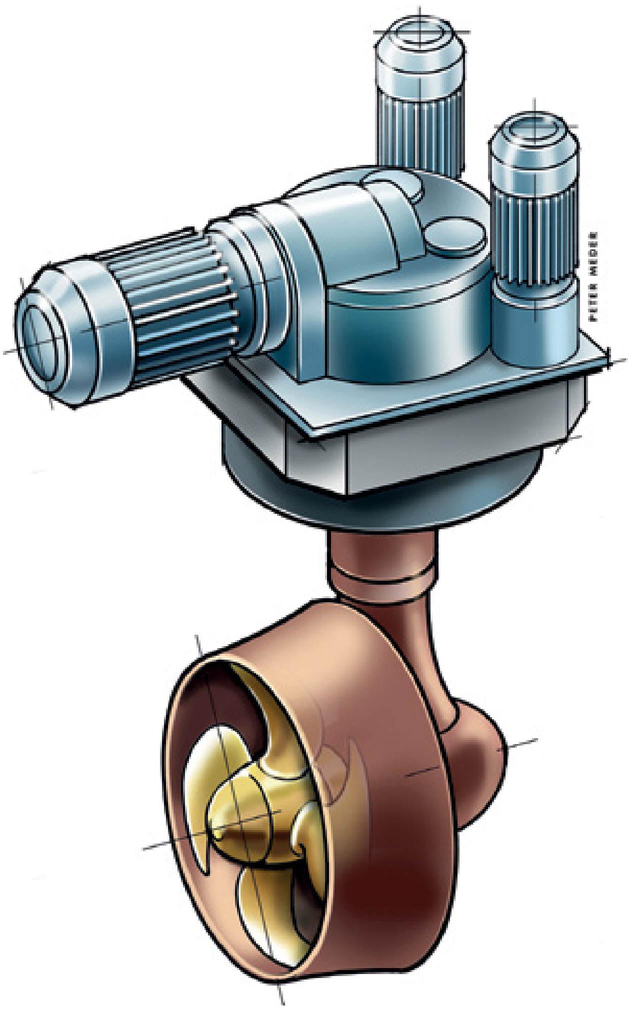
In this application it is important for stable startup and for long component life, that voltage dips and generator trips are avoided. The solution also aims to size generators as economically as possible.

1. For details of electrical wiring, see *3.2 Electrical circuit*
2. For details of startup sequence, see ***3.3 Smart Logic Controller (SLC) and sequence.***
3. For specification of the components required to implement SynchStarter, see ***3.4 Specification of components.***

3. Recommended solution

The solution is to use a VLT® frequency converter as motor starter to ramp up the motor speed with the propeller blades at zero pitch where the motor is almost unloaded – apart from the losses in the gearbox and the friction of the propeller movement through the water. It is thus possible to use a frequency converter which is rated at 30-50% only of the nominal motor current.

The output of the frequency converter is ramped up until it is synchronised with the ship's grid and the motor is then connected directly to the grid with a by-pass contactor. The thruster is now ready to operate.

