AC Induction Motor Controller

USER MANUAL

(Rev. 2.6: October 2014)

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Model

AC-L1

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1. Introduction

1.1 About SME Company

SME group, founded in 1974, is a high technology company, manufacturer of electronic controllers and related products for application in battery powered vehicles, particularly forklift trucks and specialized in the development of AC power controllers.

The group provides intelligent and innovative solutions to satisfy market requirements, achieving worldwide customer satisfaction.

SME group is able to offer a complete motion system for the different industrial lift truck ranges guaranteeing a high and safe performance customized to the client's requirements.

1.2 About this manual

This manual presents important information on configuring traction or pump systems using the *AC SmartMotion AC-L1* as well as details on sizing and selecting system components, options and accessories in an electrically powered vehicle.

This manual also presents an overview of AC induction motor and AC drives technology.

This version replaces all previous existing versions of the manual, if any.

1.3 About warning, caution and information notices

Special attention must be paid to the information presented in Warning, Caution and other kinds of information notices when they appear in this manual.

Failure to follow those recommendations may result in dangerous situations or in damages to the components, for which SME will not respond.

Warnings. A Warning informs the user of a hazard or a potential hazard which could result in serious or fatal injury if the precautions or instructions given in the warning notice are not observed.

Cautions. A caution informs the reader of a hazard or a potential hazard which could result in a serious damage to the appliance.

Information Notices. An information notice contains additional, not essential pieces of information to complete or to clarify the meaning of the paragraph they are placed into.

User Manual Reference. A User Manual Reference informs the user to look up specified user manual for more details.

1.4 Product warranty information

SME offers a two-year warranty on all the products, unless a different agreement has been put in place. Refer to the sales agreement or contract under which the *AC SmartMotion* was purchased for a complete statement of the product warranty.

1.5 How to find us

For any information on commercial and technical issues, please contact either your dealer or SME at the following address for your region:

SME S.p.A. (Europe - Headquarters)	**SME (Shangai) Co. Ltd (Asia)**	**SME Drives Inc (America)**
Via della Tecnica, n°40	No 2, Bldg. 8, 1st floor,	36 Devitt Ave North
36071 Arzignano (VI), Italy	388, Xujing Shuanglian Road	Waterloo
	201702 Qingpu District	Ontario, Canada
	Shanghai, China	N2J 3E6
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2. AC SmartMotion AC-L1 Overview

2.1 Product description

The AC-L1 Controller is designed to control AC motors.

Being based on high reliable DCB technology and exceptionally stable ITC Control Algorithm, AC-L1 Controller is a revolutionary and high quality solution for medium power applications.

The product is suitable for the following range of applications: Counterbalanced Lift Trucks, Cleaning Machines, Golf cars, Aerial Lifts, Tractors, Utility Vehicles, Tow Trucks.

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2.2 General technical specifications

AC-L1 has the following remarkable features:

- ✓ Low $R_{DS,on}$ MOSFET
- ✓ 16 bits DSP controlling 1 AC motor
- ✓ High Speed FLASH Memory
- ✓ Integrated Hall Effect Current Sensors
- ✓ **Available Supply Voltages:** 36V, 48V, 72V, 80V
- ✓ **PWM Operating Frequency:** 9kHz
- ✓ **Communication:** Serial RS-232, LIN bus and CANOpen protocol
- ✓ **Maximum Current** (measured in a two-minute time interval)**:**
  - ○ ***36/48V version:*** 625A_{rms} / 750A_{rms}
  - ○ ***72/80V version:*** 600A_{rms} / 750A_{rms}
- ✓ **Storage ambient temperature range:** -40°C ÷ +95°C
- ✓ **Operating ambient temperature range:** -40°C ÷ +55°C
- ✓ **Heatsink operating temperature range:** -40°C ÷ +95°C
  - ○ ***With linear derating:*** +80°C ÷ +95°C
- ✓ **Mechanical Characteristics:**
  - ○ ***Mechanical size:*** 210 x 190 x 91 [mm]
  - ○ ***Weight:*** 3,8 kg
  - ○ ***Connectors:*** 2x23 Ampseal terminals
  - ○ ***Protection Level:*** IP65
  - ○ Available with aluminium baseplate or finned heatsink
- ✓ **Vibration:** 5g, 10÷500Hz, 3 axes
- ✓ **I/O specifications:**
  - ○ N° 19 + 2 Digital Inputs
  - ○ N° 6 + 2 Analog Inputs
  - ○ N° 2 Digital Outputs

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- N° 3 PWM Outputs

✓ **Regulatory compliance:**

- EN1175 for safety
- EN12895 for Electromagnetic compatibility
- UL Recognized Component; meets UL583 dielectric test

The vehicle OEM takes full responsibility of the regulatory compliance of the vehicle system with the controller installed.

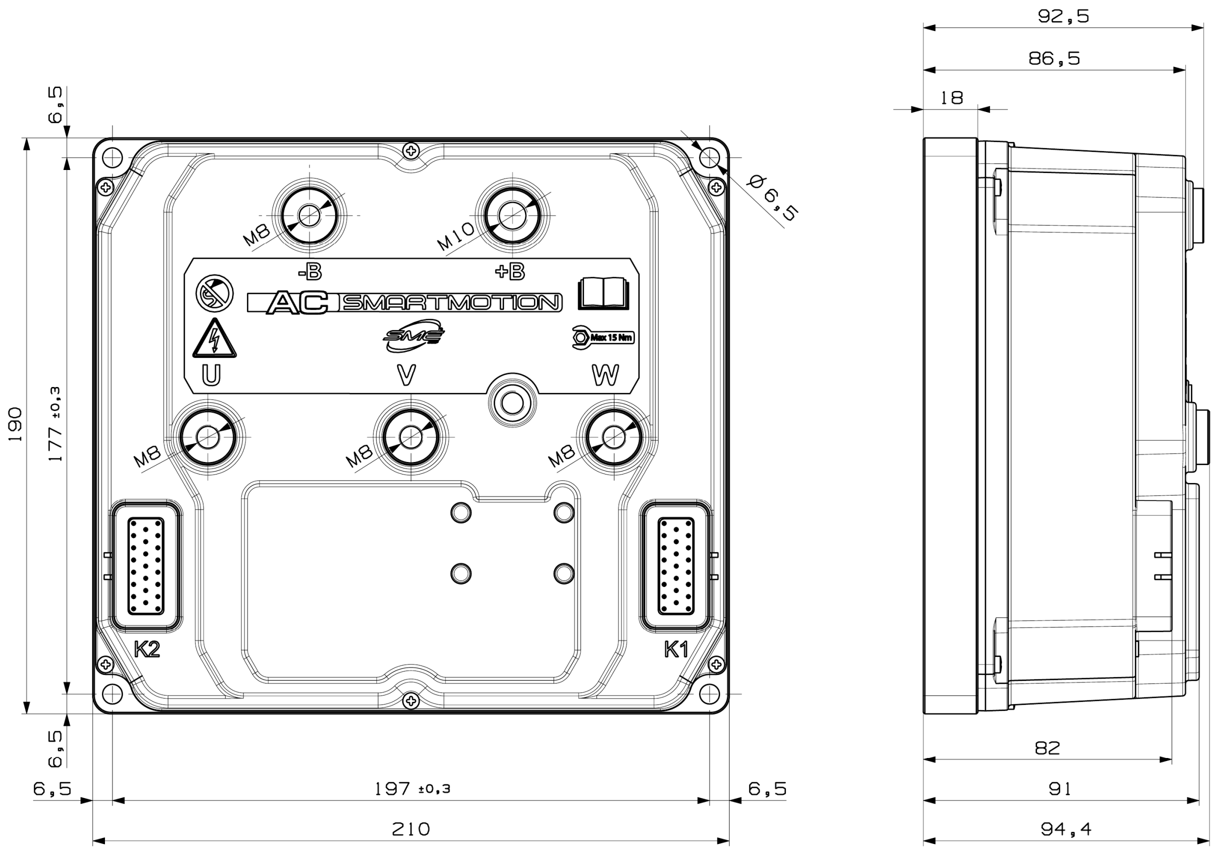

Figure 1: *AC-L1 technical drawings. All the dimensions are in millimeters.*

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The following model charts provide further details on the product family:

Model Chart for 24V version		
Model Name	**AC Inverter Max Arms(2')**	**Max Power (2')**
AC-L1 36/48V 625A	625 A_{rms}	34.6 kVA
AC-L1 36/48V 750A	750 A_{rms}	41.5 kVA

Model Chart for 36/48V version		
Model Name	**AC Inverter Max Arms(2')**	**Max Power (2')**
AC-L1 72/80V 600A	600 A_{rms}	55.4 kVA
AC-L1 72/80V 750A	750 A_{rms}	70 kVA

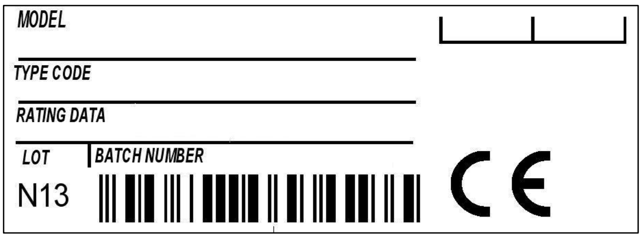
2.3 Packaging configuration

AC-M2 is available in one of the following packages:

1. with an aluminium baseplate;
2. with an aluminium baseplate and additional external heatsink.

