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AP13: Crane Drive System Configuration

SINAMICS S120 SLM Sizing and Configuration

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1 Introduction

1.1 Overview

In crane drive applications with SINAMICS S120 three different infeeder options are available:

- Basic Line Module (BLM), single or double quadrant diode or thyristor bridges
- Smart Line Module (SLM), unregulated 4-quadrant IGBT rectifier - regenerative feed/feedback unit
- Active Line Module (ALM). a self-commutated 4-quadrant rectifier - regenerative feed/ feedback, actively controlled line converter,

This document formulates requirements to the configuration of SLM drive systems for crane applications. The configurations presented are typical for ship-to-shore and rail-mounted gantry container cranes. In principle they also apply to other crane types such as bridge- or goliath cranes.

1.2 Requirement to drive system configuration

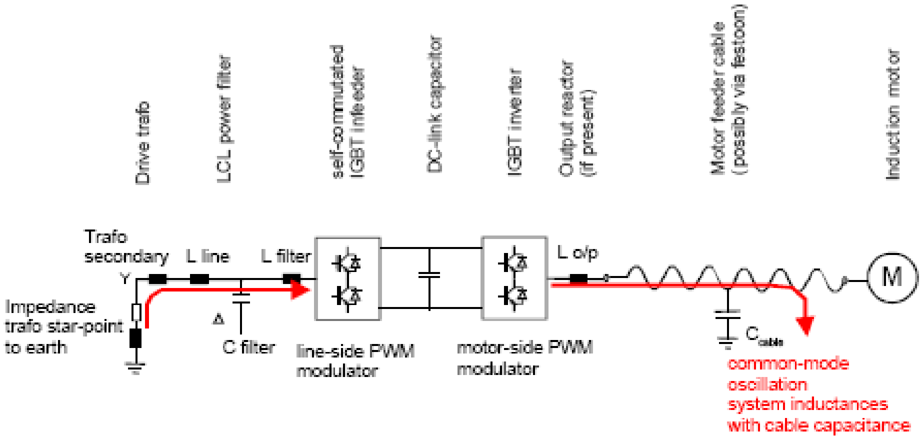
Drive systems with SLM infeeders need to be configured as follows:

1. Allowed drive system supply voltages 380-480 VAC. Until further notice the use of 500-690V SINAMICS S120 drive systems is not permitted.
2. Insulated earth (IT supply):
   - removal connection bracket for interference-suppression capacitor from the line’s phase conductors to ground,
   - insulation resistance monitoring is needed to comply with IEC60204-32.
3. Re-inforced winding insulation is necessary for motors with a rated winding voltage equal to or higher than 500V.
4. Minimal capacitance of the transformer secondary winding to ground
   Note: I DT MC CR can provide a detailed requirement specification for the supply transformer.
5. Minimal earth capacitance in cable connections between inverter and motor:
   - use cables with minimum capacitance between phase and earth, e.g. Prysmian’s PROTOFLEX EMV-FC 2YSLCY-J screened 3x70+3x10 with 290nF/m,
   - installation method ‘C’ or ‘E’ as per IEC60204-32, annex B.1.2.

2 Premature equipment failure due to parasitic effects

Depending on the crane's mechanical structure and the properties of the electrical cables used, the cable between the inverter and the motor may have relevant capacitances (phase-to-earth). In this case the switching of the line-side and motor-side converters may excite a resonance circuit formed by the inductances and the cable capacitance (see principle circuit below).

Figure 2-1 Principle circuit common mode oscillation



If the system components are not compatible, the peak voltage stress on motors and cables or the peak current stress in IGBT converters and transformers might lead to premature equipment failure.

Cable installation requirements and length limitations as per "Cabling and Wiring Guidelines for Cranes", Rev. 1.1, dated 23. March 2007 are to be observed.

Deviation from the above requirements might be required for certain cranes types, e.g.

- Ladle cranes fed from distribution busbars
- STS cranes with trolley or hoist motors on the trolley (SPT and MOT design)

For such cases a detailed assessment of the drive system configuration is to be performed and approval by DI MC GMC CR is required.

