TMEIC
We drive industry

TMdrive®-10e2 SPR

Product Application Guide

Slip Power Recovery Drive System for Wound Rotor Motors

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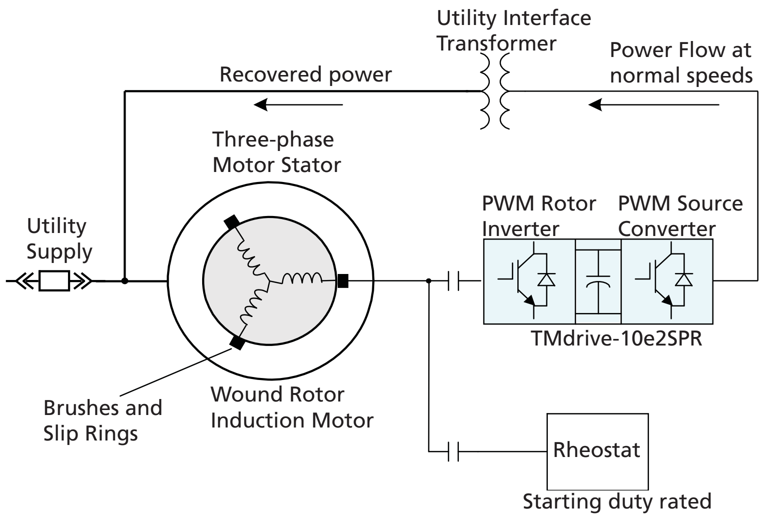
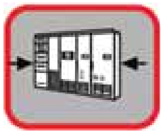
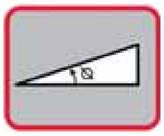
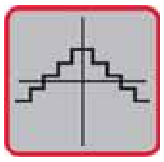
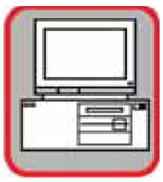
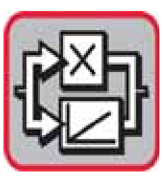
JAPAN | NORTH AMERICA | SOUTH AMERICA | EUROPE | SOUTHEAST ASIA | INDIA | CHINA | MIDDLE EAST | AUSTRALIA

Features

With the TMdrive-10e2SPR, wound rotor motor drives have entered the 21st century, offering:

- **PWM converters**
- **High power factor operation**
- **High reliability**
- **Low cost of ownership**



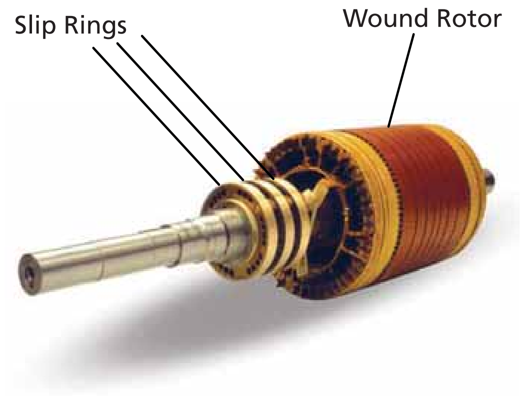
	Features	Benefits
	**Based on Standard Drive** Standard TMEIC low voltage drive hardware is applied for use as a wound rotor motor drive.	**Reliable Drive Hardware & Available Spare Parts** The TMdrive-10e2 drive hardware is in production. No modifications to the hardware are required for use as a slip power recovery drive.
	**High Power Factor, Low Harmonic Utility Interface** Source converter feeding power back into utility operates at unity power factor.	**Reduction of Current to Motor and Reduced Harmonics** Higher PF operation means reduced reactive power demands and better voltage stability. Reduced harmonics result in no filtering on utility supply.
	**Low Harmonic Currents in Rotor Circuit** PWM converter connected to rotor provides sinusoidal current to rotor	**Negligible Rotor Heating and Smooth Motor Torque** Sinusoidal current in rotor circuit results in negligible rotor heating and torque pulsations.
	**Latest Drive Control Technology** Based on current production drive control hardware and firmware.	**Intelligent Drive Control** Using modern drive control provides the latest in drive communications, operating accuracy, and diagnostics.
	**Heat Pipe Cooling Technology** The cabinet-based IGBT power bridges use heat pipe cooling technology.	**Reduces Footprint and Lowers Audible Noise** This technology saves valuable floor space and lowers the required cooling-air flow, reducing the associated audible noise..
	**Precise control of wound rotor motor while not wasting energy**	• Drive controls motor torque (rotor current) directly; motor does not have to increase slip (slow down) to increase torque • Slip power is recovered and fed back to power system when the motor is operating below synchronous speed

Slip Power Recovery

Wound rotor induction motors have been popular in some industries, particularly cement, for decades. Until about 1985, a wound rotor induction motor (WRIM) was the only large ac motor that allowed controlled starting characteristics and adjustable speed capability.