2.4 Product indication label

The product label shows important data regarding the specific product.



The meaning of each field is described in the table below.

Field	Description
Model	Product description.
Type Code	SME code for the specific product.
Rating Data	It contains the indication of the input voltages and the output currents supplied by the product.
Batch Number	Production batch number (the same value as in barcode below).
Lot	Production Month and Year

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3. Installation and wiring

3.1 General description

The AC-L1 is composed by a control section and a power section, both enclosed in a plastic cover with an aluminium baseplate or a heatsink on the bottom of the enclosure.

There is a power module which can be connected to a three-phase AC motor through the power outputs labelled as U, V, W.

Two 23 ways Ampseal connectors (named K1 and K2), permits to interface control board to vehicle system sub-devices (throttles, switches, potentiometers, etc..).

See following pages for the pin-out of these connectors.

There are two terminals (+B) and (-B) which supply the power module.

Please see Figure 1 for AC-L1 drawings.

SME recommends you to protect the AC-L1 against reversed battery polarity.

3.2 Mounting the controller

3.2.1 Overview

AC-L1 can be oriented in any direction and meets IP65 environmental protection rating. However, the location should be carefully chosen to keep the controller clean and dry.

If a clean, dry mounting location cannot be found, a cover should be used to shield the controller from water and contaminants.

The outline and mounting hole dimensions for the AC-L1 controller are shown in Figure 1.

To ensure full rated power, the controller should be fastened to a clean, flat metal surface with four 6.5 mm diameter bolts, using the holes provided.

A thermal joint compound must be used to improve heat conduction from the controller heatsink to the mounting surface.

During the design and development of your end product, you will need to ensure that its EMC performance complies with applicable regulations.

The AC-L1 controller contains **ESD-sensitive components.** Use appropriate precautions in connecting, disconnecting, and handling the controller.

For EMC and ESD purposes, SME strongly recommends that both the AC-L1 heatsink and the houses of the motors are connected to the chassis of the truck.

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Working on electrical systems is potentially dangerous; you should protect yourself against :
Uncontrolled operation: some conditions could cause the motor to run out of control: disconnect the motor or jack up the vehicle and get the drive wheels off the ground before attempting any work on the motor control circuitry.
Voltage hazard and high current arcs: batteries can supply high voltage and very high power, and arcs can occur if they are short circuited. Always disconnect the battery circuit before working on the motor control circuit.
Wear safety glasses and use properly insulated tools to prevent shorts.
Lead acid batteries: charging or discharging generates hydrogen gas, which can build up and go around the batteries. Follow the battery manufacturer's safety recommendations and wear safety glasses.

3.2.2 Screw torque for the power connections

The recommended screw torque for fixing the connections (+B), (-B), U,V and W is 6 Nm.

This value is reported on the label placed on the cover: exceeding the recommended value may cause damages.

3.2.3 Connector parts

The K1 and K2 connectors are AMPSEAL 23 Pins, manufactured by AMP. The external plug assembly is AMP cod. 770680-1, with contact 0,5-1,4mm^2, cod. 770854-1.

3.3 Cooling requirements

3.3.1 AC-L1 with aluminium baseplate and additional heatsink

A massive heatsink comprising the entire bottom surface of the AC-L1 transfers heat out of the power conversion section to the surrounding air.

Drives operating at or near continuous power output require forced air cooling to maintain heatsink temperature in the safe operating zone.

We recommend ambient temperature air to be directed over the heatsink fins to maintain heatsink temperature below 85 °C.

Either an axial blower or two small fans can provide the necessary airflow.

3.3.2 AC-L1 with aluminium baseplate

A massive heatsink comprising the entire bottom surface of the AC-L1 transfers heat out of the power conversion section to the vehicle body.

Drives operating at or near their continuous power output require different thermal resistance depending on AC-L1 size for dissipation of heat to maintain heatsink temperature in the safe operating zone.

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In this case, AC-L1 is cooled by the surface contact to the vehicle body, so it is important to pay much attention to the flatness and the roughness of the surface of the vehicle frame where AC-L1 is mounted.

Apply thermal grease to the AC-L1 before mounting for better cooling effect.

You should keep the planarity of the surface under 0.5mm, as shown in Figure 2.

3.3.3 Clearances

For all AC-L1 models 50 mm clearances in front of and behind the AC-L1 are required for airflow; 50 mm clearance above the AC-L1 is required for installation/removal of interface connectors and wiring. Refer to Figure 1 for the dimensions of AC-L1.

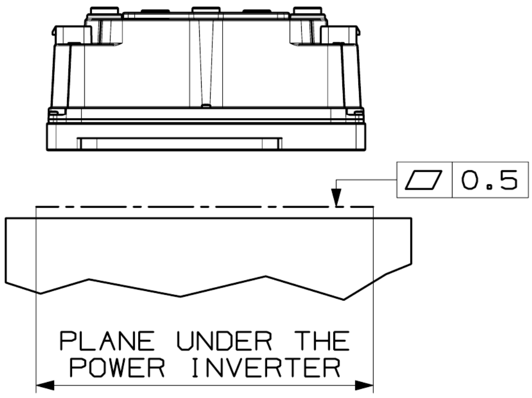

Figure 2: *Planarity specifications for the AC-L1 with aluminium baseplate.*

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3.4 List of complete pin-out

Refer to following tables for a complete AC-L1 controller K1 and K2 connectors pin-out.

K1 connector pin-out for AC-L1				SPECIFICATIONS
Pin	**Name**	**I/O**	**Specification**	**Typical Function**
1	KEY SWITCH IN	Supply Input	Rated battery +25/-30%, 6Amax	Positive supply of the control section of the AC-L1
2	DIGITAL IN 1	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
3	DIGITAL IN 2	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
4	DIGITAL IN 3	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
5	DIGITAL IN 4	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
6	DIGITAL IN 5	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
7	DIGITAL IN 6	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
8	DIGITAL OUT 1	Digital Output	Low side 0,5A	**TO BE ASSIGNED**
9	COIL RETURN	Supply Output	High side 5A max	Positive common
10	RS-232 RX	Com Input	-	Serial port
11	RS-232 TX	Com Output	-	Serial port
12	DIGITAL IN 7	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
13	DIGITAL IN 8	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
14	LIN IN/OUT	Com Input/Output	12mA pull-up	LIN display connection
15	CAN-H	Com Input/Output	CAN-bus	CAN H (No internal termination resistor)
16	DRIVER OUT 1	PWM Output	Low side 2A	**TO BE ASSIGNED**
17	DRIVER OUT 2	PWM Output	Low side 1,5A	**TO BE ASSIGNED**
18	I/O GROUND	-	-	Negative logic supply
19	DIGITAL OUT 2	Digital Output	Low side 1,5A	**TO BE ASSIGNED**
20	DRIVER OUT 3	PWM Output	Low side 1,5A (*)	**TO BE ASSIGNED**
21	+12V OUT	Supply Output	12V 300mAmax	12V supply
22	CAN GROUND	-	-	CAN- bus negative supply
23	CAN-L	Com Input/Output	CAN-bus	CAN L (No internal termination resistor)

(*) If an inductive load is connected to the driver output 3 (K1-20), there is the necessity to add an external freewheeling diode anti-parallel connected as described in the wiring diagrams.

Driver output 3 (K1-20) must be connected to the +B or to another supply source with the negative reference connected to the –B.

Driver out 1 (K1-16) and driver out 2 (K1-17) must be connected to the COIL RETURN.