3 Use of SLM as a feeding at Crane's applications

Due to the operating principle of the 6-pulse three-phase bridge circuit, the Smart Infeed causes relatively high harmonic effects on the supply system. The line current contains a high harmonic content with harmonic numbers h = n * 6 ± 1, with n = 1, 2, 3, etc. The harmonic currents produced in rectifier operation (motor operation) are identical as those of the Basic Infeed and have the same spectral distribution. The Total Harmonic Distortion factor of the current THD(I) is typically in the range from about 30 % to 45 %.

In regenerative operation, the 5th harmonic decreases significantly but all the others increase slightly so that the Total Harmonic Distortion factor THD(I) only decreases by a few percent. The use of Line Harmonics Filters for the reduction of harmonic effects is not permissible with Smart Infeeds due to the different spectrums of the current harmonics in rectifier operation (motor operation) and in regenerative operation.

A reduction of the Total Harmonic Distortion factor (THD)(I) to a value of approx. 10% can only be achieved with 12-pulse circuits, i.e. by supplying two Smart Line Modules from a three-winding transformer with a 30° phase displacement between its secondary voltages.

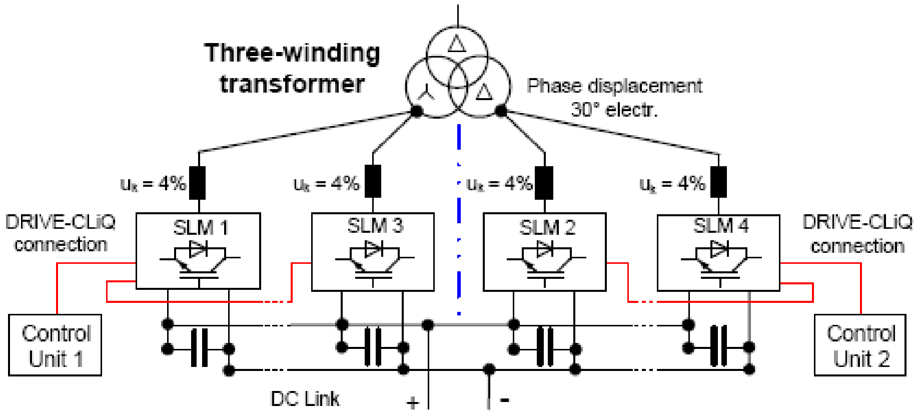
Due to these facts the 12-pulse rectifier circuit is preferred at use of SLM’s into crane applications.

A 12-pulse rectifier circuit is created when two identical 6-pulse rectifiers (SLM’s) are supplied from two different supply systems, whose voltages are out of phase by 30°. This is achieved with the use of a three-winding transformer, whose one low-voltage winding is star-connected and the other delta-connected.

The harmonic effects can be significantly reduced with 12-pulse circuits as compared to 6-pulse circuits. Due to the phase shifting of 30° between the two secondary voltages, the harmonic currents with harmonic numbers h = 5, 7, 17, 19, 29, 31, 41, 43, ... , which are still present in the input currents of the 6-pulse rectifiers, compensate one another so that theoretically only odd harmonic currents and voltages that cannot be divided by 3 with the following numbers h occur at the PCC on the primary side of the three-winding transformer: h = n * 12 ± 1 where n = 1, 2, 3, ... also i.e. h = 11, 13, 23, 25, 35, 37, 47, 49, ...

However, as in practice there is never a perfectly symmetrical load distribution between the two rectifiers, it must be assumed that harmonic currents with harmonic numbers h = 5, 7, 17, 19, 29, 31, 41, 43, … are also present with 12-pulse circuits, but with amplitudes that are maximum 10 % of the corresponding values of 6-pulse circuits.

