Practical Aspects of Inverter-fed Drives

An inverter-fed electric drive system (Illustration 1) consists of such components as a control cabinet, a source of line power, contactors, a PLC system, a frequency inverter, a filter, motor leads and a motor. For the planning and installation of drive systems, there are certain things to watch for and to abide by – as dealt with in condensed form below.

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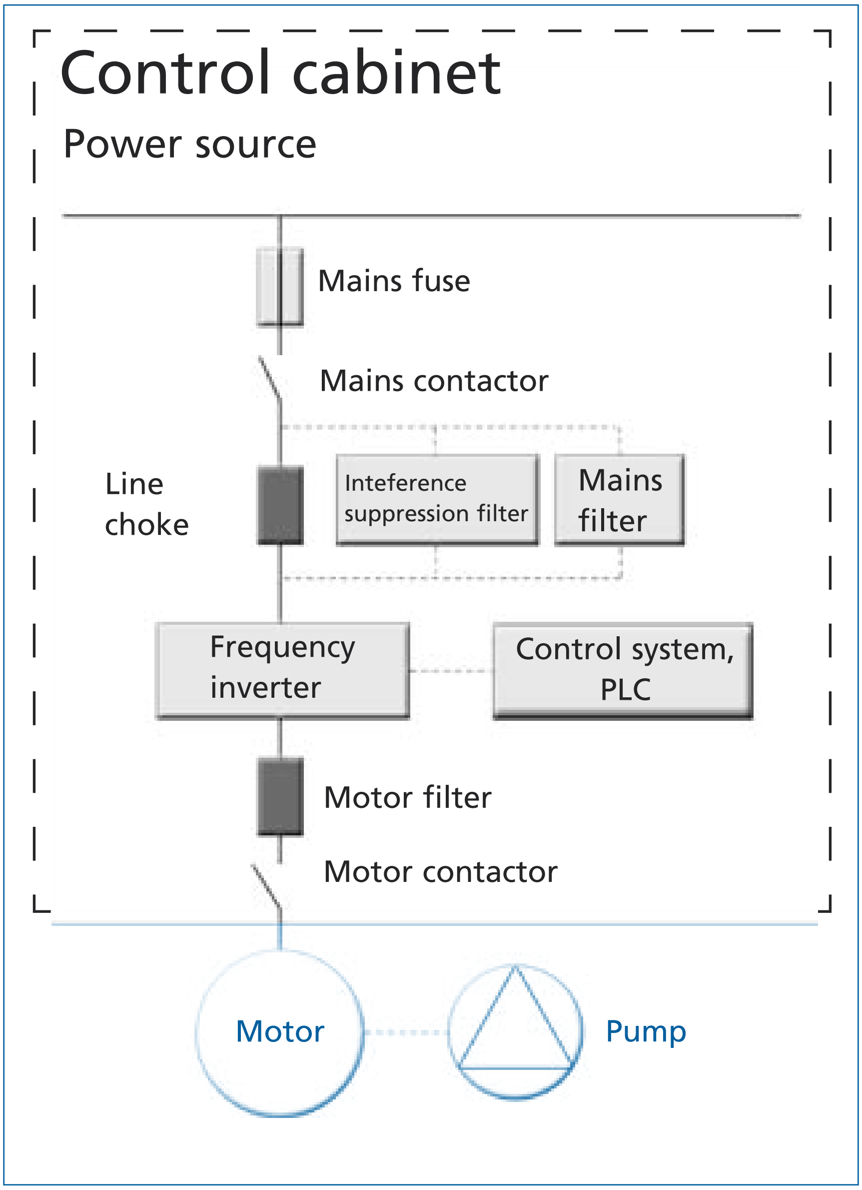

Illustration 1: Schematic diagram of an electric drive system

EMC -appropriate Drive Systems

As a rule, an electric drive system (cf. Illustration 1) consists of a control cabinet including power supply, contactors, a programmable logic controller (PLC), a filter and a motor with leads.

The arrangement of the various components in the control cabinet, in addition to the shielding and routing of lines and cables, is a major factor with regard to electromagnetic compatibility.

