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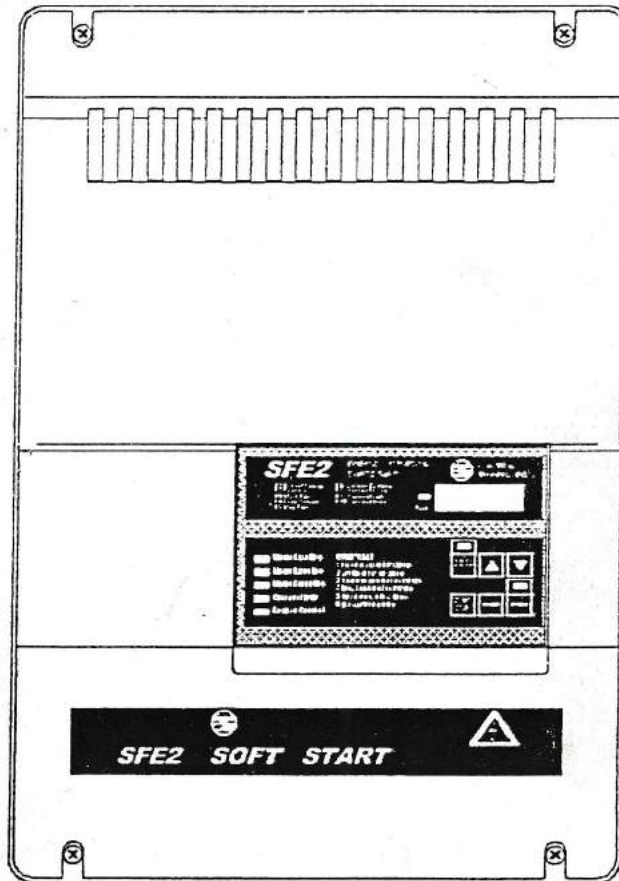
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Energy optimising  
soft-start products  
for standard AC and  
squirrel-cage motors

# SFE2



## Technical Handbook

2. del

### INSTALLATION

*instructions for qualified electricians and maintenance engineers*

### APPLICATIONS

*information for system designers and consulting engineers*

### CONCEPTS

*underlying principles for energy optimising and soft-start*

str. 53-108



## 1.4.4 continued

<b>PARAMETERS</b> Value Parameter - Read-only			
<b>PARAMETER NUMBER AND NAME</b>			
<b>MINIMUM</b>	<b>MAXIMUM</b>	<b>DEFAULT</b>	<b>UNITS</b>
Description and Notes			
<b>r10: PEAK CURRENT DETECTOR</b>			
0	8 x Unit FLC	—	Amps
Shows the peak value of current during the most recent motor starting.			
<b>r11: SOFTWARE PRODUCT NUMBER</b>			
1	255	—	—
Shows the product number of the software within the unit.			
<b>r12: SOFTWARE VERSION NUMBER</b>			
1	255	—	—
Shows the version number of the software within the unit.			
<b>r13: LAST DETECTED TRIP</b>			
1	16	—	—
Shows the fault code (E - -) of the most recent detected fault.			
<b>r14: LAST TRIP BEFORE r13</b>			
1	16	—	—
Shows the fault code (E - -) of the detected fault occurring before the fault whose code is in r13.			
<b>r15: LAST TRIP BEFORE r14</b>			
1	16	—	—
Shows the fault code (E - -) of the detected fault occurring before the fault whose code is in r14.			
<b>r16: LAST TRIP BEFORE r15</b>			
1	16	—	—
Shows the fault code (E - -) of the detected fault occurring before the fault whose code is in r15.			
<b>r17: LAST TRIP BEFORE r16</b>			
1	16	—	—
Shows the fault code (E - -) of the detected fault occurring before the fault whose code is in r16.			
<b>r18: LAST TRIP BEFORE r17</b>			
1	16	—	—
Shows the fault code (E - -) of the detected fault occurring before the fault whose code is in r17.			

1.4.4 continued

<b>PARAMETERS</b> Value Parameter - Read-only			
<b>PARAMETER NUMBER AND NAME</b>			
<b>MINIMUM</b>	<b>MAXIMUM</b>	<b>DEFAULT</b>	<b>UNITS</b>
Description and Notes			

<b>r19: 4 -20 mA INPUT</b>			
0	255	—	—
Multi-purpose sensing input.			