Figure 3-1 Parallel 12-pulse SLM infeeder concept



As Smart Line Modules have no electronic current sharing control, three-winding transformer, power cabling and line reactors must meet the following requirements in order to provide a balanced current:

- Three-winding transformer must be symmetrical, recommended vector groups Dy5d0 or Dy11d0.
- Relative short-circuit voltage of three-winding transformer uk ≥ 4 %.
- Difference between relative short-circuit voltages of secondary windings Δuk ≤ 5 %.
- Difference between no-load voltages of secondary windings ΔV ≤ 0.5 %.
- Use of symmetrical power cabling between the transformer and the Smart Line Modules (cables of identical type with the same cross-section and length)
- Use of line reactors with a relative short-circuit voltage of uk = 4 %.

A double-tier transformer is generally the only means of meeting the requirements of a three-winding transformer for this application. Alternative solutions for obtaining a phase displacement of 30 °, such as two separate transformers with different vector groups, cannot be used due to the inadmissibly high tolerances involved.
Due to the phase displacement of 30º between both secondary winding systems and the control of both systems by separate Control Units, it is generally not possible to ensure, that both systems contribute equally to the pre-charging of the connected DC link. In order to prevent the overloading of individual systems during pre-charging, the 12-pulse parallel connection of Smart Line Modules must be dimensioned in such a way that each system is individually able to pre-charge the DC link.

The current reduction from the rated value for individual Smart Line Modules in a parallel connection is 7,5 %.

4 SLM behavior during line fluctuations

For line supply under-voltages the SLM behaves as outlined in the catalog PM21. "rated voltage". The product catalog defines the minimum SLM input voltage levels for the "400V" voltage range as 3AC380V-10% with a lowest permissible voltage of 3AC380V-15% for less than one (1) minute. The maximum possible rated power is reduced to 90% of the rated values.

For under-voltages down to 85% of the rated voltage all auxiliary systems work sufficiently. If the voltage dips are expected to exceed 85 % for both main contactors and circuit breakers a UPS has to be added for buffering the control voltage supply to the main switching elements of the SLM. If the undervoltage occurs longer than 1 min also the fans have to be connected to a UPS. Up to 1 minute the reduction of the cooling (fan speed) is acceptable.

5 SLM supply voltage level

As described in product catalog, the maximum SLM input voltage levels for the "400V" voltage range as 3AC480V+10%.
Based on aspects as outlined in section 3, SLM crane drive systems should to further notice be engineered using "400V" series inverters (type number 6SL3330-7TExx-xxxx). In this case motors with a rated winding voltage up to 3AC500V may be used. Re-inforced winding insulation is necessary for motors equal to or higher than 500V. The use of 500-690V SINAMICS S120 drive systems is not permitted.

SINAMICS S120 has limitations to the maximum DC-link voltage level as a result of the sensitivity of the electrolytic capacitors in the converter's DC-link towards excessive voltage and the resulting decrease in the life expectancy of voltage-source frequency converters.

6 SLM Sizing

The power demand of the motor of each motion is calculated from the motor torque as follows:

$$P_{mot} = 2\pi \cdot n[\frac{1}{s}] \cdot T_{mot}[Nm] = \frac{2\pi}{60} n[rpm] \cdot T[Nm]$$

6.1 SLM SIZING using standard load calculation

WARNING	**The DC Link voltage must be U_{DC}= 1.5 x U_{Line}**

The SLM is sized based on the following consideration:

$$P_{H\_DC} = \sum_{i=1}^{N} \frac{P_{mot\_i} \cdot f_{overload}}{\eta_{mot\_i} \cdot \eta_{inv}} \cdot 1{,}5$$

where P_{mot_i} is the mechanical power drawn from the individual motors running simultaneously in steady state

$f_{overload}$ is the overload factor for motions with coinciding acceleration

η_{mot_i} is the efficiency of the individual motor

η_{inv} is the efficiency of the individual inverter (assume 0.985)

P_{H_DC} is the DC Link power using the standard high load duty cycle.

Herewith the DC link current IH_DC can be calculated by the following formula:

$$I_{H\_DC} = \frac{P_{H\_DC}}{U_{DC}}$$

where P_{H_DC} is the DC Link power using the standard high load duty cycle.

U_{DC} is the DC Link voltage.

The SLM can be chosen according its I_{H_DC} current from the catalog.