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K2 connector pin-out for AC-L1				SPECIFICATIONS
Pin	**Name**	**I/O**	**Specification**	**Function**
1	+5V OUT	Supply Output	5V+/-5%, 200mAmax	5V supply
2	DIGITAL IN 9	Digital Input	20mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
3	DIGITAL IN 10	Digital Input	20mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
4	ENCODER 1 B	Peripheral Input	20mA pull-up, VL<=1V, VH>=3,5V	Quad encoder channel B
5	ENCODER 1 A	Peripheral Input	20mA pull-up, VL<=1V, VH>=3,5V	Quad encoder channel A
6	DIGITAL IN 11	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
7	DIGITAL IN 12	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
8	DIGITAL IN 13	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
9	I/O GROUND	-	-	Negative logic supply
10	MOTOR THERMAL PROBE 1	Analog Input	Pull-up	Motor temperature probe
11	MOTOR THERMAL PROBE 2	Analog Input	Pull-up	**TO BE ASSIGNED**
12	ANALOG IN 1	Analog Input	0/12V pull-down	**TO BE ASSIGNED**
13	ANALOG IN 2	Analog Input	0/12V pull-down	**TO BE ASSIGNED**
14	DIGITAL IN 14	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
15	DIGITAL IN 15	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
16	DIGITAL IN 16	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
17	DIGITAL IN 17	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
18	DIGITAL IN 18	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**
19	ANALOG IN 3	Analog Input	0/12V pull-down	**TO BE ASSIGNED**
20	ANALOG IN 4	Analog Input	0/12V pull-down	**TO BE ASSIGNED**
21	ANALOG IN 5	Analog Input	0/12V pull-down	**TO BE ASSIGNED**
22	ANALOG IN 6	Analog Input	0/12V pull-down	**TO BE ASSIGNED**
23	DIGITAL IN 19	Digital Input	4mA pull-up, VL<=1V, VH>=3,5V	**TO BE ASSIGNED**

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3.5 Typical connection diagram for basic TRACTION system

Figure below shows a connection diagram of a basic traction system using the AC-L1 as control board and an AC Induction Motor.

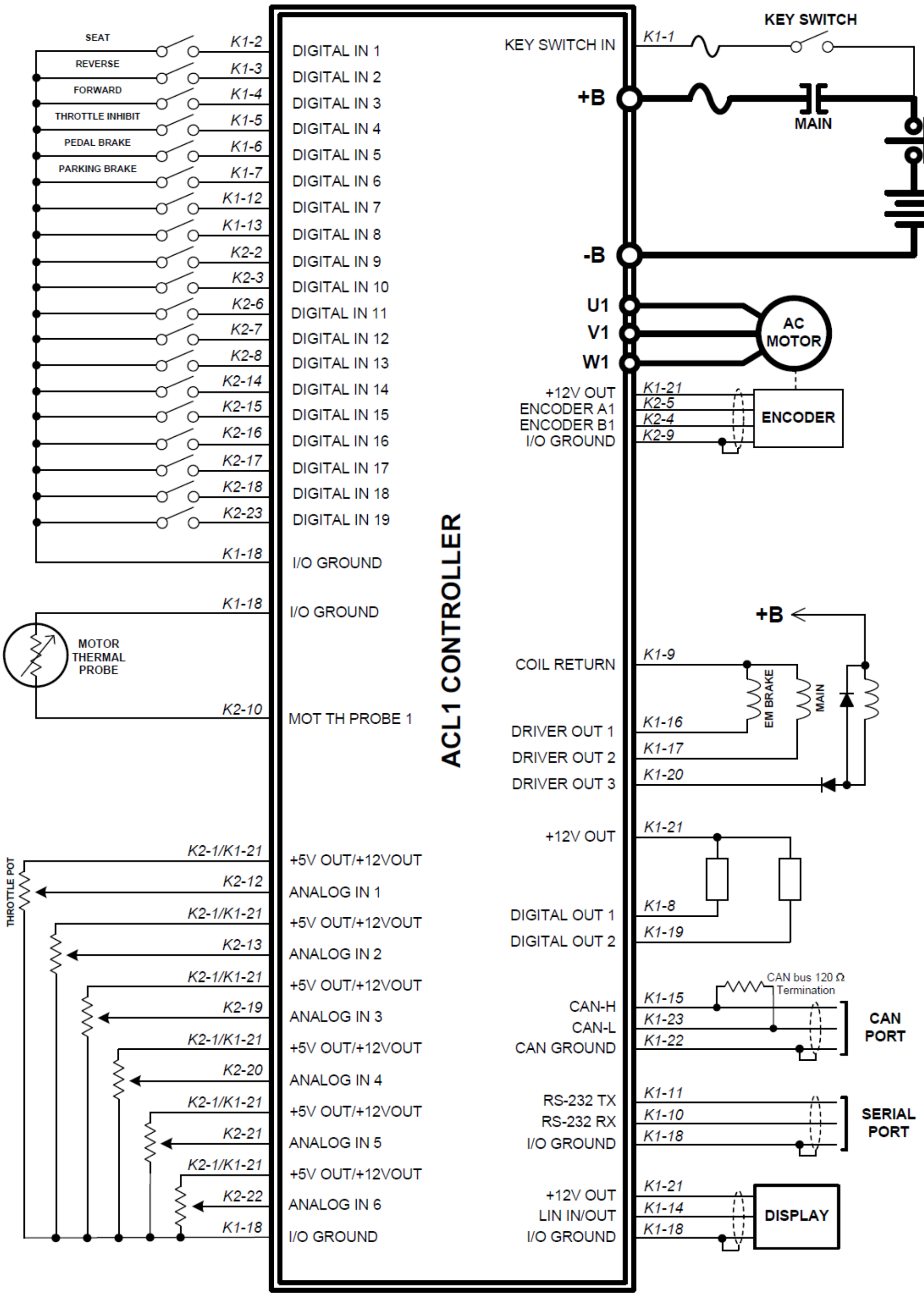

Figure 3: *Traction basic wiring diagram.*

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3.5.1 AC-L1 pin-out for basic TRACTION application

K1 connector pin-out for AC-L1 : basic TRACTION application		
Pin	**Name**	**Function**
1	KEY SWITCH IN	Positive supply of the control section of the AC-L1
2	DIGITAL IN 1	Seat switch
3	DIGITAL IN 2	Reverse direction
4	DIGITAL IN 3	Forward direction
5	DIGITAL IN 4	Throttle inhibit
6	DIGITAL IN 5	Pedal Brake
7	DIGITAL IN 6	Parking Brake
8	DIGITAL OUT 1	-
9	COIL RETURN	Positive common
10	RS-232 RX	Serial port
11	RS-232 TX	Serial port
12	DIGITAL IN 7	-
13	DIGITAL IN 8	-
14	LIN IN/OUT	LIN display connection
15	CAN-H	CAN H (No internal termination resistor)
16	DRIVER OUT 1	EM brake
17	DRIVER OUT 2	Main contactor command
18	I/O GROUND	Negative logic supply
19	DIGITAL OUT 2	-
20	DRIVER OUT 3 (*)	-
21	+12V OUT	12V supply
22	CAN GROUND	CAN- bus negative supply
23	CAN-L	CAN L (No internal termination resistor)

(*) If an inductive load is connected to the driver output 3 (K1-20), there is the necessity to add an external freewheeling diode anti-parallel connected as described in the wiring diagrams.

Driver output 3 (K1-20) must be connected to the +B or to another supply source with the negative reference connected to the –B.

Driver out 1 (K1-16) and driver out 2 (K1-17) must be connected to the COIL RETURN.

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K2 connector pin-out for AC-L1 : basic TRACTION application		
Pin	**Name**	**Function**
1	+5V OUT	5V supply
2	DIGITAL IN 9	-
3	DIGITAL IN 10	-
4	ENCODER 1 B	Quad encoder channel B
5	ENCODER 1 A	Quad encoder channel A
6	DIGITAL IN 11	-
7	DIGITAL IN 12	-
8	DIGITAL IN 13	-
9	I/O GROUND	Negative logic supply
10	MOTOR THERMAL PROBE 1	Motor temperature probe
11	MOTOR THERMAL PROBE 2	-
12	ANALOG IN 1	Throttle potentiometer
13	ANALOG IN 2	-
14	DIGITAL IN 14	-
15	DIGITAL IN 15	-
16	DIGITAL IN 16	-
17	DIGITAL IN 17	-
18	DIGITAL IN 18	-
19	ANALOG IN 3	-
20	ANALOG IN 4	-
21	ANALOG IN 5	-
22	ANALOG IN 6	-
23	DIGITAL IN 19	-

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3.6 Typical connection diagram for basic PUMP system

Figure below shows a connection diagram of a basic pump system using the AC-L1 as control board and an AC Induction Motor.