<b>r20: DC VOLTAGE INPUT</b>			
0	255	—	—
Multi-purpose sensing input.			

<b>r21: THERMISTOR INPUT</b>			
0	255	—	—
Sets an external (e.g. motor) thermistor trip (Note: When unused, insert a shorting-link between the two thermistor terminals.)			

<b>r22: HEATSINK TEMPERATURE</b>			
0	100	—	Temperature, deg. C
Shows the temperature of the heatsink. (Not fitted on some units.)			

<b>r23: THERMISTOR TRIP COUNTER</b>			
0	50	—	
Shows the extent to which the thermistor trip level has been exceeded. 0 = No trip, 50 = Trip level reached (non-linear inverse trip time curve).			

<b>PARAMETERS</b> Bit Parameter - Read/Write	
<b>PARAMETER NUMBER AND NAME</b>	
<b>BIT = 1</b>	Description and Notes
<b>BIT = 0</b>	

<b>b1: CURRENT LIMIT AND OVERLOAD TRIP SELECTOR</b>	
<b>BIT = 1 (DEFAULT)</b> TRIPS ENABLED	Enables a trip for either of the following: <ul style="list-style-type: none"> <li>the motor operates in current limit during start up for a period exceeding the time-out.</li> <li>the overload level reaches 100%.</li> </ul>
<b>BIT = 0</b> TRIPS DISABLED	

1.4.4 continued

<b>PARAMETERS</b> Bit Parameter - Read/Write	
<b>PARAMETER NUMBER AND NAME</b>	
<b>BIT = 1</b>	Description and Notes
<b>BIT = 0</b>	
<b>b2: ENERGY SAVING INPUT</b>	
BIT = 1 (DEFAULT) OPTIMISE	For BIT = 1, the optimising mode is active. For BIT = 0, the unit disables optimising and overrides some fault detection features. (Used for applications with a bypass contactor; refer to sec 2.2.)
BIT = 0 OVERRIDE	
<b>b3: KICKSTART INPUT</b>	
BIT = 1 KICKSTART ENABLED	Enables the unit to provide a voltage necessary for motor breakaway. (P11 determines the voltage level and P10 determines its duration.)
BIT = 0 (DEFAULT) KICKSTART DISABLED	
<b>b4: LOCAL START/STOP INPUT</b>	
BIT = 1 MOTOR RUNNING	If the unit is in keypad control, then, BIT = 1, indicates that the motor is running. BIT = 0, indicates that the motor is stopping or has already stopped.
BIT = 0 (DEFAULT) MOTOR STOPPING	
<b>b5: SHEARPIN TRIP SELECTOR</b>	
BIT = 1 TRIP ENABLED	Enables or disables the shearpin over-current trip (P16).
BIT = 0 (DEFAULT) TRIP DISABLED	
<b>b6: UNDER-CURRENT TRIP SELECTOR</b>	
BIT = 1 TRIP ENABLED	Enables or disables the under current trip (P15).
BIT = 0 (DEFAULT) TRIP DISABLED	

1.4.4 continued

<b>PARAMETERS</b> Bit Parameter - Read/Write	
<b>PARAMETER NUMBER AND NAME</b>	
<b>BIT = 1</b>	Description and Notes
<b>BIT = 0</b>	
<b>b7: LOW VOLTAGE SOFT-STOP SELECTOR</b>	
BIT = 1 LOW VOLTAGE STOP	Enables the operator to select either a normal or a low voltage soft-stop. (Note: For some applications the low voltage soft-stop can cause motor instability.)
BIT = 0 (DEFAULT) NORMAL STOP	
<b>b8: PROGRAMMABLE RELAY TABLE SELECTOR</b>	
BIT = 1 USE READWRITE BITS	Applications can use any bit from a Bit Parameter Table to operate the programmable relay (P20). The setting for b8 selects the Bit Parameter Table used with parameter P20.
BIT = 0 (DEFAULT) USE READ-ONLY BITS	
<b>b9: RAMP HOLD INPUT</b>	
BIT = 1 HOLD	Enables the user to hold the start-up delay angle at the level that exists when b9 goes from BIT = 0 to BIT = 1.
BIT = 0 (DEFAULT) NOT HOLD	
<b>b10: TABLE TO USE</b>	
BIT = 1 TABLE 2	The unit can keep two user-defined tables in storage memory. The bit b10 determines which table the unit will use.
BIT = 0 (DEFAULT) TABLE 1	
<b>b11: THERMISTOR SELECTOR</b>	
BIT = 1 (DEFAULT) ENABLE TRIP	Enables or disables parameter r21, the thermistor input. (Note: When BIT = 0 (Disable Trip), the thermistor status is still available through r21.)
BIT = 0 DISABLE TRIP	