6.2 SLM SIZING using freeload calculation

Using the freeload calculation the SLM is sized based on the two following considerations:

- The average power in the power unit must be calculated for the duration of the load duty cycle,
- The magnitude of the short-time power must be checked.

The average power of the active line module can be calculated using:

$$P_{average} = \sum_{i=1}^{N} \frac{P_{mot\_i}}{\eta_{mot\_i} \cdot \eta_{inv}}$$

where P_{mot_i} is the mechanical power drawn from the individual motors running simultaneously in steady state

η_{mot_i} is the efficiency of the individual motor

η_{inv} is the efficiency of the individual inverter (assume 0.985)

The maximum power can be calculated using the formula:

$$P_{\max} = \sum_{i=1}^{N} \frac{P_{mot\_i} \cdot f_{overload}}{\eta_{mot\_i} \cdot \eta_{inv}}$$

where P_{mot_i} is the mechanical power drawn from the individual motors running simultaneously in steady state

$f_{overload}$ is the overload factor for motions with coinciding acceleration

η_{mot_i} is the efficiency of the individual motor

η_{inv} is the efficiency of the individual inverter (assume 0.985)

With $P_{average}$ and P_{max} the SLM can be selected via the required rated SLM input current:

$$I_{Line\_average} = \frac{P_{average}}{\sqrt{3} \cdot V_{Line} \cdot \eta_{SLM}} \text{ and } I_{IN\_\max} = \frac{P_{\max}}{\sqrt{3} \cdot V_{Line} \cdot \eta_{SLM}}$$

where V_{Line} is the line voltage

η_{SLM} is the efficiency of the SLM inverter (assume 0.98)

The SLM can be chosen according its $I_{Line\_average}$ and I_{Line_max} current from the catalog.

7 Available motor voltage

The motor voltage in applications with SLM depends on the line voltage and the modulation mode of the Motor Modules.

7.1 Motor voltage with pulse edge modulation PEM

At low output frequencies and low depth of modulation, i.e. at low output voltage, the SINAMICS S120 utilize the space vector modulation SVM option and switch automatically over to pulse-edge modulation PEM if the depth of modulation required at higher output frequencies is so high that it can no longer be provided by space vector modulation (output voltage > 92 % of input voltage).

For PEM the fundamental frequency RMS value of the output voltage can then be calculated as:

$$V_{PEM\_\max\_theo} = \frac{\sqrt{6}}{\pi} \cdot V_{DCLink} = 0{,}78 \cdot V_{DCLink}$$

where $V_{Pem\_max\_theo}$ is the theoretical maximum possible output voltage

V_{DCLink} is the DC Link voltage

However, the motor voltage then has an unsuitable harmonic spectrum which causes major stray losses in the motor and utilizes the motor inefficiently. It is for this reason that pure square-wave modulation is not utilized on SINAMICS converters. The pulse-edge modulation method used on SINAMICS converters permits a maximum output voltage which is only slightly lower than the line voltage, even when allowance is made for voltage drops in the converter:

$$V_{PEM\max} = 0{,}745 \cdot V_{DCLink}$$

where $V_{Pem\_max\_theo}$ is the theoretical maximum possible output voltage

V_{DCLink} is the DC Link voltage

NOTE Pulse-edge modulation PEM is only available in vector control mode.

NOTE With the introduction of Firmware version V2.3 and the simultaneous changing of the hardware, pulse-edge modulation is available as standard for Motor Modules / chassis format and Motor Modules /Cabinet Modules format since autumn 2005.

NOTE With the introduction of Firmware version V2.5 SP1 and the simultaneous changing of the hardware, pulse-edge modulation is available as standard also for Booksize units since autumn 2007.

Exceptions:

- Parallel converters on which two or more power units operating in parallel are supplying one motor with a common winding system. Under these conditions pulse-edge modulation cannot be selected.
- Converters with output-side sine-wave filter. Pulse-edge modulation cannot be selected under these conditions.

