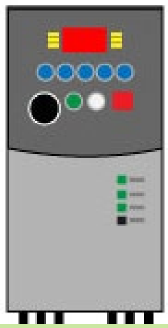

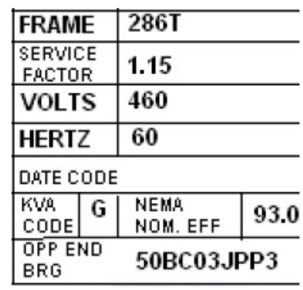

Use of KT7 Motor Controllers

With Variable-Frequency Drives

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Introduction

A motor branch circuit, including a Variable Frequency Drive (VFD) and one or more KT7 Motor Circuit Controllers, is a complex system and its performance depends on all components, devices, configuration, and their interconnection.

In applications where a KT7 Motor Controller is to be used on the output (load side) of a VFD, several factors must be considered due to the influences of voltage pulses and current harmonics. Current harmonics and reflected voltage waves generated with long cables at the motor terminals can have a significant negative impact on the KT7 and switchgear performance if they are not taken into account appropriately.

This publication explains some considerations for the selection of Motor Circuit Controllers with VFDs. European (IEC) nomenclature refers to KT7 as Motor Protection Circuit Breakers. In North America, UL508 nomenclature refers to KTA7, KTC7, and KTV7 as a Self-protected Combination Motor Controller, or a Type E Motor Controller applicable under NEC §430-52.C.6. These clarifications aside, the application issues for use with variable frequency drives do not change globally. The information in this paper has been developed through known engineering principles and validated through testing and simulation.

Typical Applications

Series KT7 Motor Circuit Controllers provide the functional control and protection requirements as specified by local electrical codes such as the National Electrical Code (NEC). Whether in single- or multi-motor installations, the KT7 provides several key control and protection functions required for these types of installations. KT7 Controllers used as a Self-protected Manual Motor Controller can provide the individual motor circuit with the following functionality:

- Disconnect function, providing approved isolation of motor circuits
- Manual motor controller, turning the individual motor circuit on and off
- Motor overload protection, protecting the motor from thermal overload
- Short circuit protection for the individual motor and the conductors

General

KTA7 and KTC7 controllers are designed to handle the operational frequency range up to 60 Hz. Since they include magnetic short circuit trip coils, the carrier frequency (PWM) of the VFD should be selected as low as possible and must not exceed 4 kHz to avoid overheating. This is in agreement with recommendations given for line terminators and filters.

The actual motor operational current of the controller (KTA7) should be as close as possible to the low end of their current (setting) range to keep the power loss at a minimum.