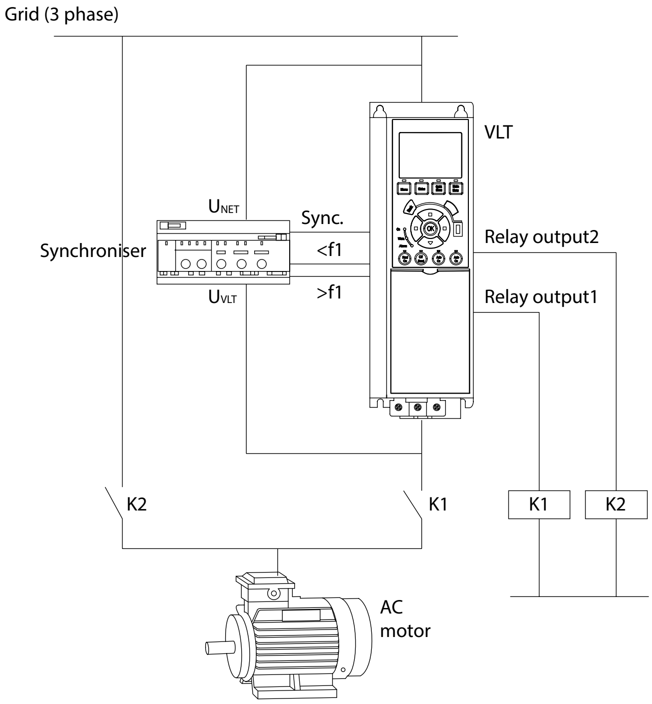


3.1. Principle of SychStart

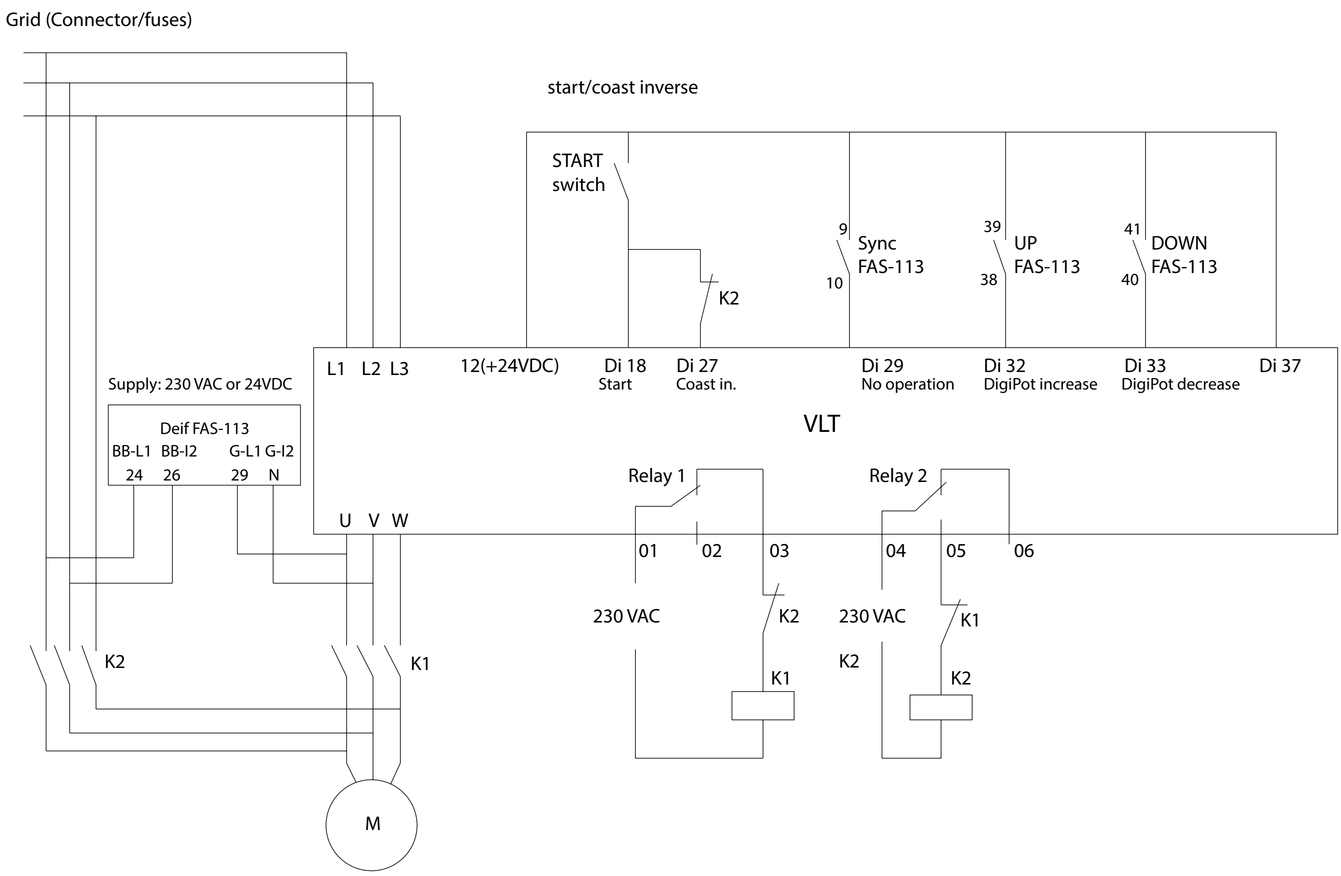
A Danfoss VLT® frequency converter controls the motor ramp up speed and the ramp up time. The DEIF FAS-113 synchroniser measures input phase and output phase.