1.4.4 continued

<b>PARAMETERS</b> Bit Parameter - Read-only	
<b>PARAMETER NUMBER AND NAME</b>	
<b>BIT = 1</b>	Description and Notes
<b>BIT = 0</b>	
<b>br1: PROGRAMMABLE INPUT STATE</b>	
BIT = 1 INPUT SET	Indicates the state of the Bit Parameter - Read/Write pointed to by parameter P21 (programmable input).
BIT = 0 INPUT CLEAR	
<b>br2: RUN RELAY</b>	
BIT = 1 MOTOR RUNNING	Indicates that the motor, BIT = 1 should be running BIT = 0 should not be running
BIT = 0 MOTOR NOT RUNNING	
<b>br3: TOP OF RAMP INDICATOR</b>	
BIT = 1 TOR	Indicates, BIT = 1 the start-up ramp is complete and the motor is running BIT = 0 the motor is starting or stopping or stopped
BIT = 0 NOT TOR	
<b>br4: ALARM INDICATOR</b>	
BIT = 1 ALARM	Indicates, BIT = 1 a fault has occurred BIT = 0 the unit is functioning correctly
BIT = 0 NORMAL	
<b>br5: DWELL INDICATOR</b>	
BIT = 1 IN DWELL	Indicates that the motor is, BIT = 1 operating in the dwell period, which occurs between 'Top of Ramp' and the optimising mode BIT = 0 not operating in the dwell period
BIT = 0 NOT IN DWELL	
<b>br6: CURRENT LIMIT INDICATOR</b>	
BIT = 1 CURRENT LIMIT	Indicates that the unit is, BIT = 1 operating in current limit BIT = 0 not operating in current limit
BIT = 0 NOT CURRENT LIMIT	

1.4.4 continued

<b>PARAMETERS</b> Bit Parameter - Read-only	
<b>PARAMETER NUMBER AND NAME</b>	
<b>BIT = 1</b>	Description and Notes
<b>BIT = 0</b>	
<b>br7: REMOTE START/STOP INPUT</b>	
BIT = 1 SWITCH CLOSED	Indicates that the START/STOP switch of an external circuit is, BIT = 1 closed BIT = 0 open
BIT = 0 SWITCH OPEN	
<b>br8: VOLTAGE/CURRENT MODE INDICATOR</b>	
BIT = 1 VOLTAGE MODE	Indicates that the unit operates, BIT = 1 in a voltage mode BIT = 0 in a current mode
BIT = 0 CURRENT MODE	
<b>br9: NOISE INDICATOR</b>	
BIT = 1 NOISY SUPPLY	The unit can trip when it operates from an AC supply that has an abnormal level of electrical noise. Bit br 9 indicates whether the supply has an acceptable or a high level of electrical noise.
BIT = 0 CLEAN SUPPLY	
<b>br10: INTEGRATING INDICATOR</b>	
BIT = 1 ABOVE OVERLOAD	Indicates that the motor current is, BIT = 1 above the overload setting (P18) BIT = 0 below the overload setting (P18)
BIT = 0 BELOW OVERLOAD	
<b>br11: 4-20mA COMPARATOR</b>	
BIT = 1 HIGHER	Indicates whether the 4-20mA input is higher or lower than P23
BIT = 0 LOWER	
<b>br12: INVERSE 4-20Ma COMPARATOR</b>	
BIT = 1 LOWER	Inverse of br11. For use in negative logic control
BIT = 0 HIGHER	