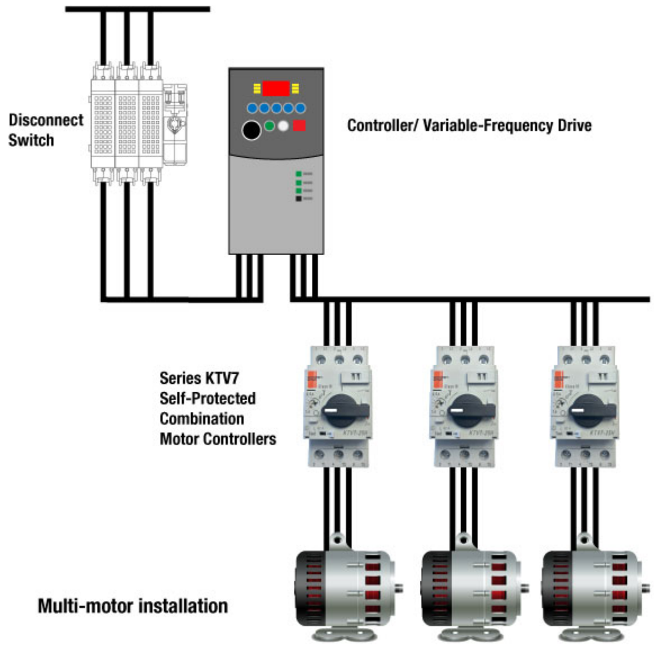


Figure 1 - Typical Multi-motor Installation with VFD

When KT7 controllers, due to a partially loaded motor, operate at currents lower than the minimum current setting they are usually not able to trip thermally when additional heating in the magnetic trip coil occurs. The controller, however, is still permanently experiencing the load of the voltage pulses as described below. Magnetic only versions (KTB7) rated lower than 10 A with separate bimetallic overload-relays are also not suitable for these applications since the controllers have no thermal trip capability for self-protection. In addition, separate bimetallic overload relays rated 1A and below would suffer from heating as well and probably not trip for self-protection.

The user manual for each VFD drive should be referred to for the cable length limitations based on drive size and the quality of the insulation system in the chosen motor. There are various options of filter solutions available to reduce voltage rise time or occurrences of reflected waves. The application of filter solutions like line reactors and reflected wave reactors can be beneficial with regard to reduced voltage rise times.

To maintain the insulation coordination required for the entire drive system, the occurrence of reflected waves at the motor terminals must be limited to 1400 Vpk (e.g. IEC Motors, Category A) since the isulation voltage of the switchgear is only 690 VRMS. The maximum permissible operational voltage therefore is $500V_{RMS}$ for these applications. As an optimal solution, sine wave filters would reduce the occurrence of reflected voltage waves.

Motor Controllers on the "line side" of a VFD

NEC §430.52 c.1 requires a UL489 rated Molded Case Circuit Breaker or set of fuses for short-circuit protection on the line side of a VFD. NEC §430.52 c.6 allows a Self-Protected Combination Controller (KTA7 or KTC7) to be used on a single-motor application.

The input current of VFDs is non-sinusoidal, containing high peaks and harmonic currents. The peak values can be 1.5…4 times higher than the VFD output currents. The KT7 controller used on the line side of the drives will provide branch circuit protection against short circuits and isolation of the complete VFD circuit through the disconnecting function.

When the motor operates at low speed (low frequency of the output current) the peak input current value can rise noticeably and tripping of the line side breaker may occur.

- To avoid nuisance tripping, the line side branch circuit protection device must be selected according to the maximum input current to the VFD, not to the rated motor full load current.
- Since KTA7 is a self-protected motor controller and should be selected to match motor full load current, the thermal overload function will compete with the overload function of the VFD. This fact alone suggests an alternative approach may be useful. However, many have applied KTA7 or KTC7 successfully because the peaks of VFDs are transient in nature.
- KTU7, a UL489 approved thermal-magnetic molded case circuit breaker, can be used on the line side of a VFD to provide short circuit protection per NEC §430-52 c.1. The selection of a thermal-magnetic breaker can be as large as 2.5 times full load current. The selection, combined with the 15 times fixed magnetic rating, allows for short circuit protection measured in milliseconds and avoids the problems of selecting a Self-protected Motor Controller based on full load amps. This method avoids competing overloads tripping with the VFD overload. KTU7 is available up to 30 amps (80% rated, maximum 24 amps continuous).
- Refer to the VFD User Manual for the listing of approved branch circuit protection devices and their sizing recommendations.

Motor Controllers on the "load side" of a VFD

General

When bypassing a VFD via paralleling, using a contactor for example, branch circuit protection is required for either path. The load side must include external overload protection for either the contactor or the VFD.

In multiple motor applications, NEC §430, part III, requires individual motor overload protection, that is (thermal) overload function, on the load side of a VFD only (see NEC Part X, §430.124 c).

When the devices are installed on the load side of a VFD, several aspects must be considered to help ensure proper and reliable operation. VFDs are limited to a maximum output current. The fixed short circuit trip level a KTA7 motor controller on the other hand is approximately 13 times the maximum current setting. Alternatively, KTC7 motor controllers are approximately 17 times the maximum current setting. Since the cut off time of the VFD is in the range of microseconds, and the reaction time of the KTA7 or KTC7 trip unit is in the range of milliseconds, no short circuit protection function of an individual branch in a multi motor application is provided by the controller. Even if the trip current value does not exceed the maximum output current of the VFD, only a thermal trip might occur.