After reaching 80% of the maximum grid frequency, the speed is controlled by two synchroniser relays (f↑ and f↓) and is ramped up slightly above the grid frequency.

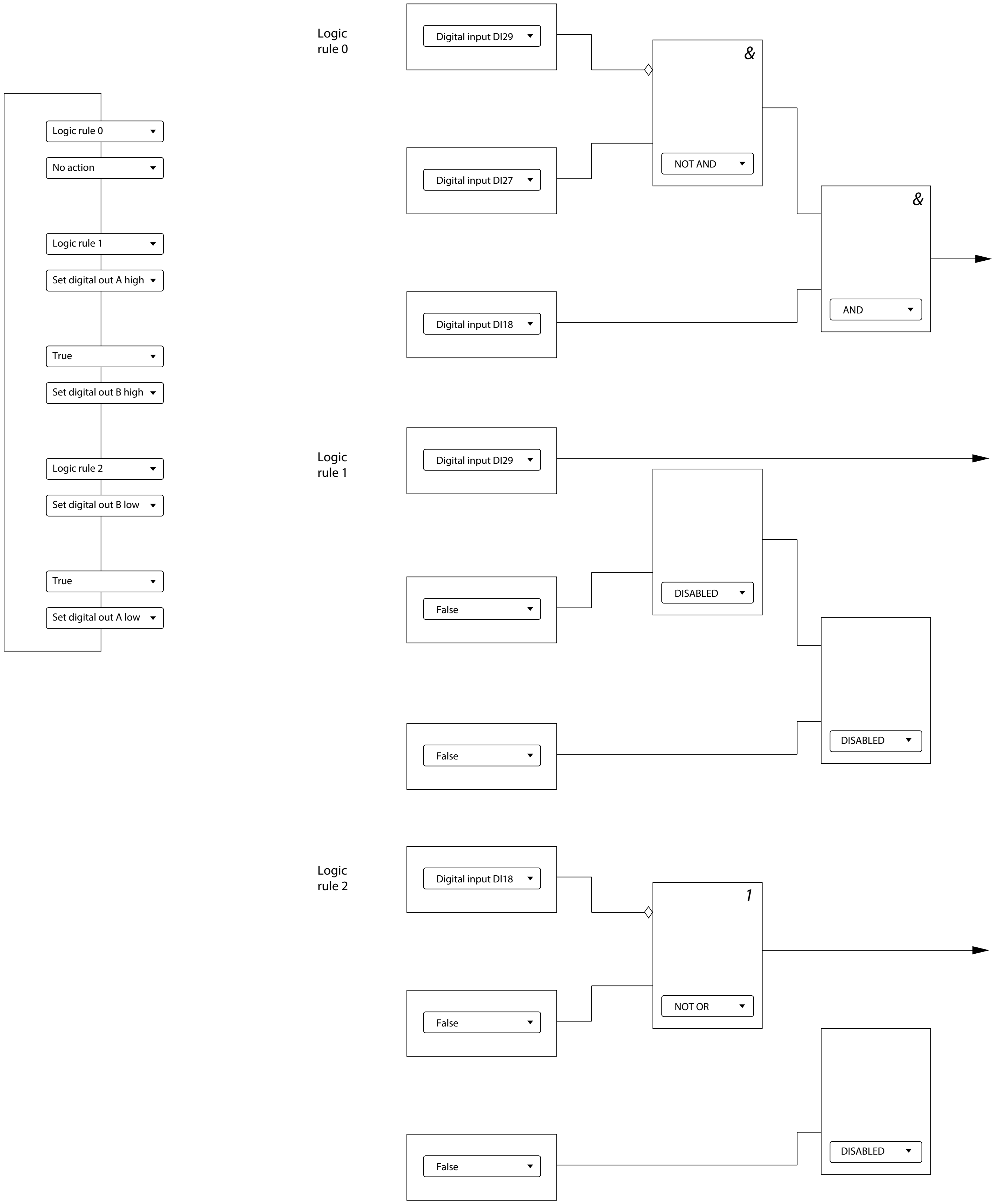
When the frequency output variables (voltage, frequency and phase) equal the input mains variables within a certain range, the output of the synchronisation relay gives a signal which is used to by-pass the frequency converter. The motor then connects direct on line (DOL) to the grid of ship.