A WRIM is a machine with a 3-phase wound stator that is usually connected directly to the power system. The rotor also has a 3-phase winding, usually connected in a wye (or star) circuit. The three terminals of the rotor winding are connected to separate slip rings, which are normally connected to a liquid rheostat or resistor bank. Changing rotor resistance changes the motor speed. In the past the power in the resistor was lost as heat. The slip power recovery drive, TMdrive-10e2SPR, is used to vary the motor speed by varying the power taken off the rotor and returned to the utility supply.

SAG Mill for grinding ore



Rotor from WRIM showing Slip Rings

Large pumps in a Water Treatment Plant

Wound rotor motors continue to be applied in some industries, especially in ore processing, cement, and water/wastewater. Speed control of wound rotor motors has traditionally employed slip power recovery (SPR) drives for cost and energy efficiency reasons. Older implementations of SPR technology saved energy, but had disadvantages of low power factor operation and torque pulsations.

The use of state-of-the-art low voltage PWM converters eliminates these disadvantages while retaining all the energy savings. This new implementation builds on the standard line of TMEIC low voltage induction motor drives used in process industries such as metal processing and paper machines. Therefore the hardware is very reliable and familiar. The TM-10e2SPR is appropriate for new motors or existing motors.

Cement Plant

Applications

Application 1. Slip Power Recovery Drive System for a Kiln ID Fan

A cement plant was using a 5500HP Induced Draft (ID) fan powered by a wound rotor induction motor (WRIM). Due to market conditions, the airflow was being restricted by an inlet damper operating in the 35% open range. The fan motor running continuously at full speed with restricted air flow wasted a lot of energy.

The TMEIC TMdrive-TM10e2 SPR drive was applied to the 5500HP 13kV stator voltage WRIM. The SPR drive was applied on the motor rotor in addition to the existing liquid rheostat starting means. Only the rotor power is sent through the SPR drive so it is much more efficient than a full-rated stator drive. Also, all the existing starting means and operational controls could be left in place for this solution. That meant that if the SPR had a problem, the plant did not have to shut down, it could simply return to its previous mode of operation. This feature proved to be a key point for giving the plant the confidence to proceed with the project.

The Customer Need
Reliability, energy savings and a backup option to avoid a shutdown of the plant if the new system suffered an event were important considerations for this project.

The Best Solution: TMdrive-10e2SPR drive applied to the WRIM

- The TMdrive-10e2SPR equipment selected saves energy by regenerating the power from the rotor of a WRIM when the motor is run slower than full speed.
- To determine the effectiveness of the project for energy savings, measurements were taken before the SPR installation and after the SPR was in operation.
- The average demand reduction of 1400 kW saved the plant 40% on its annual energy usage for the fan. Return on investment was less than one year.

Cement Plant

Application 2. Slip Power Recovery Drive System for a grinding mill

This new $250 M ore processing facility in Papua New Guinea can process up to 4.7 million tons of ore per year, resulting in about 275,000 ounces of annual gold production. This variable speed drive application is a dual-pinion SAG mill driven by two 5,000 kW wound rotor induction motors. Two TMdrive-10SPRs control motor speed by recovering rotor current and returning the power to the utility supply.

The Customer Need
Reliability, power dependency and logistics were a challenge for this project. Limited access to the mine's extremely remote location required power recovery and stellar reliability in its operations.