Due to the PWM voltage pulses and the surge impedance of the motor, reflections of the voltage pulses occur at the terminals of the motor. Their amplitude is dependent of the

- system voltage
- voltage rise time t_{rise} of the VFD
- current rating of the KT7 controller (surge impedance)
- operational voltage (DC_{BUS}-voltage)
- location of the controller (close to the VFD output or close to the motor)
- cable type and length between KT7 controllers and motor (surge impedance)

System voltages up to 240V AC need no specific consideration. To reduce the impact on the system components at higher operational voltages,

- the interconnection between VFD and motor should be as short as possible and not exceed manufacturers' recommendations.
- Location of the KT7 motor controller near the motor is the preferred solution.

The formula to determine the maximum permissible ("critical") cable length l_{crit} at which reflected voltage phenomena are fully developed given by motor and drive manufacturers is a suitable estimation also for applications with KT7 controllers located near the VFD:

Equation 1

$$l_{crit} \approx \frac{v_{cable} \; X \; t_{rise}}{2}$$

- l_{crit} - critical length
- v_{cable} - propagation speed
- t_{rise} - rise time of VFD pulses

Typical pulse propagation speed on a cable is $v_{cable} \approx 150$ m/microsecond. The voltage rise time trise is dependent on the drive semiconductor technology.

Semiconductor Technology	t_{rise} [µs]		l_{crit} [m]	
	t_{rise} min.	t_{rise} max.	t_{rise} min.	t_{rise} max.
BJT	0.2	2	15	150
GTO	2	4	150	300
IGBT	0.05	0.4	3.75	30

Example: Assuming a voltage rise time of 200 nanoseconds (example: for BJT) the critical length is 15 m.

If KT7 controllers are located near the output of the VFD, those devices rated 10 A and above are not significantly affected by these effects due to their constructional properties. The surge impedance of motor controllers < 10 A, however, does not match that of the cable sufficiently therefore reflected voltage waves originated at the motor terminals and returning to the KT7 controller cause high dielectric stress on the trip coils resulting in accelerated aging of the insulation and probably disabling of the instantaneous short circuit trip function.

For:

- Standard KTA7 or KTC7 controllers rated 10 A and higher the maximum cable lengths of drive manuals apply.
- Standard KTA7 or KTC7 controllers below 10 A the value according to the equation or the drive manual applies, whichever is lower.

Always take measurements of rise times on site to verify the real conditions.

Multiple motors (usually having smaller individual HP ratings in the range of 2HP to 7 ½ HP) are frequently connected to the load side of the variable frequency drive. These are exactly the kind of applications where harmonics or reflected voltage waves cause high dielectric stress on instantaneous short circuit (magnetic trip) functions of the motor controller. KTV7 is designed with higher magnetic trip values for the smaller full load current applications compared to KTA7 and KTC7. Most of the KTV7 units are rated as Self-protected Combination Motor Controller (Type E) and therefore provide individual motor short-circuit protection per NEC 430-52.c.6 as well as overload protection per NEC 430-32 on the load side of the drive. All KTV7 units are rated for Group Installation per NEC430-53.C which means the short circuit device on the line side of the VFD should be selected according to the rules for a branch circuit device for a group and in this case the KTV7 complies with the need for an group rated overload relay required for motors greater than 1 HP. Please use available reference data to determine which KTV7 are Type E rated and which are to be used only in Group Installation. In summary, KTA7 and KTC7 are not designed for use on the load side of a VFD and KTV7 is designed to endure on the load side of a VFD.

Single Motor Applications

NEC §430.52 c) requires an MCCB, Self-protected Motor Controller, or set of fuses for short-circuit protection on the line side only. Not every Motor Circuit Controller provides approved isolation. To cover a disconnect function, if required, load switches suitable for use as disconnecting means (switch disconnector per IEC) should be used. A Self-protected Combination Motor Controller, or Type E device, does provide approved isolation.