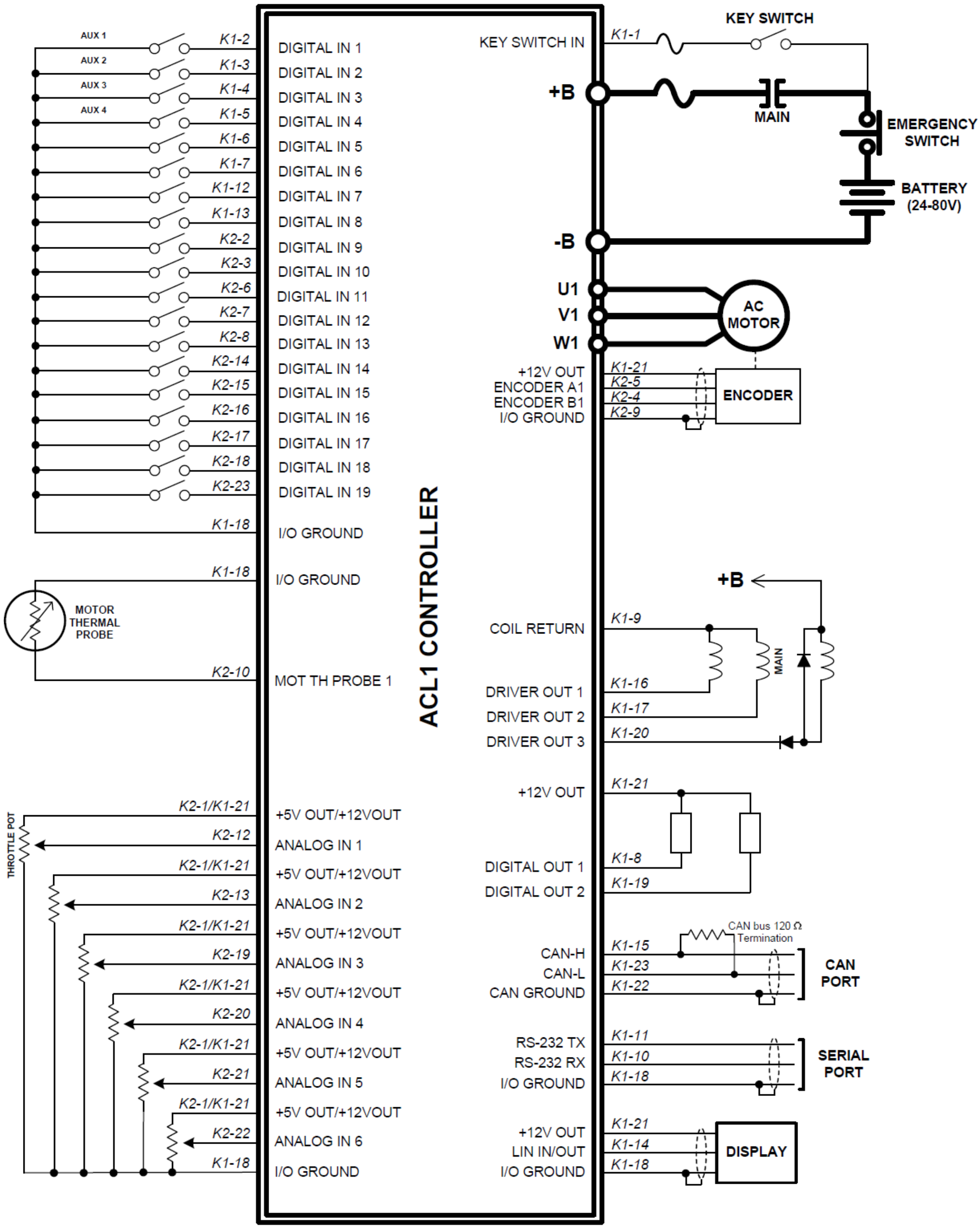

Figure 4: Pump basic wiring diagram.

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3.6.1 AC-L1 pin-out for basic PUMP application

K1 connector pin-out for AC-L1 : PUMP application		
Pin	**Name**	**Function**
1	KEY SWITCH IN	Positive supply of the control section of the AC-L1
2	DIGITAL IN 1	Auxiliary input 1
3	DIGITAL IN 2	Auxiliary input 2
4	DIGITAL IN 3	Auxiliary input 3
5	DIGITAL IN 4	Auxiliary input 4
6	DIGITAL IN 5	-
7	DIGITAL IN 6	-
8	DIGITAL OUT 1	-
9	COIL RETURN	Positive common
10	RS-232 RX	Serial port
11	RS-232 TX	Serial port
12	DIGITAL IN 7	-
13	DIGITAL IN 8	-
14	LIN IN/OUT	LIN display connection
15	CAN-H	CAN H (No internal termination resistor)
16	DRIVER OUT 1	-
17	DRIVER OUT 2	Main contactor command
18	I/O GROUND	Negative logic supply
19	DIGITAL OUT 2	-
20	DRIVER OUT 3 (*)	-
21	+12V OUT	12V supply
22	CAN GROUND	CAN- bus negative supply
23	CAN-L	L line input for CAN (No internal termination resistor)

(*) If an inductive load is connected to the driver output 3 (K1-20), there is the necessity to add an external freewheeling diode anti-parallel connected as described in the wiring diagrams.

Driver output 3 (K1-20) must be connected to the +B or to another supply source with the negative reference connected to the –B.

Driver out 1 (K1-16) and driver out 2 (K1-17) must be connected to the COIL RETURN.

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K2 connector pin-out for AC-L1 : PUMP application		
Pin	**Name**	**Function**
1	+5V OUT	5V supply
2	DIGITAL IN 9	-
3	DIGITAL IN 10	-
4	ENCODER 1 B	Quad encoder channel B
5	ENCODER 1 A	Quad encoder channel A
6	DIGITAL IN 11	-
7	DIGITAL IN 12	-
8	DIGITAL IN 13	-
9	I/O GROUND	Negative logic supply
10	MOTOR THERMAL PROBE 1	Motor temperature input
11	MOTOR THERMAL PROBE 2	-
12	ANALOG IN 1	Throttle potentiometer
13	ANALOG IN 2	-
14	DIGITAL IN 14	-
15	DIGITAL IN 15	-
16	DIGITAL IN 16	-
17	DIGITAL IN 17	-
18	DIGITAL IN 18	-
19	ANALOG IN 3	-
20	ANALOG IN 4	-
21	ANALOG IN 5	-
22	ANALOG IN 6	-
23	DIGITAL IN 19	-

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3.7 SME external devices description

AC-L1 can be connected to SME external devices described below.

3.7.1 Encoder

A Hall-effect 64-pulse quadrature encoder manufactured by SME is coaxially enclosed in the AC motors in order to provide a closed-loop control of the torque and the speed.

AC-L1 control board provides both a 5V power supply (pin K2-1) and a 12V power supply (pin K1-21). Both these power supplies are referenced to a dedicated ground terminal (pin K2-9).

To increase immunity use shielded cables and keep them separated from power leads.

Channel A has to be connected to pin K2-5 and Channel B to pin K2-4.

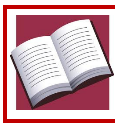
The environmental protection rating is IP65.

If you need to make use of other types of encoder, please contact SME in order to verify the technical feasibility.

3.7.2 Displays

SME displays (Compact or Mini) are optional devices which show overall information about your system. They have to be connected to controller through LIN interface.

COMPACT ***MINI***



SME Compact Display User Manual

SME Mini Display User Manual

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3.8 Programmable parameters

AC-L1 controller has a number of parameters that can be calibrated using SME PC Graphical User Interface (GUI).

These programmable parameters allow the vehicle functions and performances to be customized to fit the needs of different applications.

The programmable parameters are grouped into main categories (i.e. system, motor & control, traction / pump), and into additional subgroups, each with its own programming menu.

Most of AC-L1 default settings are fixed by SME software developers; even if user opt to leave most of the parameters at their default values, each parameter can be calibrated inside an allowable range.

User must perform the initial set-up procedures outlined in following section, to adjust some parameters which calibrate the specific system basic characteristics.