The Best Solution: TMdrive-10SPR for each mill motor

- The TMdrive-10SPR has high reliability and a good track record.
- Configured in a twin motor arrangement, the motors share load in the tandem mill. The first motor provides speed control, the second motor provides torque control
- Continuously recovers an estimated 770 kW
- Inherent fault tolerance - a failure of the SPR drive will not prevent the motor's operation
- The SPR drive offers high overall system efficiency, thus saving energy, and can perform additional VAR compensation

SAG Mill and Motor

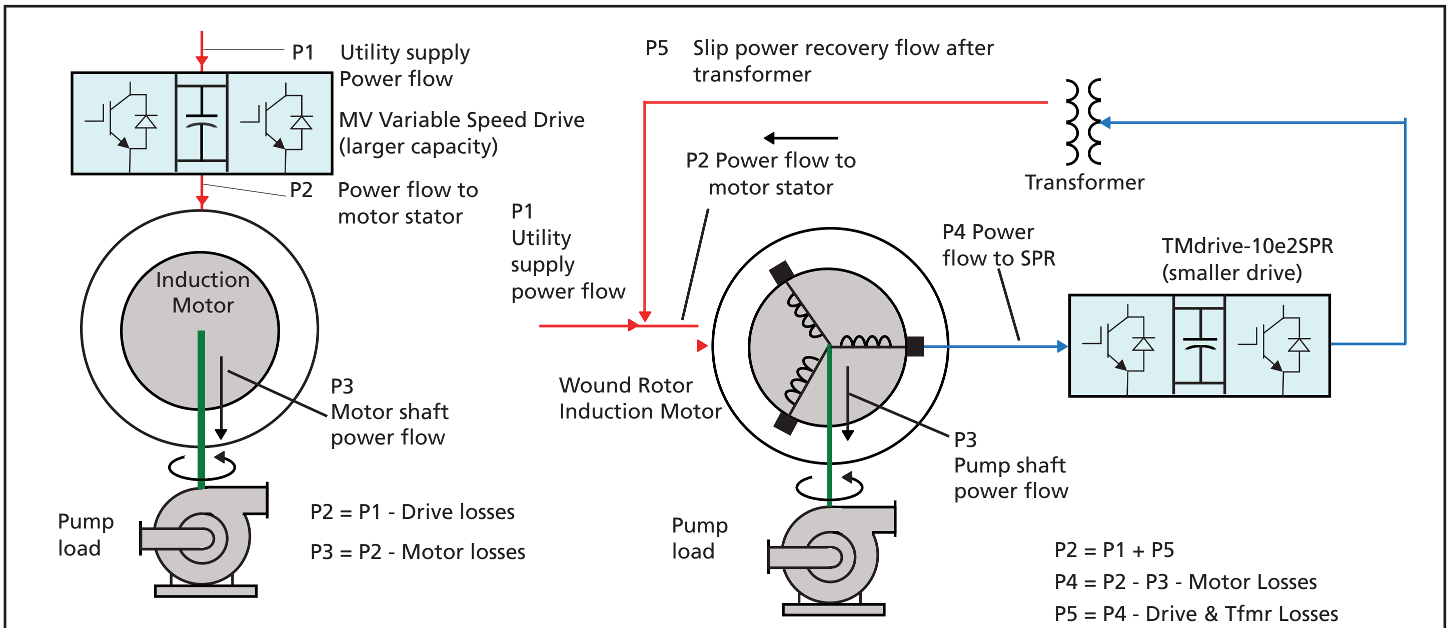
Applications

Application 3. Energy Savings using Slip Power Recovery Drive System

The example below compares the case of an induction motor driven by a large standard drive, with the case of a WRIM controlled by a small SPR drive, and calculates the energy savings. In the larger standard drive system, all the motor power passes through the drive. With the SPR drive, only a fraction of the motor power passes through the drive.

For a rated pump load of 5,000 hp, running at 90% speed, the power saving using the SPR drive is 88 kW. With an electrical cost of 7¢/kWh, the annual savings amount to $53,960. At lower speeds the savings are even higher.

Compared to a WRIM using only a rheostat to control speed, where all of the slip power is wasted as heat, the SPR drive saves $176,000 annually.