3.2. Electrical circuit



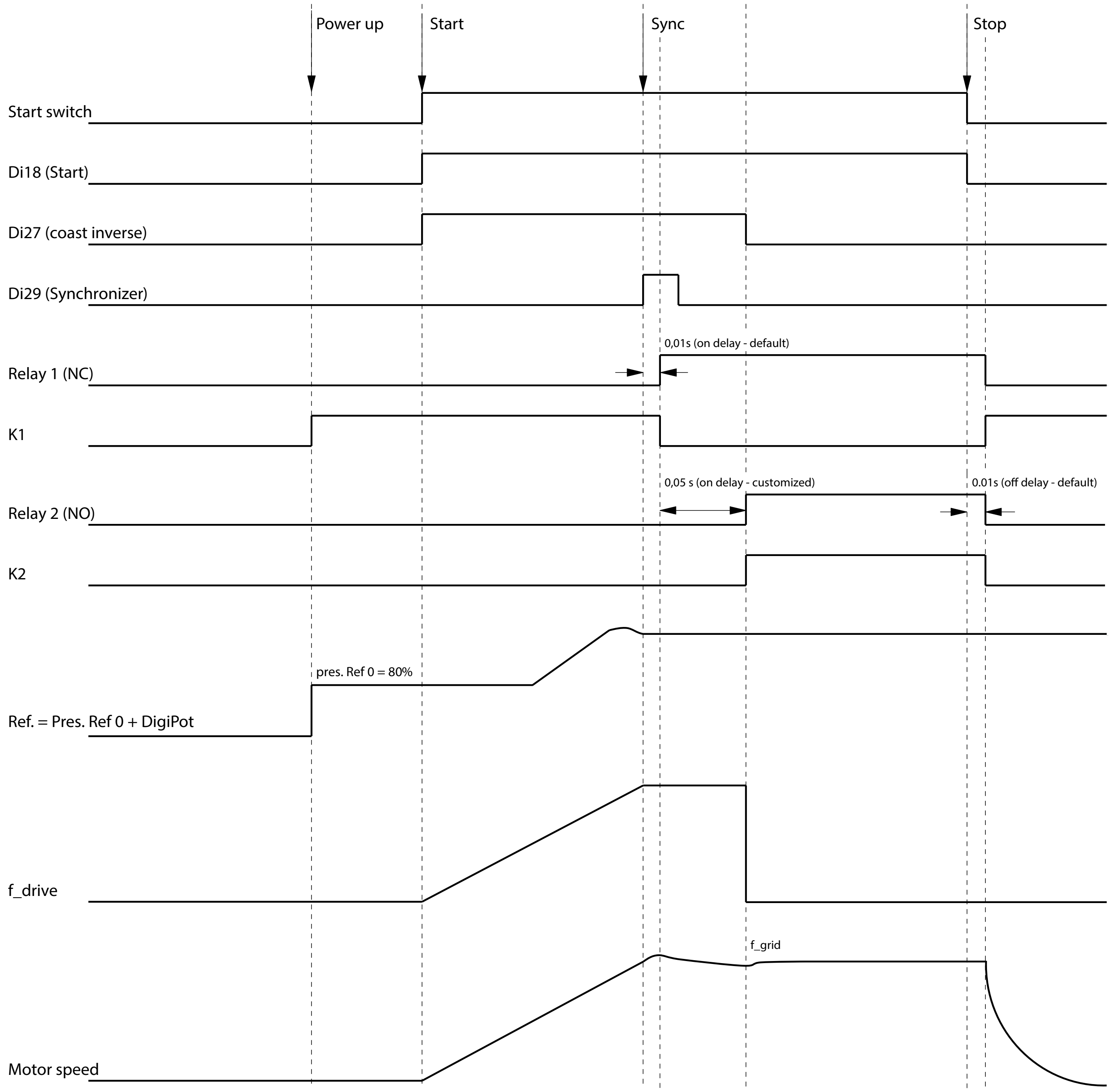
3.3. Smart Logic Controller (SLC) and sequence