This way user is ensured that the controller is set up to be compatible with his application.

Do not drive the vehicle until initial set-up has been completed.

For more information about programmable parameters and calibration procedure refer to GUI own manuals.

SME SmartView GUI User Manual

3.9 Initial setup

As explained before, most of parameters are initially set to default values, but some settings need to be selected and set according to the system and wiring specification.

For traction systems with only one traction motor:

SME Traction Quick Start Guide

For traction systems with two traction motors:

SME Dual Traction Quick Start Guide

For systems with CANopen bus:

SME CO Network Quick Start Guide

4. Main Functions

4.1 System configuration

The system can be configured for single/dual traction or pump applications.

4.2 Battery Discharge Algorithm (BDI)

Real-time evaluation of battery State of Charge (SoC) for lead acid batteries through the Coulombian current integration and Open Circuit Voltage measure.

4.3 Battery protections

Battery Under-Voltage and Over-Voltage protections can be adjusted to match battery specifics and to extend battery life.

4.4 Mains power management

External main line contactor is completely configurable, self-managed and short-circuit protected.

Interlock input controls the main line contactor activation and deactivation for extra safety requirements.

4.5 Operating profiles

Three Operating Profile can be selected by switches combination or by display.

4.6 Generic outputs

System digital outputs can be used to command:

- alarm beeper (on active fault, on BDI low, on reverse direction, on forward direction, on vehicle roll-off);
- brake lights / horn;
- motor cooling FAN (PWM or ON/OFF mode);
- controller heatsink FAN (PWM or ON/OFF mode);
- motor and controller heatsink cooling FAN (PWM or ON/OFF mode);
- deceleration lights.

4.7 LIN display

The LIN display type can be selected and totally configured by user.

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4.8 Service

Service time interval can be choose by OEM. When the timer expires, controller automatically sets the Service Time Expired indication.

4.9 Motor & control

Motor parameters are easy to set and compatible with IEEE equivalent model circuit.

Motor current limit/versus speed characteristic is settable by user depending on the application requirements.

It is available a motor overheat protection configurable by user.

Indirect Field Oriented Control (IFOC) produces high performance and dynamic in all speed range by decoupling rotor flux and torque producing components of stator current.

Auto-Set Of Control Parameters allows an easy and quick tuning of control PID regulators gains.

4.10 Dual traction

In the case of vehicles with dual traction motors, steering angle (from potentiometer or switches) is used to generate separate speed/torque request for left and right wheel motor. This allows the motors to operate with different speeds/torques, which assists in turning the vehicle and avoids wheels scrub.

4.11 CANopen network

Through CANopen network is possible to build complex distributed control systems over a CAN data bus and interact with other devices like displays and battery management systems (BMS).

4.12 Traction / Pump control mode

Traction control mode can be selected between SPEED or TORQUE mode to cover applications from industrial vehicles to on-highway vehicles.

Pump is controlled only in SPEED mode for hydraulic applications.

Acceleration, deceleration, braking and reversal rates can be changed depending on the vehicle desired performance.

4.13 Throttles and brakes

Traction and Pump throttles and Traction brakes are totally configurable by the user and protected from wiring disconnection.

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4.14 Inching

Inching function permits to move a vehicle backward or forward with two switches only if all traction commands are released.

A time-out is used to avoid vehicle continuing movement if one of the switches gets stuck or is shorted.

4.15 Speed and current limits

Maximum motor speed and current can be limited by inputs (digital, analog or display-turtle button) status, by the active Operating Profile and when the battery is discharged.

4.16 Emergency reverse (EMR) and crawl speed

These functions are usually used in electric stackers.

When EMR switch is activated, it forces traction to reverse drive condition at a specified speed value and time.

When traction is not enabled and crawl switch input is active traction motor can moved anyway in forward or reverse direction at a specific fixed speed.

These functions are available only in SPEED control mode.

4.17 Hill hold

This function held at standstill a vehicle on a hill for a settable time. At the end of this time, the vehicle will enter in controlled roll-off. Hill hold can be activated never, always, after pressing pedal brake, by digital switch or by display.

This function is available only in SPEED control mode.

4.18 Pump auxiliary inputs

Pump motor speed request can come also from at maximum of four digital inputs. If more than one input is active, the user must choose the logic of selection (lowest/highest request).

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5. User interface

5.1 Introduction

This chapter aims to give a brief general description of SME PC GUI (monitoring, configuration, diagnostic and update functions).

A deep explanation of all the functions and the capabilities of these tools is beyond the goal of this manual, so you should refer to the specific manual.

5.2 PC Graphical User Interface (GUI)

5.2.1 Overview

SME PC GUI is a software tool designed to communicate with the controller through:

- RS-232 serial port, using an interconnection cable (SME Code IV049A, Figure 5);
- USB port, using a serial-to-USB converter
  - ✓ Supported: Prolific chip
  - ✓ Recommended: FTDI chip

5.2.2 Serial interconnection cable

Below is represented the schematic of interconnection cable to interface PC and the control board.

Refer to specific AC-L1 pin-out to wire properly the controller Rx, Tx and ground terminals. The use of a shielded cable is necessary to avoid electromagnetic interference.

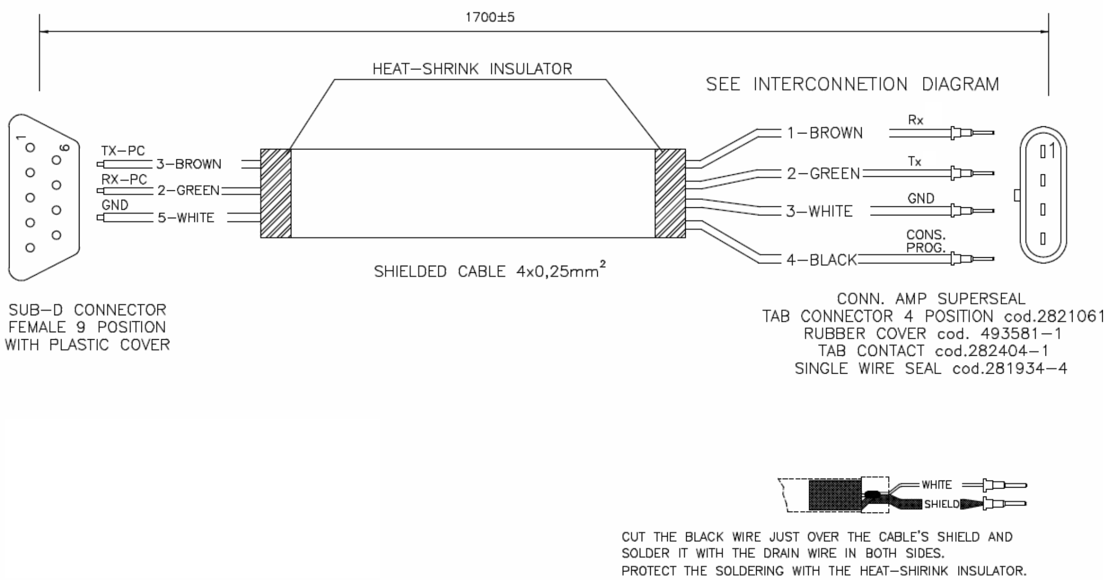

Figure 5: *Serial Interconnection cable.*

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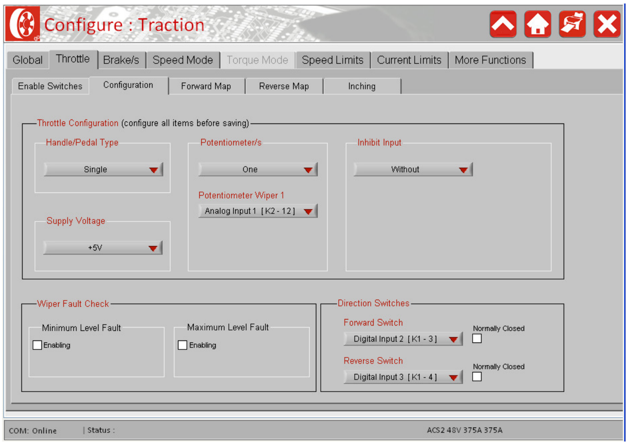
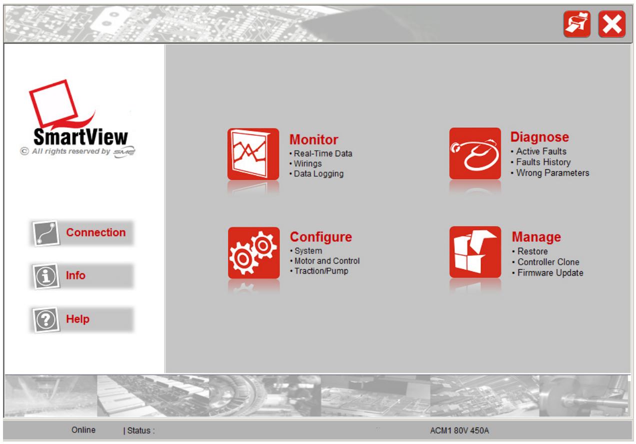
The connection between PC and SME Control board is characterized by a 38,4 Kbps.