Multi Motor Applications

The following rules apply as referenced above:

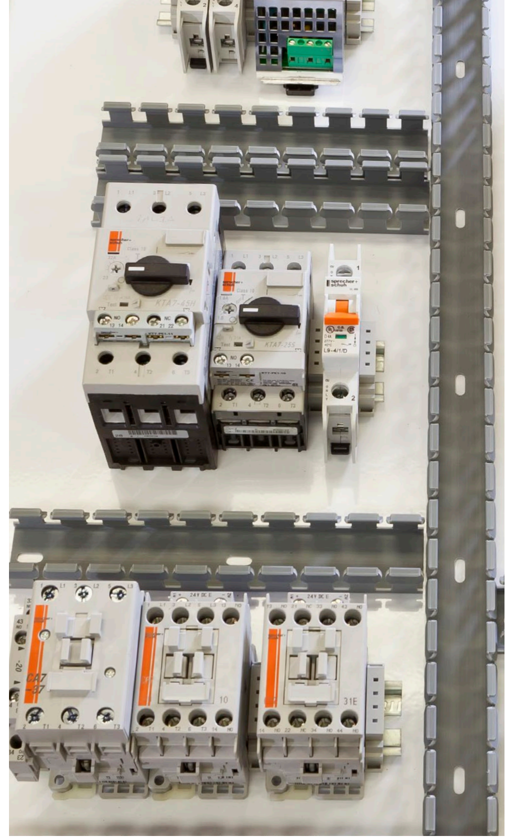
- Cable between VFD and Self-protected Motor Controller (example: KTA7) kept as short as possible.
- Wire lengths between motor controller and motor should not differ more than 10%.
- The lowest motor rating (highest impedance) defines the permissible cable length

Conclusion

Unless specifically stated as suitable for use, switchgear selection in these applications should take into account the complexity of the system dynamics such as capacitive loads and reflected wave. There are several factors that must be considered in the installations where Self-protected Motor Controllers are used at the output of VFD to minimize the influence of voltage pulse and current harmonics.

- The motor controller should be selected so that its current setting is close to the low end of the setting range. This reduces the basic temperature level at the trip coil.
- For motor controllers rated 10 A and higher - The interconnection between the VFD and motor should be as short as possible and not exceed drives manufacturer recommendations.
- For motor controllers below 10 A - The maximum permissible ("critical") cable length l_{crit} value according to Equation 1 or the drive manual applies, whichever is lower. Using Equation 1 to determine l_{crit} values given by motor and drive manufacturers, at which reflected voltage phenomena are fully developed, is also a suitable estimation for applications with motor controllers located near the VFD.
- The preferred location of motor controller installations is as close to the motor as possible, in order to reduce the cable length between the motor and motor controllers. The chopping frequency of the VFD should be as low as possible and not exceed 4 kHz.
- Filter solutions, like line reactors and reflected wave reactors, can be applied to reduced voltage rise times. Application of sine wave filters would eliminate the occurrence of reflected voltage waves altogether. These are generally suggested by drive manufacturers.
- Always take measurements of peak voltages to verify effectiveness of the measures.
- The surge impedance of electronic overload relays is also low in principle and unless specifically stated they are not suitable for this kind of application since their current sensor technology may not be able to measure the load current and harmonics correctly when operating at frequencies outside their nominal sensing range.
- Main circuits of contactors and load switches are normally not affected as described above, due to their low surge impedance. However, depending on capacitive load through long cables or capacitor charging currents, contact welding might occur when switched under load, so consideration related to capacitive load should be taken in account in selection of these devices to be used with drives.
- Consider the use of KTU7 on the line side of the VFD when continuous currents are less than 24 amps.
- KTV7 should be applied on the load side of the VFD where short circuit as well as overload functions are required.

Notes



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Tech-KT7andVFDs_v3 05/2016
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