The Sync relay output of the FAS-113 is connected to digital input 29 of the frequency converter. The SLC will state "SL digital out A" set to high which is actually connected to Relay out 1 (par. set 540.0) as well as Relay out 2 (par. set 540.1).

The switching time is set by par. set 541.0 (On Delay Relay 1 = 0.01 sec → default) and par. set 541.1 (On Delay Relay out 2 = 0.05 sec → customised).

After By Pass, when motor is DOL, the NO-contact of Relay 2 will coast the drive. Relays will be set to normal when drive is switched off by Di18.



Note:

1. The mechanical delay for relays K1 and K2 not considered in this timing diagram.
2. The On delay for relay 2 should be as short as possible (K1 should break before make for relay K2).

3.4. Specification of components

3.4.1. List of components

Component type	Abbreviation in drawings	Component name	Specification
Frequency converter	VLT	VLT® AutomationDrive FC 302*	Frequency converter is sized such that the maximum output current of the FC 302 equals the starting current of the unloaded motor. The starting current is approximately 30-40% of the nominal current of the motor.
Contactor 1	K1	e.g. Eaton series* DILM185A – DILH2600 or equivalent	3 pole NO-contacts (dimension for max. current of VLT) 1 NC-contact (for interlock). Change over time < 100 ms (Note: P_K1 can be smaller than P_K2)
Contactor 2	K2	e.g. Eaton series* DILM185A – DILH2600 or equivalent	3 pole NO-contacts (for switching motor DOL) 1 NC-contact (for interlock). 1 NC-contact (for Digital input – Coast inverse) Change over time < 100 ms
Synchroniser	DEIF FAS-113 DG	DEIF FAS-113 DG synchroniser with integrated RC-filters	See details below. 24 DC Supply: 2913010160-01, measuring voltage: 400 VAC 230 VAC Supply: 2913010160-02, measuring voltage: 400 VAC

** See also Appendix 1*

3.4.2. DEIF FAS-113DG Synchroniser

- The FAS-113DG synchronises the output of the FC 302 to the ship's grid.
  It closes a by-pass contactor when the voltage difference, the slip frequency and the phase angles are within the preset limits.
- DIN rail or base mounted
- Dimensions: W/H/D: 150 x 75 x 110mm
- Power supply: 230V AC or 24V DC

4. Features and benefits

Feature	Benefit
With SynchStarter, the starting current can be reduced to a low value, that is below the nominal motor current.	There is no need to oversize the ship generators to handle the starting current of the thruster motor.
Smooth speed ramp up	Mechanical wear on the thruster gearbox is reduced.
	There is no power loss in the frequency converter during operation.
Compact components	No additional panel space required
Synchroniser has built-in low pass filter	No additional hardware required
Equipment already has required marine type approvals	No additional approvals required

5. Customer reference – Gitte Henning

The "S 349 Gitte Henning #8" is designed for pelagic fishing. The trawler was built as a turnkey project by Western Baltija Shipbuilding, Lithauania and delivered in April 2014. The ship owner is Henning Kjeldsen in Skagen, Denmark.

As the sizing of the generators was optimised for best energy efficiency – without a large power reserve - the ship's generators were too small to start the 1.47 MW variable pitch azimuth thruster with a soft starter or star/delta starter. It was out of the question to install larger generators.

Danfoss and the electrical contractor, SEMCO Maritime A/S helped to find a practical solution. Using a VLT® frequency converter to limit the starting current, whilst starting the thruster with the propeller blades in neutral position, it was possible to retain the specified generators.