User can communicate with the controller during working operations and can analyse real-time main system variables.

SME GUI is user friendly and intuitive.





Operator is easily guided through the process of parameter set-up and has an effective data analysis instrument.

SME utility helps user to identify faults and causes of malfunctioning.

Following functions are in particular very useful:

1. **Monitor.** The user can see the real-time state of system, I/O state, battery, motor, controller, active cutbacks and wiring. All these variables can be logged and stored in the specified file.
2. **Configure.** The user can set system, motor & control and traction/pump parameters.
3. **Diagnose.** The user can evaluate the health system state and visualize the active faults list and the fault history.
4. **Manage.** The user can update the firmware, restore default settings and clone the controller parameters.

Please, refer to the specific SME GUI manual for a detailed description of the software and its functions.

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5.2.3 System requirements

This paragraph reports the minimum hardware that the PC where SME GUI is going to be installed should have.

Minimum requirements

- 350MHz Pentium class or higher microprocessor
- 128MB or greater of RAM
- Serial port/USB port
- Graphic card 1MB
- Windows XP/Vista/7/8/8.1
- 1024x768 resolution video adapter

Recommended requirements

- 1GHz Pentium class or higher microprocessor
- 512MB of RAM
- Serial port/USB port
- Graphic card 2MB
- Windows XP/Vista/7/8/8.1
- 1024x768 resolution video adapter

6. Diagnostic and troubleshooting

6.1 Overview

Diagnostic information about anomalous working condition is provided by using SME PC GUI or by SME display.

SME AC SmartMotion Fault List

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7. EMC suggestions

7.1 General overview on EMC

Electromagnetic compatibility (EMC) encompasses two areas: emissions, i.e. the ability to work without causing electromagnetic disturbances to the nearing devices, and immunity, i.e. the ability to work in the presence of RF energy.

7.2 EM emissions

Signals with high frequency content can produce significant emissions if connected to a large enough radiating area (created by long wires spaced far apart).

Also the contactor and motor drivers can emit significant disturbances, because their outputs are pulse width modulated square waves that are rich in harmonics (however, if a contactor supply is not modulated, its emission will be zero).

The best way to minimize this kind of emission is to make the wires from the controller to the contactor or motor as short as possible and place, if possible, each current near its return (i.e.: bundle contactor wires with coil return and bundle motor wires separately).

Another good solution is to put the controller, the wires, the motors and the contactor in a shielded box, especially if very low emissions are required.

Emissions can also couple to battery supply leads and throttle circuit wires outside the box, so ferrite beads near the controller may also be required on these unshielded wires in some applications.

It is best to keep the noisy signals as far as possible from sensitive wires.

7.3 Immunity to EM disturbances

Immunity is generally achieved by preventing the external electromagnetic disturbance from coupling into sensitive circuitry.

The RF energy can get into the controller circuitry via conducted paths and radiated paths. Conducted paths are created by the wires connected to the controller.

They act as antennas and the amount of RF energy coupled into them is proportional to their length.

The RF voltages and currents induced in each wire are applied to the controller pin to which the wire is connected. SME controllers include bypass capacitors on the printed circuit board's wires to reduce the impact of this source of noise on the internal circuitry, but in some applications an additional filtering in the form of ferrite beads might also be required.

Radiated paths are created when the controller circuitry is immersed in an external field. This radiation may couple with the traces on the board and generate various kinds of malfunctions. If radiated disturbance is an issue, a good solution is to increase the distance between the controller and the possible sources of disturbance or to shield the controller by placing a metal enclosure around it.

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If a shield is required, holes should be added for ventilation purposes. In this case, using several small holes instead of few larger holes is preferable, because holes reduce the shielding capabilities (remember that reduction in shielding is a function of the longest linear dimension of a hole rather than the area).

The same concept applies to seams or joints segments of a shielded enclosure: it is important to minimize the open length between the points where good ohmic contact is made.

If the ohmic contact itself is not continuous, the shielding effectiveness can be maximized by making the joints between adjacent pieces overlapping rather than abutted.

The shielding effectiveness of an enclosure is further reduced when a wire passes through a hole in the enclosure, because RF energy on the wire from an external field is radiated into the interior of the enclosure.

A known countermeasure to this is to connect a series inductor (or ferrite bead). If a capacitor between the shield and the cable is used instead of the inductor, the capacitor must have a voltage rating and leakage characteristics that will allow the end product to meet applicable safety regulations.

The +B (and -B, if applicable) wires that supply power to control panels —such as an electronic throttle, or control wires such as keyswitch, direction, etc.— should be bundled with the other control wires to the panel so that all these wires are routed together.

If the wires to the control panel are routed separately, a larger loop area is formed.

Larger loop areas produce more efficient antennas which will result in decreased immunity performance.

All low power I/O should be kept separate from the motor and battery leads.

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8. Appendix A: General technical overview of SME technology

8.1 History of AC induction motors and AC controllers

The AC induction motor, which was invented in the 1880s, is the basic workhorse of industry; induction motors perform almost 90 percent of the electrical to mechanical power conversion in industrial machinery.

The motivation for the development of the AC drives technology was the exploitation of the advantages of the AC induction motor. By the early 1980s, thanks to rapid developments in microelectronics and power semiconductors technology, was possible to offer AC induction motor/controller combinations which were competitive with traditional DC motor/drives in many classes of applications.

Within a few years, machine tool and industrial robot manufacturers were selecting AC motors and adjustable frequency drives for their superior torque and speed capabilities, reliability and improved thermal performance.

The recent advancements in control techniques, such as flux vector control, have greatly enhanced the speed and torque control capability as well as efficiency and dynamic performance of AC induction motor/drives.

8.2 Technical advantages of AC induction motors

The main benefits of AC technology when compared to DC technology, include lower costs, higher operating reliability and longer lifetime.

With no brushes or commutator, AC induction motors are practically maintenance free and are easily sealed for superior environmental protection and higher IP ratings. With no requirement for periodic brush inspection and maintenance, the vehicle designer has more flexibility in the placement of an induction motor.

AC induction motors provide higher acceleration and deceleration torque, particularly at high speed, where the commutation limit of DC brush type motors limits their ability to generate torque.

AC drives inherently provide four quadrant operation which means that an AC drive can directly accelerate or brake a motor in both directions. The forward and reverse contactors required by many DC drives are eliminated, along with the associated noise, dead time and maintenance requirements.

Regeneration during braking is a natural characteristic of AC drives. No external components such as contactors or regeneration resistors frequently associated with DC motor/drive systems are required. Furthermore, AC drives return a higher percentage of the regenerated energy to the vehicle battery, providing extended operating time compared to commonly used DC systems.

Closed loop speed regulation, another built-in characteristic of Flux vector controlled drives, has significant implications about safety and efficiency for the vehicle.

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8.3 AC motor general description and principles of operation

8.3.1 General description of an AC motor

An AC motor has two main parts: a stator, which is fixed, and a rotor, which rotates with the shaft.

The stator is the stationary part of the motor. Within the stator assembly there is an iron core constructed from thin iron sheets coated with insulation. Copper wire, which forms the phase windings, is placed in the slots of the iron core.

The rotor is the moving part in the motor. The rotor core is made of a stack of sheet-steel laminations. Aluminium, copper or bronze conductors are placed in slots around the outer periphery of the rotor core, and these conductors are shorted together by circular end rings at each end of the rotor. A speed sensor and a thermal sensor are enclosed in the motor too.

8.3.2 Principle of operation

Figure below shows a two-pole AC motor supplied by a three-phase current.