Frequency inverters, filters, motor contactors and various other drive components must be grouped together as closely as possible in order to minimize the

EMC: Electromagnetic compatibility.

Frequency inverters: Power electronic components for converting a fixed alternating voltage into a variable-frequency a.c. voltage.

Coupling capacitances and inductances: The influence of electromagnetic fields on electric conductors (coupling) can also be described in terms of capacitance and inductance.

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length of the cables between the individual components, thus reducing the resultant *coupling capacitances and inductances*.

The manner in which the components are connected to each other also plays a major role with regard to EMC. Several additional rules of EMC-appropriate control-cabinet configuration (cf. Illustration 2) are listed in the following.

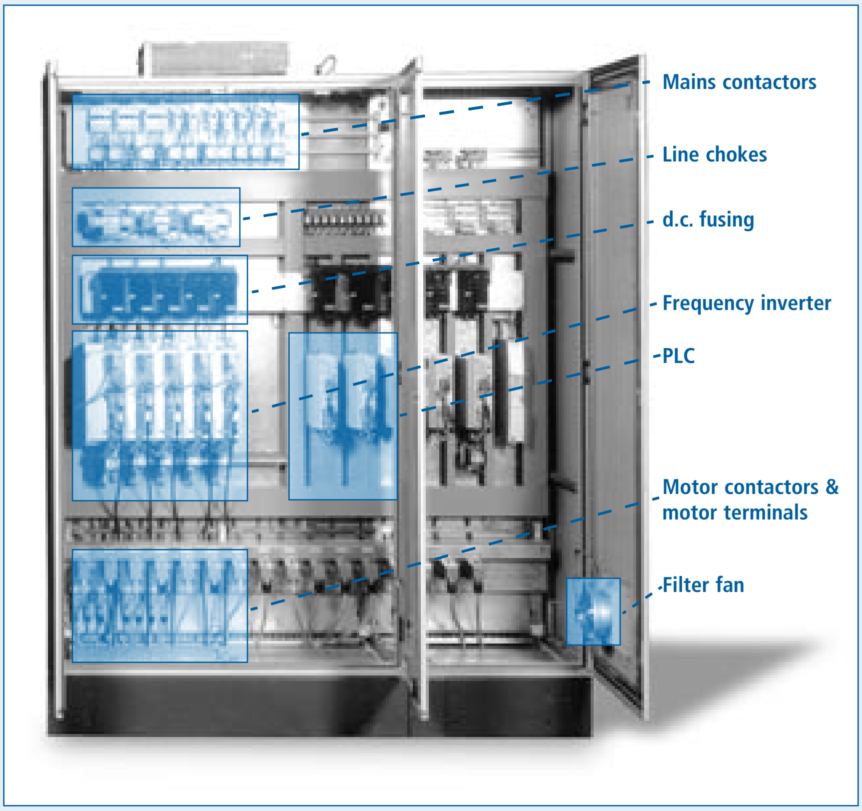

Illustration 2: Hard-wired control cabinet with inverter

Arrangement and Wiring

- Lines carrying analog or digital signals must be kept as far apart as possible and always installed at right angles to power cables.
- 24 V power-pack lines must be routed together along their entire length to avoid looping.
- Contactors, relays, solenoid valves, etc., should be circuited with interference suppression combinations.
- Unshielded conductors in one and the same circuit (forward and return lines) must be twisted.
- The terminals for power supply and motor cabling in the control cabinet should be kept at least 10 cm apart.

Shielding of Cables

- For lines carrying analog signals, the shielding should only be connected at one end, i.e., at the frequency inverter end, with ground potential.
- In the case of digital-signal lines, however, the shielding must be connected at both ends, with ground potential, to suppress emitted interference.
- Lines measuring less than 30 cm in length can be left unshielded.
- The shielding must always be connected by means of a suitable large-area clamp, either to the grounded conducting mounting plate in the cabinet or directly to the equipment shield plate.
- The shielding connection should not be attached to the cable clamp rail, which only serves as a strain relief device.
- The connecting clamp can be situated as far as 500 mm from the end of the cable.
- An unshielded length of max. 10 cm is permissible at points where the shielding is interrupted by a contactor.
- In case of a system control cabinet with a high degree of protection, the braided screen may be grounded with an EMC-appropriate PG cable gland.