The solution required a 560 kW VLT® AutomationDrive frequency converter with a DEIF synchroniser and bypass contactors. Both could be installed in the thruster switchboard with no requirement for additional space.

Additional Danfoss products installed included two 400 kW VLT® frequency converters for the refrigeration compressors, and an active harmonic filter to meet the class requirements

S 349 Gitte Henning #8

Key benefits for the ship:

- No voltage fluctuations occur, as the starting current is limited to max. 630 A and the by-pass peak current is only 110%.
- DEIF FAS-113DG has a built-in low pass filter, so no additional hardware is needed.
- The VLT® and DEIF units already had the necessary marine type approvals.

Facts about the trawler "Gitte Henning":

- RSW fishing vessel for pelagic fish
- 13 refrigerated seawater tanks (RSW), with total capacity of 3200 cubic metres
- Length: 86.5m
- Width: 17.9m
- Size: 4138 GRT
- Main engine: Wärtsilä, 5220 kW

S 349 Gitte Henning

6. Links

Frequency converter manuals, Danfoss:

Installation and commissioning:

- VLT® AutomationDrive FC 302 Operating Instructions

Planning and dimensioning:

- VLT® AutomationDrive FC 302 Design Guide

Download here:
http://vlt-drives.danfoss.com/Support/Technical-Documentation/

Synchroniser manuals, DEIF:

Installation and commissioning:

- User manual DEIF FAS-113 DG

Download here:
http://109.238.53.160:8080//Publication/DownloadDocument.ashx?id=R1bf3f53b0-b2a7-4753-bd32-8217410996d5&FileName=_FAS-113DG__installation_instructions_4189340126_UK.pdf

Appendix 1

Installation and commissioning

Connect frequency converter and hardware according to 3.2 Electrical circuit.

For installation and commissioning instructions refer to

- VLT® AutomationDrive FC 302 Operating Instructions
- User manual DEIF FAS-113 DG

IMPORTANT!

1. The DEIF FAS-113 DG will **NOT** check the phase sequence. Before commissioning: check phase sequence of input (L1, L2, L3) and output (U, V, W) of frequency converter.
2. Be sure that FAS-113 DG is connected in the right way. Don't mix up the terminal connections.

(Supply) Input	Grid voltage FAS-113	Output voltage FAS-113	(VLT) Output
L1	BB-L1 (24)	G-L1 (29)	U
L2	BB-L2 (26)	G-L2 (31)	V

Commissioning checklist

Check wiring according to 3.2 Electrical circuit.
Pay special attention to L1, L2, L3 versus U, V, W and the connection of the DEIF FAS-113 DG Synchroniser.

1. Check Phase Sequence of the motor direct on line (DOL) and output of Frequency Drive manually.
2. Power up
3. Download the newest software into the drive with MCT-10
4. MCT-10: Set up the drive to the appropriate type, power size, software version
5. Adjust general motor settings according to name plate of AC-motor.
   Notice: some of the parameters cannot be filled in exactly while motor power in theory is too big for the drive.
6. When all checkups are done, start the SynchStarter via the starting switch (connected to Di 18/19)
7. During start up, check the DEIF FAS-113 DG synchroniser. Check LEDs.

a) POWER indicates supply voltage (230 VAC or 24 VDC)
b) UBB indicates main voltage.
c) UG indicates VLT output voltage. This LED will light up when UVLT-output = approx. 230 VAC at 30 Hz.
d) Δf lights up when the VLT output frequency meets main frequency (margin is adjustable with pot. frequency (0.1-0.5 Hz)
e) ΔU lights up when VLT output voltage meets main voltage (margin is adjustable with pot. VOLTAGE (2 – 12%)
f) SG LEDs blink when FAS-113 DG controls the VLT frequency.
g) SYNC LED blinks when VLT output is in sync with mains.

8. If by-passing is not very smooth, adjust parameter 541.1 On Delay, Relay (relay 2)
9. Default starting points of pots: Tn: 12 o'clock; Xp: 5 o'clock; FREQ: 5 o'clock; VOLTAGE: 12 o'clock; BREAKER: 12 o'clock.