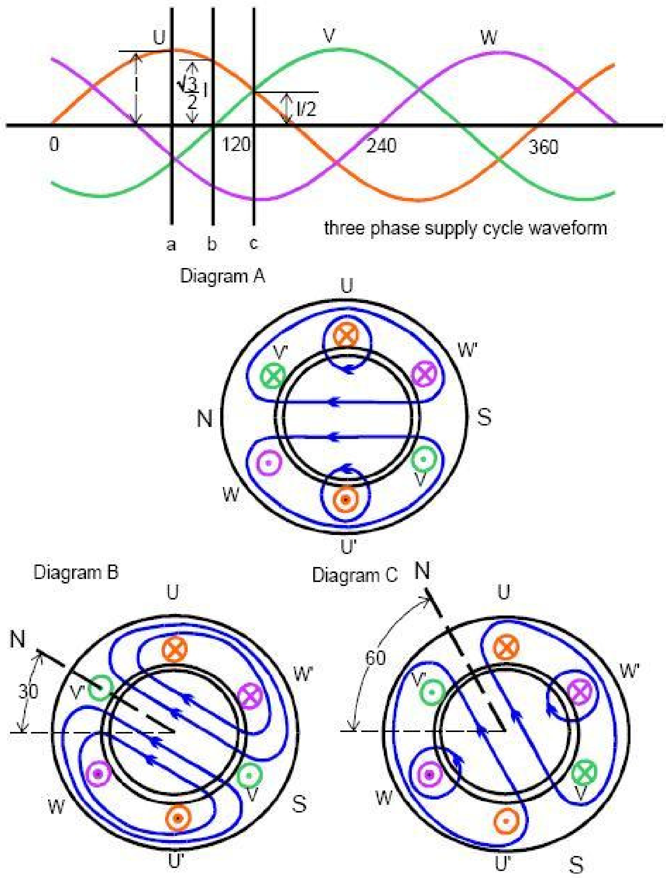

Figure 6: *Stator currents and flux in a two-pole AC motor.*

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The power supply generates a rotating magnetic flux whose angular speed (*synchronous speed*) is given by the following general formula:

$$RPM = \frac{2 f 60}{p}$$

where *f* is the three-phase frequency and *p* is the number of poles (in Figure 6, *p*=2).

If the rotor angular speed is different from the synchronous speed, a flux density derivative will appear in the rotor windings, which in turn will generate a current on those windings because they are shorted.

In the case of a counter-clockwise rotation of the stator flux, the currents in the rotor conductors are shown in Figure 7. The currents in the rotor generate a rotor flux density.

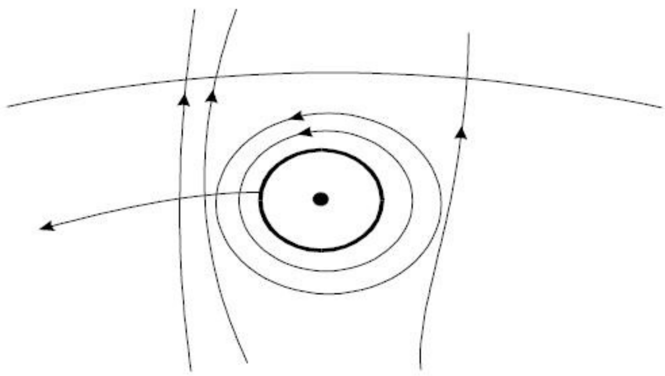

Figure 7: *Stator and flux lines around a rotor conductor.*

Above figure shows the local interaction between stator and rotor flux density around a rotor winding: the rotor flux tends to increase the total magnetic flux in the right side of the conductor, while decreases the total magnetic flux in the left side.

The net consequence on the conductor is a force directed towards left. Similar effects happen in the other rotor windings and this causes an electromagnetic torque on the rotor, which starts to rotate.

The greater the speed of the rotating magnetic field produced by the stator relative to the speed of the rotor windings, the greater the voltage produced in the rotor windings.

If rotor speed becomes the same as the speed of the stator's rotating magnetic field, (i.e. synchronous speed), no voltage and consequently no torque is produced by the rotor. Because of friction, the rotor cannot continue to rotate at synchronous speed.

Rotor speed must then fall below synchronous speed until the voltage and torque produced balance the rotor losses and any load on the motor shaft.

The amount by which rotor speed and the speed of the rotating magnetic field produced by the stator differ is called slip.

Slip, usually expressed as a percentage of the synchronous speed, is closely proportional to motor torque over a limited range.

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8.3.3 Electrical model

From an electrical point of view, an AC motor is a load which can be represented, in a fairly simplified and non-exhaustive model, as the network in diagram below (the real equivalent model is more complex).

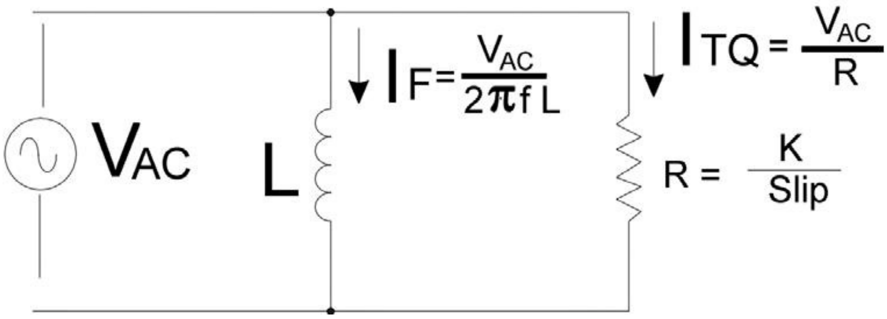

Figure 8: *Simplified AC motor electrical model.*

The strength of the rotating magnetic field is proportional to I_F, the current flowing through the magnetizing inductance L.

I_F is a mathematical aid which is used to describe the magnetic energy which is stored in the motor and is therefore known as *magnetizing current*. The value of L depends on the design of the motor.

Current flows through L is proportional to the voltage applied and inversely proportional to the frequency.

The torque produced by the motor is proportional to the slip. Increasing the slip decreases R, the rotor's equivalent resistance seen by the stator.

Current I_{TQ} is dependent on both the value of resistance R and the voltage input. Power consumed/regenerated by the rotor is mostly active power.

I_F and I_{TQ} can both be set by controlling the frequency and the magnitude of V_{AC}, the voltage applied to the motor's stator winding.

It is desirable to maintain I_F at a constant value which produces maximum field strength in the motor's magnetic circuit, while varying I_{TQ} to satisfy the changing torque requirement. Maintaining constant I_F requires the ratio of V_{AC}/f be held constant.

As motor speed increases, the frequency f increases proportionally: until a point is reached (typically the nominal speed) where V_{AC} cannot be increased further (for example, because it has reached the maximum allowable voltage supplied by the batteries). and V_{AC}/f can no longer be held constant.

Then, above the nominal speed, the controller is forced to limit the flux and, as a result, the output torque is lessened too.

However, the controller is able to partially counteract this torque reduction by increasing the slip, thus allowing the motor to be efficiently even at speeds higher than the rated one.

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8.4 ITC vector drive system

As stated above, in the last few decades the improvements in Electronics have made possible to use complex control system also for AC induction motors, in order to precisely set the output torque by employing Intelligent Torque Controls (ITC).

The most efficient algorithm is the flux vector control, which is based on a flux and torque control, depending on motor parameters knowledge and speed and current measurements. It is more complex than different control algorithms (like scalar control or slip control), but it gives much more performance, zero speed control, fast and precise dynamical response and more efficiency.

8.4.1 Basic operation of ITC vector drive system

The motor control algorithm used by SME is known as Field Orientated Control.

A schematic block diagram of a flux vector control is reported in Figure 9.

The vector flux control used by SME motor drive systems involves the following blocks:

- **Speed reference block**. The reference speed is set by pedal accelerator, which is limited and interlocked with other various signals such as: Seat, Hand brake, Pedal brake, Start, Forward, Reverse, Steering position.
  The resulting speed N_r is compared with the motor actual speed N_m calculated from the motor speed sensor signal. A regulator sets a required torque T_r to correct the speed error.
- **Speed sensor.** A quadrature pulse encoder is installed in the AC motor as speed sensor measuring the speed and the direction of the rotation.
- **Flux position.** The flux position is estimated and sent to the PWM modulator and current decoupling blocks.
- **Current decoupling**. The phase currents are measured and decoupled using suitable transformations and sent to the flux and torque estimators.
- **Torque control**. The required torque T_r is compared with the estimated torque T_e and the error is sent to a PI regulator.
- **Flux control**. The required flux F_r is compared with the estimated flux $F_{e.}$
- **Inverter voltage**. Combining the U_{sx} and U_{sy} voltage with flux frequency, a Space Vector PWM modulator is used to generate the logic state of the signals which drive the MOSFET's in the power module.