Standard Drive & Induction Motor — Slip Power Recovery Drive and Wound Rotor Motor

Operating Conditions	Power Flow	Standard Drive & Induction Motor	Slip Power Recovery Drive & Wound Rotor Motor
Pump Load at Full Speed, shaft kW	–	3730 kW (5,000 hp)	3730 kW (5,000 hp)
Pump load at 90% speed, shaft kW	P3	2720 kW	2720 kW
Utility supply power flow	P1	2980 kW	2892 kW
Power flow to motor stator	P2	2863 kW	3180 kW
Power flow to Slip power recovery drive	P4	0	300 kW
Slip power recovery after transformer	P5	0	288 kW
Difference in utility power flows	–	–	88 kW
P1 (Induction motor) - P1 (WRIM)			
SPR system savings with 7¢/kWH electrical power	–	–	$53,960 per year

A Look Inside

Control Functions

Each inverter and regenerative converter shares a common set of control boards. The primary control board performs several functions:

- Speed and torque regulation
- Sequencing
- I/O mapping
- Diagnostic data gathering

A mounting bracket is provided for an optional LAN interface board.

Incoming Power (Main and Control)

The converter in each lineup is fed 3-phase ac power. AC entry panels contain main AC breaker and support both top and bottom entry. In addition, 3-phase ac control power is fed to each converter and inverter in the lineup. A control power disconnect is provided in each cabinet.

Harmonic Filter

Optional advanced harmonic filter panel can be integrated into the lineup. The filter is arranged in an LCL configuration.