Recommended synchroniser settings

Setting of		Range
T_N	Control pulse length	25...500
X_p	Proportional band	±0.25... ±2.5 Hz
f_{set}	Slip frequency	0.1...0.5 Hz
ΔU_{max}	Acceptable voltage difference	±2... ±12% of U_{BB}
T_{BC}	Breaker closure time	20...200 ms

LEDs

LEDs		Light
U_G	Generator voltage*	Green when value is within the acceptable range Switched off, if outside this range
U_{BB}	Busbar voltage*	
Δf	Frequency difference*	
ΔU	Voltage difference	
SYNC	Synchronising	Yellow, when relay is activated
SG ▲	Increased speed (frequency)	
SG ▼	Decreased speed (frequency)	

** When all 4 LEDs are lit, the conditions for transmission of synchronisation pulses are fulfilled.*

Note: In addition to the status (4 conditions above) the FAS-113DG supervises the actual df/dt (ROCOF). If this is too large, no synchronisation pulses will be transmitted, and the Δf LED flashes.

The allowable df/dt ratio depends on the fset setting:

- fset 0.1 Hz corresponds to a df/dt ratio of max. 2.5 Hz/s
- fset 0.5 Hz corresponds to a df/dt ratio of max. 12.5 Hz/s

TN determines the duration of the control pulse. A short TN is applied for very fast-reacting speed governors. A long TN is applied for slowly-reacting speed governors.
Recommended starting point: 200 ms.

If the frequency tends to oscillate around the fset value:

1. Reduce TN (min. pulse: 25 ms), until stable control is obtained,
2. Reduce Xp (for example to 1 Hz), until the control loop becomes unstable again
3. Select a suitable Xp value between these values (for example to 2.5 Hz).

Xp determines the span within which the pulse ratio changes proportionally to the frequency deviation from the fset value.
Recommended starting point: 1.25 Hz

fset is set to the required slip frequency.
Set to 0.5Hz to ensure a swift synchronisation (emergency generators).
Set to 0.1Hz to ensure a very accurate synchronisation.
Recommended starting point: 0.5 Hz

ΔUmax determines the acceptable difference between input and output
voltages. Set to ±2% at a stable network. Set to ±12% when synchronising at an unstable network
Recommended starting point: 7%

TBC is set to the circuit breaker closure time, indicated on the circuit breaker.
Recommended starting point: in the middle

Recommended frequency converter parameter settings

ID	Name	Setup	
101	Motor Control Principle	U/f or VVC+	VVC+ is the best option. Use U/f only when it's necessary to set the motor voltage to a certain level in order to synchronise.
155.1	U/f Characteristic - U	400	The output voltage of the frequency converter at nominal speed. This parameter is very important and must not deviate to much from the supply voltage. If the deviation is to big than the synchronising relay will not switch and drive will not be by-passed. Value of this parameter is depending on supply voltage and if motor is connected in delta or star.
162	Slip Compensation	0	
172	Start Delay	0 – 60 sec.	Use Start Delay in U/f mode (101) to prevent that drive will start while motor is coasting.
173	Flying Start	Enabled	Use Flying Start in VVC+ mode to enable the drive to catch a motor spinning .
217	Over-voltage Control	Enabled	
303	Maximum Reference	51 Hz / 61 Hz	The maximum reference must be a higher than the grid frequency. The DEIF FAS-113 will ramp up the speed to fgrid + Δf (Δf = 0,1..0,5 Hz)
310.0	Preset Reference	80%	The frequency converter will ramp up to 80% of Maximum Reference. When Preset reference is reached then FAS-113 will take over the speed control by using the digital potentiometer inputs.
341	Ramp 1 Ramp Up Time	30	
501	Terminal 27 mode	Input	
502	Terminal 29 mode	Input	
510	Terminal 18 Digital Input	Start	
512	Terminal 27 Digital Input	Coast inverse	
513	Terminal 29 Digital Input	No operation	Di29 is synch pulse for transfer of motor to main supply via SLC
514	Terminal 32 Digital Input	DigiPot increase	Controlled by FAS-113, relay f↑
515	Terminal 33 Digital Input	DigiPot decrease	Controlled by FAS-113, relay f↓
540.0	Function Relay (relay 1)	SL digital output A	See 4.2 Smart Logic Controller (SLC)
540.1	Function Relay (relay 2)	SL digital output B	See 4.2 Smart Logic Controller (SLC)
541.0	On Delay, Relay(relay 1)	0.01 s Factory set.	See 4.2 Smart Logic Controller (SLC)
541.1	On Delay, Relay(relay 2)	0.05 s	Secure K1 break before K2 make
1300	SL Controller Mode	On	Activate Smart Logic Controller (SLC)
1301	Start Event	True	SLC is working all the time
1302	Stop Event	False	SLC is working all the time
1340.0	Logic Rule Boolean 1	Digital input Di 29	Synch pulse from DEIF is present
1340.1	Logic Rule Boolean 1	Digital input Di 29	Synch pulse from DEIF is present.
1340.2	Logic Rule Boolean 1	Digital input Di 18	Start input for frequency converter is present.
1341.0	Logic Rule Operator 1	NOT AND	
1341.2	Logic Rule Operator 1	NOT OR	
1342.0	Logic Rule Boolean 2	Digital input Di 27	Coast inverse input for frequency converter is present
1344.0	Logic Rule Boolean 3	Digital input Di 18	Start input for frequency converter is present.
1351.0	SL Controller Event	Logic Rule 0	
1351.1	SL Controller Event	Logic Rule 1	
1351.3	SL Controller Event	Logic Rule 2	
1352.0	SL Controller Action	Set digital out A high	Activate relay 01 (K1)
1352.0	SL Controller Action	Set digital out B high	Activate relay 02 (K2)
1352.0	SL Controller Action	Set digital out B low	Deactivate relay 02 (K2)
1352.0	SL Controller Action	Set digital out A low	Deactivate relay 01 (K1)