1.4.4 continued

<b>PARAMETERS</b> Bit Parameter   -   Read-only	
<b>PARAMETER NUMBER AND NAME</b>	
<b>BIT = 1</b>	Description and Notes
<b>BIT = 0</b>	

<b>br13: DC INPUT COMPARATOR</b>	
BIT = 1 HIGHER	Indicates whether the DC input is higher or lower than P24
BIT = 0 LOWER	

<b>br14: INVERSE DC INPUT COMPARATOR</b>	
BIT = 1 LOWER	Inverse of br13. For use in negative logic control
BIT = 0 HIGHER	

1.4.4 continued

<b>CODE TABLE</b>	<i>for selecting and entering an instruction</i>
<b>CODE 0: NO SELECTION</b>	<p>The displays shows a 0 when either of the following occurs:</p> <ul style="list-style-type: none"><li>• First entering the Code Table</li><li>• Pressing the COMMAND push-button switch to enter another instruction (Code 1 to Code 6)</li></ul>
<b>CODE 1: READ DATA FROM STORE</b>	<p>An instruction to put Value and Bit Parameters into temporary memory from storage memory. This allows the operator to change the Value and Bit Parameters - Read/Write.</p>
<b>CODE 2: WRITE DATA TO STORE</b>	<p>An instruction to put Value and Bit Parameters into storage memory from temporary memory.</p>
<b>CODE 3: REMOTE CONTROL OF MOTOR</b>	<p>An instruction which enables the control of the soft-start from an external circuit.</p>
<b>CODE 4: LOCAL CONTROL OF MOTOR</b>	<p>An instruction which enables the control of the soft-start from the keypad module.</p>
<b>CODE 5: LOAD DEFAULT VALUES</b>	<p>An instruction to put the default settings into temporary memory. (Note: Use CODE 2 after this instruction to put these settings into unit storage memory.)</p>
<b>CODE 6: PASSWORD ENTRY</b>	<p>An instruction which prevents unauthorised changing of the operating parameters of the unit. It allows the operator to do either of the following:</p> <ul style="list-style-type: none"><li>• Enable the password of the user</li><li>• Set a password</li></ul>