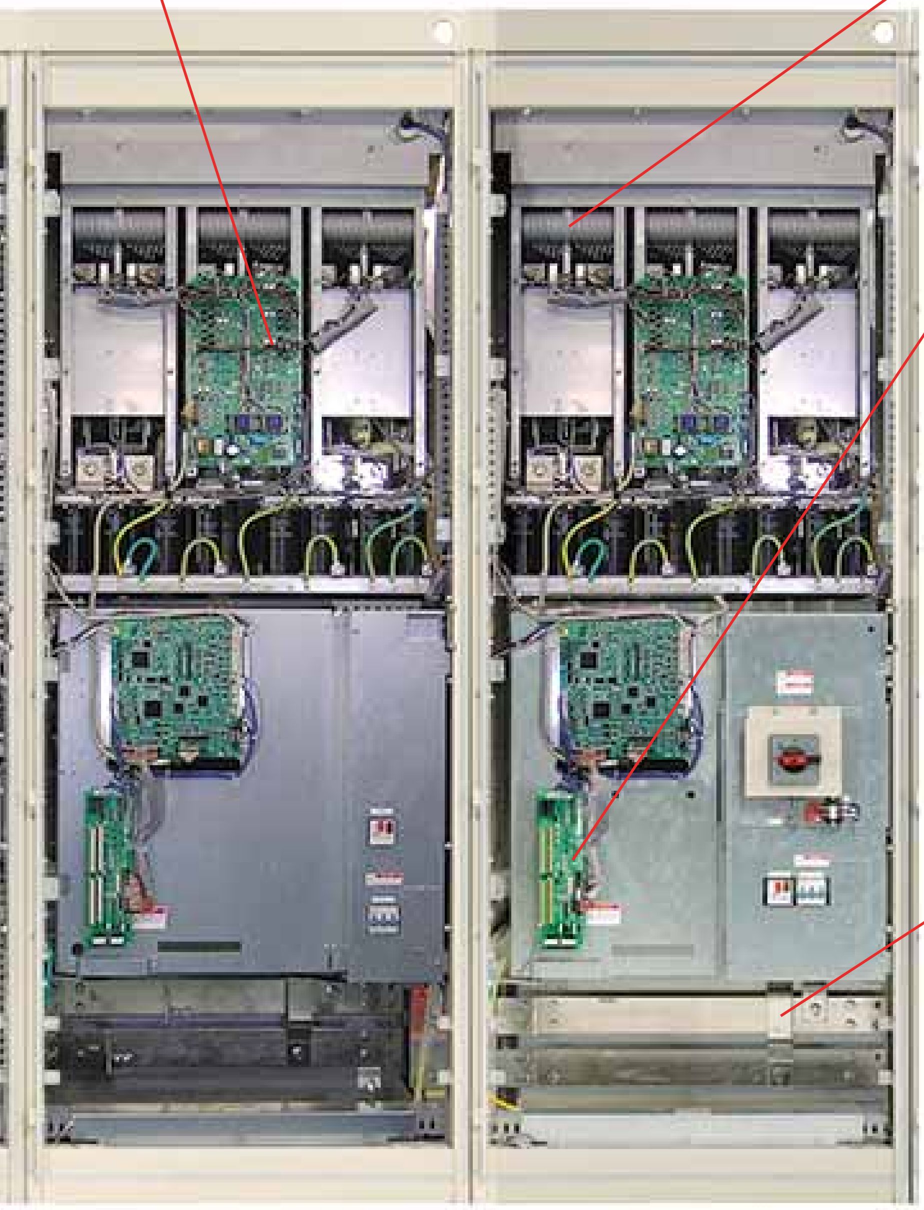
Two-Level Phase Leg Assembly

The cabinet style inverters have modular two-level phase leg assemblies. Each phase leg includes:

- IGBTs with flyback diodes
- Heat pipe assembly
- IGBT gate driver circuit board

Heat Pipe Cooling Technology

The cabinet style inverters and regenerative converters use heat pipes to cool the IBGT power switches and capacitors. This technology reduces the footprint of the power bridge as well as the airflow requirements, saving valuable floor space and dramatically reducing the audible noise.



I/O Board

All TMdrive-10e2 products share a common I/O board. The I/O board supports an encoder, 24 V dc I/O, 115 V ac inputs, and analog I/O, standard. In addition, a resolver interface option can be provided. All I/O are terminated to a two-piece modular terminal block for ease of maintenance.

DC Bus

The converter in each lineup generates dc power for each of the inverters. The inverters then create variable frequency ac power to control the induction motors. This dc power for the lineup is conveyed on a solid copper bus near the bottom of the cabinets. Tin-plated bus may be used.

Operator Interface

High Function Display

- LCD backlight gives great visibility and long life
- Bar graphs, icons, menus, and digital values combine to provide concise status information, often eliminating the need for traditional analog meters

Easy-to-understand navigation buttons allow quick access to information without resorting to a PC-based tool

RJ-45 Ethernet port is used for the local toolbox connection

Instrumentation Interface

- Two analog outputs are dedicated to motor current feedback
- Five analog outputs can be mapped to variables for external data logging and analysis

Interlock button disables the drive

Switch to local mode and operate the equipment right from the keypad

How to Apply SPR

Application of the TMdrive-10e2SPR starts with the motor speed range, the rated rotor current, the rated rotor voltage (at standstill), and any overload requirements. The speed range and the rotor voltage determine the maximum operating voltage of the TMdrive-10e2SPR. The rotor voltage is at rated value at standstill and reaches zero at synchronous speed. Therefore, the voltage at minimum controlled speed is:

Vc = Vrated * (100-Nmin), where
Vrated = rated rotor voltage, and
min = minimum controlled speed in percent

The rated rotor current and overloads determine the required inverter current capacity. The inverter continuous current rating must be equal to the rated rotor current and must be rated for any overloads.

The rating of the converter is determined from the speed range and the power to be recovered from the rotor. For a variable torque load (pump or fan), the maximum regenerated power is 15% of the motor rating. By contrast, the power regenerated from a motor powering a constant torque load is equal to motor rating times the speed range in percent.

As an example, consider a 3000 HP motor with a 4 kV stator, a rotor voltage of 1200V, rotor current of 1150 A, speed range of 70 – 96%, and no overloads exceeding 150% for 60 sec, driving a fan. The maximum rotor voltage is 360 V, so a 460 V inverter is applicable. The inverter size is a 1000 frame with a current rating of 1506 amps. The regenerated power is 335 kW, so the line converter is a 700 frame. Other components such as the utility interface transformer and rotor contactors must also accommodate these ratings.

Specifications

Inverter Specifications for models without DC disconnects

Frame	Weight kg (lbs)	Full Load Loss (kW)	460 V ac Rotor Current A ac	Allowable Overload %	575 / 690 V ac Rotor Current A ac
400	395 (869)		528	100 - 150	352
		6.3	469	175	302
			411	200	264
500			753	100 - 150	486
	400	7.5	669	175	417
	(880)		586	200	365
700			960	100 -150	586
	405	9.3	861	175	502
	(892)		753	200	440
900			1130	100 - 150	720
	410	13.5	969	175	617
	(902)		848	200	540
1000			1506	100 - 150	972
	800	14.9	1339	175	883
	(1760)		1171	200	729
1400			1920	100 - 150	1172
	810	18.6	1721	175	1005
	(1782)		1506	200	879
1800			2260	100 - 150	1440
	820	27	1937	175	1234
	(1804)		1695	200	1080