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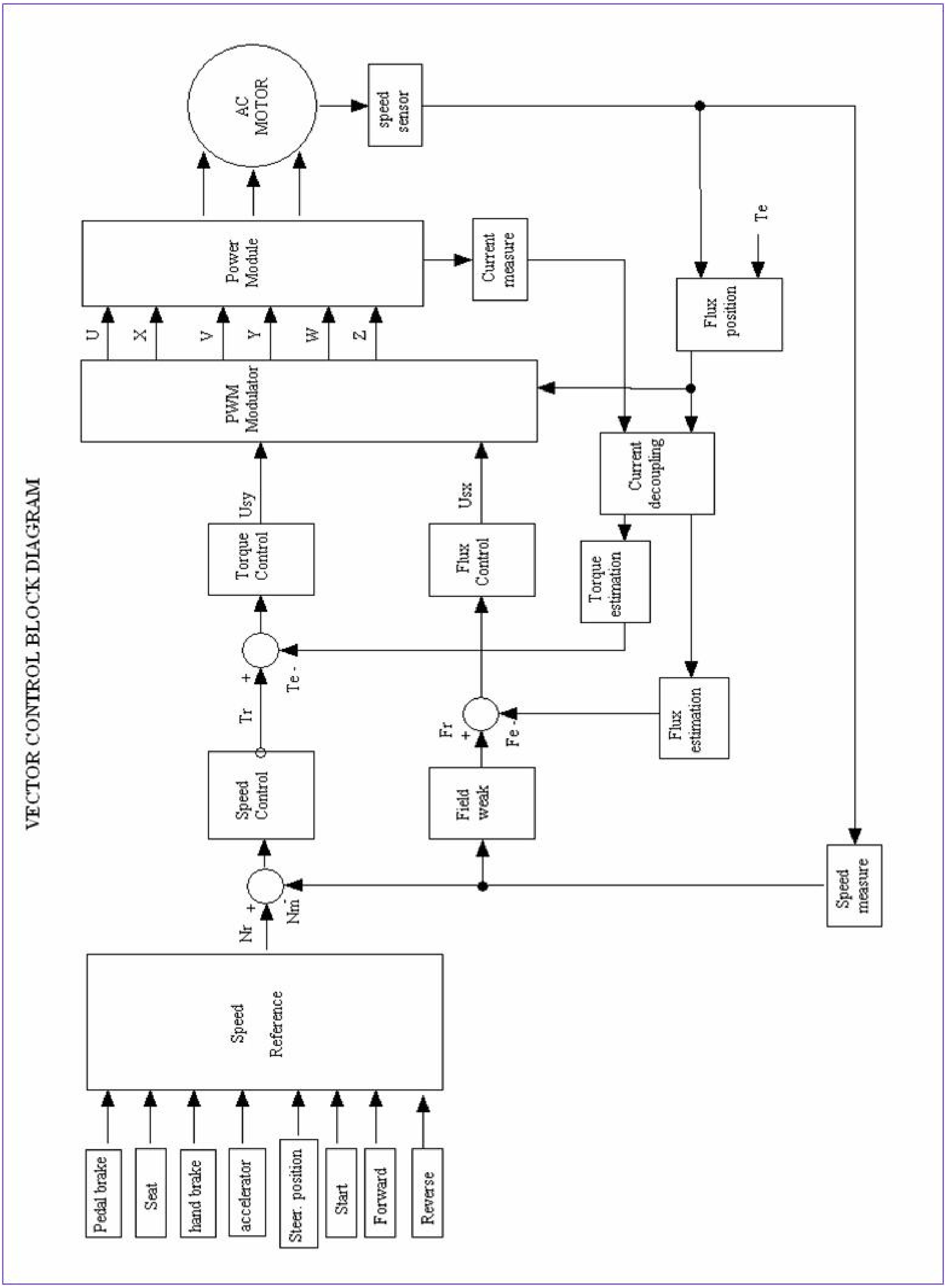

Figure 9: *Flux Vector control schematic.*

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8.4.2 Main ITC components

The most important components of the Intelligent Torque Control system developed by SME are the following:

- The control unit, which is made of a panel assembly containing the power inverter and a control board; main board, wired directly to the power modules and can manage up to 4 inverters. The presence of the DSP (Digital Signal Processors) guarantees powerful software performance and high dynamic performance in vector torque control.
- An asynchronous three-phase drive motor equipped with a speed sensor (64 impulses/rotation)
- The compact display.

The software control algorithm can be customized and a wide range of parameters can be set to optimize system performance and to adjust the settings of the main functions according to the user's needs.

The user can interact with the control board by making use of a software application (named SME GUI) developed by SME, or through the LIN display, a complete console capable of diagnostic function engineered by SME. In both cases, you can obtain an exhaustive "on line" diagnostic of all the lift truck functional parameters and adjust them too.

The control board can be upgraded by connecting a PC through the serial port (or through the USB 1.x or higher by inserting the appropriate UART-USB adapter); indeed the SME GUI application permits you to load and upgrade the firmware of the control panel in any working conditions.

8.4.3 Basic ITC functions

The following basic hardware and software functions characterize the SME system:

- protection against reverse battery polarity;
- anti-roll-back, with adjustable deceleration rates;
- anti-roll-off;
- regenerative braking;
- electrically assisted braking;
- management of Static Return to Off function (SRO);
- speed compensation (load/unload);
- speed acceleration/deceleration;
- speed reduction;
- redundant control of acceleration pedal (applying a control switch or a double potentiometer);
- continuous control of main contactor applied to DC power line;

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- seat switch open check with delay time;
- battery Discharged Indicator with adjustable reset value;
- over temperature protection for inverter and motor;
- low and high battery voltage limit;
- speed feedback;
- hill hold;
- standby for supply;
- diagnostics and stored fault code;
- mains fault detection (fuse/contactor);
- continuous temperature measuring (controller and motor);
- short-circuit protection.

8.4.4 ITC characteristics

The system developed by SME allows the OEM to get high performance, thanks to the following specific features:

- DSPs high performance control with custom software, loaded in the internal FLASH memory;
- one serial asynchronous RS-232 interface for PC communication in order to obtain:
  - parameters modification, in order to customise the system;
  - diagnosis functionalities;
  - software updates;
- one throttle (0-12V) and all on/off emergency micro-switches interface;
- one encoder (0-5V) interface for the motor;
- motor torque control by speed and current loop;
- controlled acceleration and deceleration rates of the motor;
- automatic traction speed limitation depending on steering angle;
- controlled stop of the vehicle;
- automatic energy recovery during braking;
- LIN (Local Interconnect Network) display interface;
- automatic vehicle speed limitation by digital and analog inputs;
- full protection of drives against motor over current, power transistors overheating and both maximum and minimum battery voltage;
- low maintenance costs by using AC induction motors;
- a CAN network, which can be used to build more complex control systems with other control boards or to connect particular kinds of sensors or devices, giving further flexibility.

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9. Appendix B: Document History

Rev. 1.1, June 2013:

Added a specification for driver output 3: if an inductive load is connected to the driver output 3 (K1-20), there is the necessity to add an external freewheeling diode anti-parallel connected as described in the wiring diagrams.

Corrected North-America region address.

Added supported USB-to-serial types.

Aligned Configure EM Brake parameters to actual SME GUI: now there is a tab for EM Brake and one for motor activation times.

Rev. 1.2, July 2013:

Corrected GUI images.

Rev. 1.3, December 2013:

Added dual traction system and CANopen net.

Rev. 2.0, December 2013:

Refactoring in all documentation and added references to single features user manual.

Rev. 2.1, January 2014:

Corrected front page and header. Deleted 3.10 paragraph. Some adjustment into 'General technical specification' paragraph.

Rev. 2.2, January 2014:

Added safety rules information.

Rev. 2.3, January 2014:

Corrected wiring diagrams (drive out 3 must be connected to +B).

Added connection description for drive outs below the first connector table.

Rev. 2.4, April 2014:

Corrected temperature range specifications.

Corrected SME Shangai company name.

Made more visible "the vehicle OEM takes full responsibility of the regulatory compliance of the vehicle system with the controller installed."

Restyled tables borders.

Rev. 2.5, May 2014:

Added deceleration lights in generic output.

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Rev. 2.6, October 2014:

Changed SME Group logo.

Added crawl speed function in par. 4.16.

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