The mounting plate in the control cabinet must have a highly conductive, e.g., galvanized, surface.

If that is not possible, the contact faces of the mains filter, frequency inverter and shielding connections must be rendered electrically conductive by removing a generous portion of the surface finish / paint at each point.

Motor Cables

The shielding for the motor cables is dependent on the other filtering measures. Cables with copper braiding have a better shielding effect than those with steel armouring. The shielding must have large-area connections at both ends (clamps, all-round contacts) with ground potential (e.g., on the mounting plate).In addition to reducing the inverter‘s output current (derating), elevated inverter switching frequencies also increase the *discharge currents*. Depend-

Shielding: An electrically conductive surface with the purpose of attenuating the electromagnetic field.

Discharge currents: Currents that flow against ground potential at high frequencies due to coupling capacitance.

ing on the equipment output, the additional capacitive discharge currents can expose the frequency inverter to amperage in the vicinity of the *rated current*. For small inverters (up to about 5.5 kW), this can have particularly serious effects. In order to minimize the discharge currents in the case of long motor cables (> 50 m), preference should be given to cables with as little capacitance as possible.

Appropriate filtering measures provide additional protection against capacitive current discharge (cf. section on filter systems).

MOTOR REQUIREMENTS

Self-cooling three-phase a.c. motors are not adequately cooled at low speeds. The flow of air is too weak, and the motor requires a PTC resistor as protection against overheating. Pulsing of the frequency inverter's intermediate circuit voltage heightens the load on the windings and insulation of inverter-driven motors. As a consequence, the motor winding must display the following design features for inverter operation:

- adequate insulation resistance with regard to *rate of voltage rise*
- *interphase insulation*
- double enameled wire
- thermal class F or higher
- impregnated windings

An appropriate external measure (e.g., a sine filter) can be helpful in the case of motors with insulation that is not suitable for inverter operation.

FREQUENCY INVERTER / INVERTER SIZE REQUIREMENTS

The requirements for and functions of a frequency inverter that is ideally suited for pump applications include:

– Energy optimization

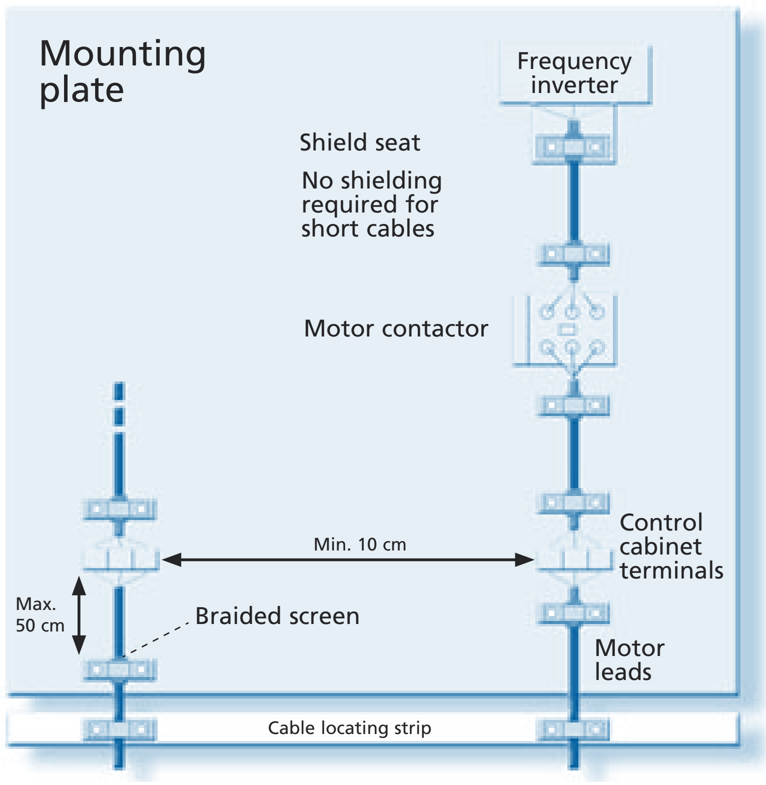

Illustration 3: Shield seat in the control cabinet

Energy can be saved in the part-load range by reducing the level of motor magnetization.