Source Converter Specifications

		460 V ac			575/690 V ac			
Frame	Weight kg (lbs)	Loss kW	Power kW	Current A ac	Allowable Overload	Power at 575 V ac	Power at 690 V ac	Current A ac
300	475	3.7	236	308	150	196	235	205
	(1045)			290	200			180
700	680	8.5	533	697	150	445	534	465
	(1496)			697	200			407
900	795	11	709	926	150	590	709	617
	(1749)			895	200			540
1400	1330	17	1067	1394	150	890	1067	929
	(2926)			1394	200			813
1800	1560	27	1417	1852	150	1180	1416	1235
	(3432)			1790	200			1080

Inverter Specifications

Inverter Power Output

Output Voltage	**460 V design** supports motor voltages up to 460 V, including 230 V, 380 V, 415 V, 440 V and 460 V **690 V design** supports motor voltages up to 690 V, including 575 V and 690 V
Output Frequency	0-200 Hz (0-400 Hz, Optional) Continuous operation below 0.4 Hz requires derate
Output Chopping Frequency	1.5 kHz for all frames Up to 3 kHz available with derating
Inverter Type Modulation	Two-level voltage converter Pulse Width Modulation (PWM)
Power Semiconductor Technology	Low Loss Trench IGBT
Inverter Efficiency	98.5%

Motor Control

With Speed Sensor (Resolver or Encoder)

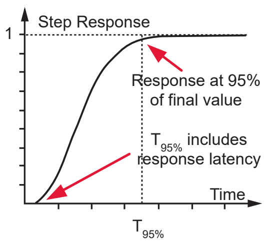
- Speed regulator accuracy: +/- 0.01%
- Maximum speed response: 60 rad/sec
- Torque linearity: +/- 3% with temperature sensor
  +/- 10% without temperature sensor
- Maximum Torque current response: 1000 rad/sec
- Torque range: 0-400% of rated motor torque
- Maximum flux control range: 20%-100%

Without Speed Sensor

- Speed regulator accuracy:
  +/- 0.1% with temperature sensor
  +/- 0.2% without temperature sensor
  (Using 1% slip motor at rated flux)
- Maximum speed regulator response: 20 rad/sec
- Minimum continuous speed: 3%
- Torque linearity: +/-10%
- Maximum Torque current response: 1000 rad/sec
- Torque range: 0-150% of rated motor torque
- Maximum flux control range: 75%-100%

Inverter notes

1. All inverter cabinets are 605 mm (24 in) in depth. All equipment requires a steel support of at least 50 mm (2 in) under the panel (not included in these dimensions). All shipping splits are 2.4 m maximum.
2. A minimum of 500 mm (20 in) should be allocated above cabinet for fan maintenance. No back access is required. A minimum of 500mm (20 in) front clearance is required and 1500 mm (59 in) of front clearance is recommended.
3. Motor power ratings assume no options, 150% overloads, motor efficiency of 95%, motor power factor of 0.85, ambient temperature 0-40˚C (32-104˚F), and altitude below 1000 m (3280 ft) above sea level. Use actual motor data for final inverter selection.
4. The specified current ratings are continuous to which the referenced overload can be applied for a maximum of 60 seconds. Refer to application example on page 14.
5. Inverters support bottom cable entry. Top cable entry is supported with one 600 mm (24 in) auxiliary cabinet between every two inverter cabinets.
6. Each of the inverters requires 3-phase control power.
7. For high-performance torque regulation, a temperature sensor is mounted in the motor.
8. Speed and current regulator responses are computed per the adjacent figure in radians/s. Speed regulator responses shown are maximum available. Actual response will be limited by drive train mechanical conditions. Accuracy and linearity specifications shown are as measured under controlled conditions in our lab and while typical may not be achievable in all systems.
9. Air is pulled in through the front and out through the top for all cabinets.
10. The dc bus for the lineup has a maximum current capacity of 2350 amps.
11. For frames 2-250, add 500 VA of control power for inverter enclosure.