Selection Table: Drives and Contactors

Note:
This table only provides an approximate indication of the drives and contactors to use.
Always check or measure real motor current in no-load and loaded condition.

3 Phase AC Motor 400 V/50Hz			FC 302 (380-500VAC) High overload		FC 302 (380-500VAC) Normal overload		Contactors (example Eaton)	
Power [kW]	I_{nom} [A] Motor → DOL	I_{unload} [A]* Motor → VLT	P[kW] VLT	I_{max}[A] VLT 160%-60s	P[kW] VLT	I_{max}[A] VLT 110%-60s	K1 VLT	K2 DOL
90	180	72 (40%)	30	98	37	80	DILM95	DILM185A
110	220	88 (40%)	30	98	45	99	DILM95	DILM225A
132	264	106 (40%)	37	117	55	117	DILM150	DILM300A
160	320	125 (39%)	45	144	75	162	DILM150	DILM400
200	400	152 (38%)	55	170	75	162	DILM185A	DILM500
250	500	185 (37%)	75	235	110	233	DILM250	DILM570
315	630	227 (36%)	75	235	110	233	DILM250	DILM650
355	710	249 (35%)	90	266	132	286	DILM300A	DILM750
400	800	272 (34%)	110	318	132	286	DILM400	DILM820
450	900	297 (33%)	110	318	160	347	DILM400	DILM1000
500	1000	320 (32%)	132	390	160	347	DILM400	DILH1400
560	1120	347 (31%)	132	390	200	435	DILM400	DILH1400
630	1260	378 (30%)	132	390	200	435	DILM400	DILM1600
710	1420	426 (30%)	160	473	250	528	DILM500	DILM1600
800	1600	480 (30%)	200	593	250	528	DILM650	DILH2000
1000	2000	600 (30%)	250	720	315	647	DILM750	DILH2200

**Assumption*

I_{unload} [A] = 30% at 90 kW motor + 10% of mechanical losses = 40%
I_{unload} [A] = 20% at 1000 kW motor + 10% of mechanical losses = 30%

indicates nominal motor load
indicates no-load motor current level

Notes:

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Danfoss VLT Drives, Ulsnaes 1, DK-6300 Graasten, Denmark, Tel. +45 74 88 22 22, Fax +45 74 65 25 80www.danfoss.com/drives, E-mail: info@danfoss.com