– Slip-power compensation
Active slip-power compensation makes up for slip by raising the frequency.

– Control functions
If a PI controller is integrated into the system, certain process variables, e.g., the differential pressure in the system, can be controlled by way of the pump speed.

– Communication functions
Control signals, status signals and alarm signals can be transmitted and received by way of communication interfaces.

– Boost voltage
This additional voltage increases the level of magnetization upon starting of the motor, thus effecting a higher breakaway torque.

The use of an optimally sized frequency inverter is of decisive importance for the economic efficiency and functionality of the system. The size of the frequency in-

Rated current: Current for which the equipment was designed (formerly nominal current).

Rate of voltage rise: Increase in voltage also referred to as „du/dt".

Interphase insulation: Supplementary insulation between the individual phases of the motor.

Apparent power: voltage * current * √3 = effective power / cos(Phi).

Low-frequency phase effects: Interference emitted into the electric grid at relatively low frequencies (in comparison with the switching frequency of the frequency inverter: 1-10 kHz).

verter depends on the motor‘s load characteristic, not on its size.

The Required Capacity of the Frequency Inverter Can Be Determined According to One of the Following Three Criteria

– Sizing according to motor current:
The maximum continuous output current of the frequency inverter must be at least as high as the maximum motor current occurring in the system. Hence, oversizing of the frequency inverter can be avoided by measuring the motor current actually encountered in the system.

– Sizing according to the motor‘s *apparent power*:
The frequency inverter must be selected to ensure that its apparent power output is equal to or greater than the motor‘s apparent power uptake.

– Sizing on a standard-series basis:
It is also possible to size the frequency inverter according to the standard series corresponding to the given standardized motor. This approach, however, is rather inaccurate, especially when the motor is not being loaded to full capacity.

Requisite Filter Systems for Inverter-Fed Drives

Rectification of the line voltage on the input end of the frequency inverter, together with the high-frequency switching operations for generating a variable frequency on its output end, causes various EMC-related problems. Such problems can be minimized by the use of filters (Illustration 4).

There are presently three different kinds of input filters (line-side filters) from which to choose: line chokes, interference suppression filters, and mains filters.

Line chokes consist of line-side inductances (coils) inserted in front of the frequency inverter.
They have the following characteristics:

- They reduce the *low-frequency phase effects*.
- They alter the shape of the line current toward the sinusoidal.
- They lower the effective line current by reducing its harmonic content (= lower line, cable and fusing loads).
- They enhance the equipment‘s longevity by reducing the a.c. load on the electrolytic capacitors in the intermediate circuit.
- They improve the frequency inverter‘s surge strength.

The purpose of an interference suppression filter is to reduce the line-side, conducted EMC interference by attenuating the high-frequency phase effects.

This does not, however, render the line choke superfluous. Basically, a mains filter is a combination of a line choke and an interference suppression filter. It attenuates both the high-frequency and the low-frequency phase effects and helps the line current approach a sine-wave shape.

The Following Factors Also Make it Necessary to Include an Output Filter (Motor-End Filter)

- Long motor cables
- Motors with insulation that is not inverter-capable (older models)
- Magnetic noise in the motor
- Absence of shielded motor cables

Various types of filters can be used to solve such problems. The various types differ mainly in their quality of filtration and price, with the latter depending on the former.

Distinctions are drawn between *motor reactors*, motor filters and *sine filters*.

As a rule, equipment manufacturers are more than willing to provide extensive planning aids to assist in arriving at a suitable configuration for the drive system.

Motor reactor: Protects the motor by reducing the capacitive discharge currents and the rate of voltage rise.

Sine filter: Special filter to generate a sinusoidal shape of the voltage. To be used in the case of long motor cables; for inverters for power supply; for minimizing the motor noise; for no-break power systems.

Illustration 4: Filtering options