Environmental (Inverters and Converters)

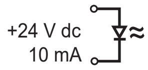
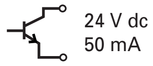
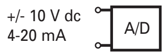
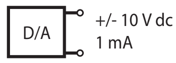
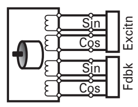
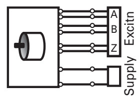
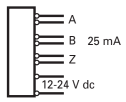
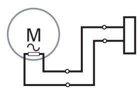
Operating Temperature	0 to 40°C (32 to 104°F) at rated load 20 to 50°C (-4 to 122°F) with derating Derate current -2.5% per ˚C above 40˚C, all frames Derate current -2.5% per ˚C below 0˚C, frames 400 and larger
Storage Temperature	-25 to 55°C (-13 to 131°F)
Temperature Humidity	5 to 95% relative humidity Non-condensing
Altitude	0 to 5000 m (16400 ft) above sea level Derate current ratings: 1% per 200 m (656 ft) altitude above 1000 m (3280 ft) Derate voltage 2.25% per 200 m (656 ft) for 460 V inverters above 4000 m (13120 ft) for 690 V inverters above 2000 m (6560 ft)
Vibration	IEC60721-3-3 Class 3M2 2 Hz<f<9 Hz: Half amplitude sine wave is within 1.5 mm 9 Hz<f<200 Hz: Vibration acceleration is 5 m/s² or less

Mechanical (Inverters and Converters)

Enclosure	IP20 (NEMA 1). IP32 is optional
Cable Entrance	Bottom is standard Top with optional auxiliary cabinet
Wire Colors	Per CSA/UL and CE
Short Circuit Ratings	100 kA for ac and dc buswork 10 kA for control power (UL) 15 kA (IEC)
Acoustic Noise	70 dB (78 dB for TMdrive-P10e2 690 V 1200F/2400F Type F Frames)
Mean Time to Repair	30 minutes to replace power bridge phase-leg
MTBF	> 41,000 hours
Code Conformance	Applicable IEC, JIS, JEM, UL, CSA and NEMA standards
Equipment Markings	c UL us E221104 Canada United States European Union

Flexible I/O Interface

I/O Interface

Digital Inputs		• Quantity 2 for UVS (SIL 2) • Quantity 4 configurable mapping
Digital Outputs		• Quantity 2 for UVS (SIL 2) • Quantity 4 user defined • Open Collector
Analog Inputs		• Quantity 1 configurable • Differential • 13-bit resolution
Analog Outputs		• Quantity 1 user defined • Non-Isolated • 10-bit resolution
(Optional) Speed Feedback Resolver Input		• Excitation frequency of 1 or 4 kHz • Source for resolvers is Tamagawa: www.tamagawa-seiki.co.jp
Speed Feedback Encoder Input		• A quad B with marker • Maximum frequency of 100 kHz • Differential or single-ended 5 or 15 V dc
Speed Tach Follower Output		• A quad B with marker • Maximum frequency of 100 kHz
Motor Temp. Feedback		• High-resolution torque motor temperature feedback • 1 kΩ positive temperature coefficient RTD or other sensor requires selecting Option Unit

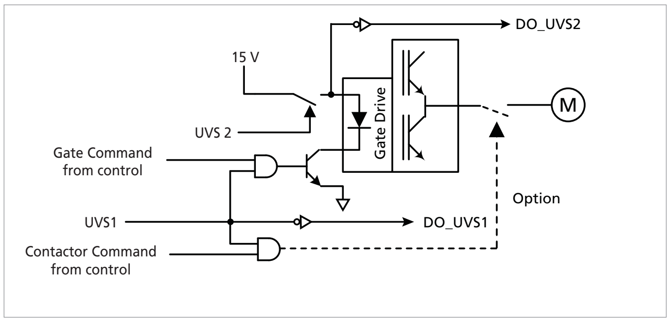
LAN Interface Options

TC-net I/O	8 words in/out
Ethernet Global Data (EGD)	10 words in/out
Profibus-DP	10 words in/out
Modbus RTU	10 words in/out
ControlNet	10 words in/out
DeviceNet	5 words in, 10 words out

TOSLINE-S20 and ISBus legacy LANs can also be supported on request

Safety Integrity

Safety features according to IEC 618005-2 (Safety Integration Level 2) and ISO 13849-1 (Category 3). Safety integrity level 2/category 3 is insured by independent gate command lockout via two hardware inputs; UVS1 and UVS2. In addition, when the optional output contactor is supplied it is also disabled by the UVS1 signal providing additional protection.