7.2 DC Link voltage for SLM

The SLM is a line-commutated rectifier / regenerative unit and produces an unregulated, load-dependent DC link voltage V_{DCLink} from the three-phase line voltage V_{Line}. Under no-load conditions, the DC link is charged to the peak line voltage value, i.e. $V_{DCLink} = 1.41 \cdot V_{Line}$.
When the DC link is loaded, its voltage drops in case of the voltage drop at the 4 % reactor. At partial-load the DC link voltage will be $V_{DCLink} \approx 1.32 \cdot V_{Line}$ and at full load,

$$V_{DCLink} \approx 1{,}30 \cdot V_{Line}$$

As the DC link voltage is unregulated, line voltage fluctuations cause the DC link voltage to fluctuate correspondingly.

7.3 Calculation of the available motor voltage in SLM applications

With the facts from 8.1and 8.2 the available motor voltage under full load in SLM application is:

$$V_{Motor} \approx 0{,}745 \cdot 1{,}30 \cdot V_{VLine} \approx 0{,}97 \cdot V_{Line}$$

where V_{Motor} is the output voltage of the Motor Modules

The following table shows the calculation of typical line voltage values.

Table 7-1 calculation of typical line voltages

VLine [V]	VMotor [V]
3 AC 528 (480+10%)	512
3 AC 516	500
3 AC 480	466
3 AC 400	388
3 AC 380	369
3 AC 342 (380-10%)	332

As the DC link voltage is unregulated, line voltage fluctuations cause the DC link voltage to fluctuate correspondingly

8 Overview SINAMICS S120 configurations with SLM

Figure 8-1 Single 12 pulse configuration Smart Line Module (SLM) feeding common DC-bus.

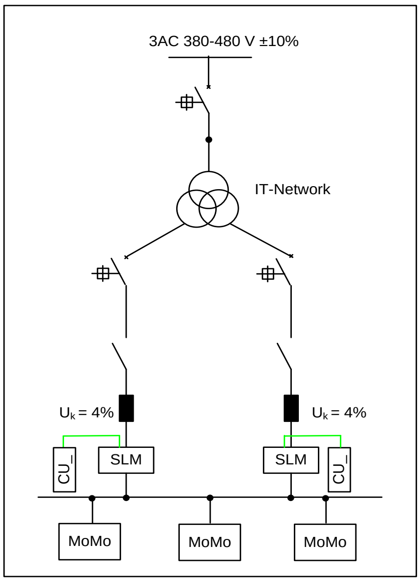
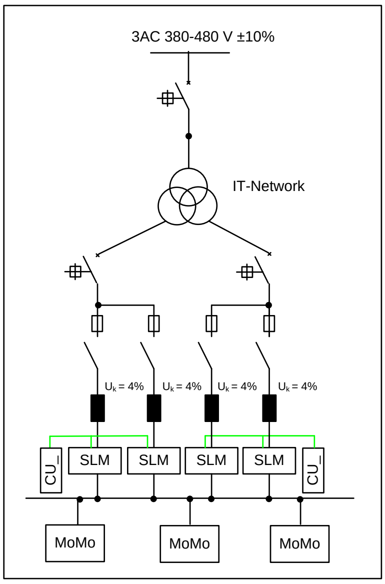


Figure 8-2 *Double 12 pulse configuration Smart Line Module (SLM) feeding common DC-bus. Typical solution for drive systems where the power rating of one single 12 pulse configuration SLM is sufficient.*



9 Appendix

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9.3 Application support

Siemens AG
Digital Industries
Motion Control
Cranes
DI MC GMC CR
Frauenauracher Str. 80
91056 Erlangen, Germany

mailto: applications.cranes.aud@siemens.com

9.4 Links and literature

Table 9-1

No.	Topic
\1\	Siemens Industry Online Support https://support.industry.siemens.com
\2\	Link to this entry page of this application example https://support.industry.siemens.com/cs/ww/en/view/48293880
\3\	

9.5 Change documentation

Table 9-2

Version	Date	Modifications
V1.0	03/2009	First version
V1.1	05/2020	Review
V1.2	01/2021	Review