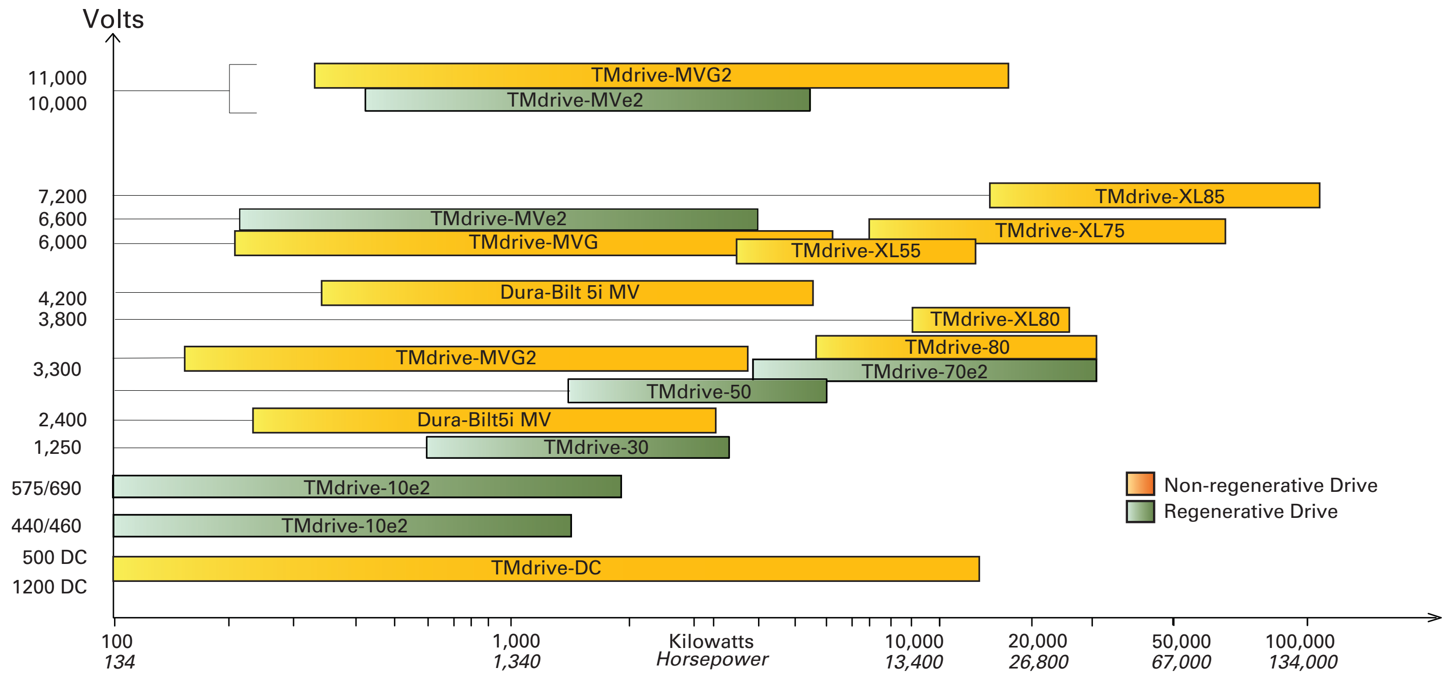
Option I/O Unit A

Digital Inputs	• Adds Quantity 5 configurable • Relay or solid state
Digital Outputs	• Adds Quantity 5 user defined • Relay (1 A) or solid state (70 mA)
Analog Inputs	• Adds one isolated channel
Analog Outputs	• Adds one isolated channel

Option I/O Unit B

Digital Inputs	• Adds Quantity 6 configurable • Relay or solid state
Digital Outputs	• Adds Quantity 6 user defined • Relay (1 A) or solid state (70 mA)
Analog Inputs	• Adds two isolated channels
Analog Outputs	• Adds two isolated channels

TMEIC AC Drives Offer Complete Coverage



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P-0002-102
April 2019