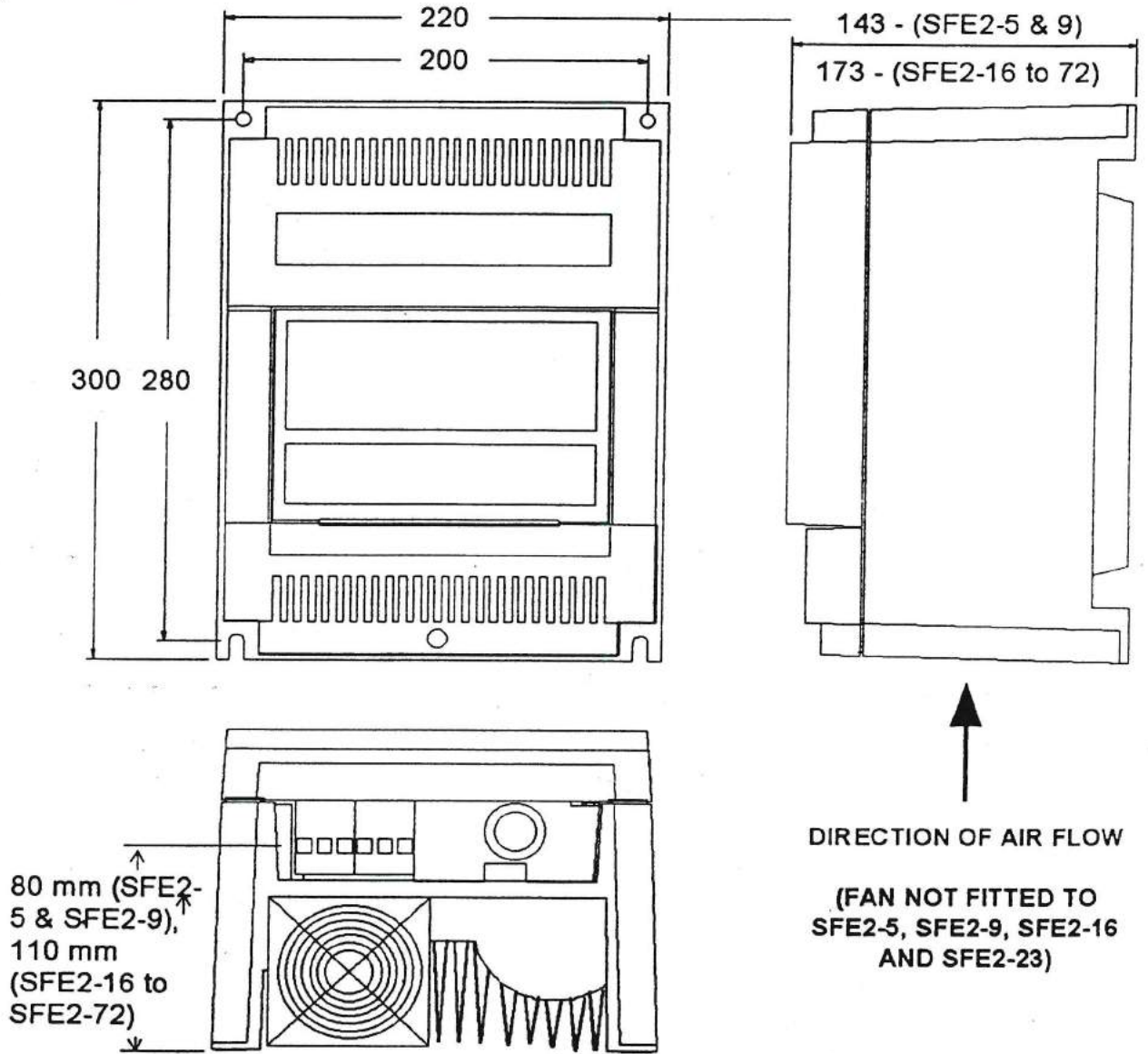
## 1.4.4 continued

<b>FAULT CODES</b>	the display shows one of these codes when an error in operation occurs. The unit then becomes inactive.
<b>E1</b>	<b>PHASE LOSS TRIP</b> If one or more AC supply phases is missing, the unit will trip. Check the supply fuses and the wiring to the unit.
<b>E2</b>	<b>THERMAL SWITCH TRIP</b> Fan-cooled units are fitted with an internal thermal switch; if an over temperature is detected the unit will trip.
<b>E3</b>	<b>LOSS OF VOLTAGE SIGNAL</b> If the reference AC supply phase is missing, the unit will trip. Check the supply fuses and the wiring to the unit.
<b>E4 - E9 *</b>	<b>THYRISTOR SENSING TRIPS</b> Indicates that one or more of the thyristor control signals is malfunctioning. (Contact the manufacturer if these faults occur.)
<b>E10 *</b>	<b>THYRISTOR SHORT CIRCUIT</b> The unit will trip if a thyristor becomes short-circuited across the poles.
<b>E11 *</b>	Unused.
<b>E12 *</b>	<b>CURRENT LIMIT TRIP</b> During start-up, the current limit (Parameter P17) is active. The unit trips if it operates in current limit beyond the period fixed during manufacture.
<b>E13 *</b>	<b>OVERLOAD TRIP</b> During normal operation the overload level detection (Parameter P18) and time delay, (Parameter P7) are active. The unit trips if it operates at the overload level for a period longer than the delay and Bit b1 is enabled.
<b>E14 *</b>	<b>SHEARPIN TRIP</b> At top-of-ramp, the Shearpin Level (Parameter P16) and time-out (Parameter P13) are active. The unit trips if it operates above its shearpin level for the time-out period and Bit b5 is enabled.
<b>E15 *</b>	<b>UNDER CURRENT TRIP</b> At top-of-ramp, the Under Current Level (Parameter P15) and time-out (Parameter P12) become active. The unit trips if the output current falls to the under current level for the time-out period provided Bit b6 is enabled.
<b>E16 *</b>	<b>THERMISTOR OVERTEMPERATURE TRIP</b> If Bit(b11 is enabled, a high resistance at the Thermistor input on the Control Terminal Panel will cause the unit to trip.

\* Various bit parameters enable these trips.

**1.5 SPECIFICATION AND DATA**

**1.5.1 Mechanical Outline - Chassis Size 1**

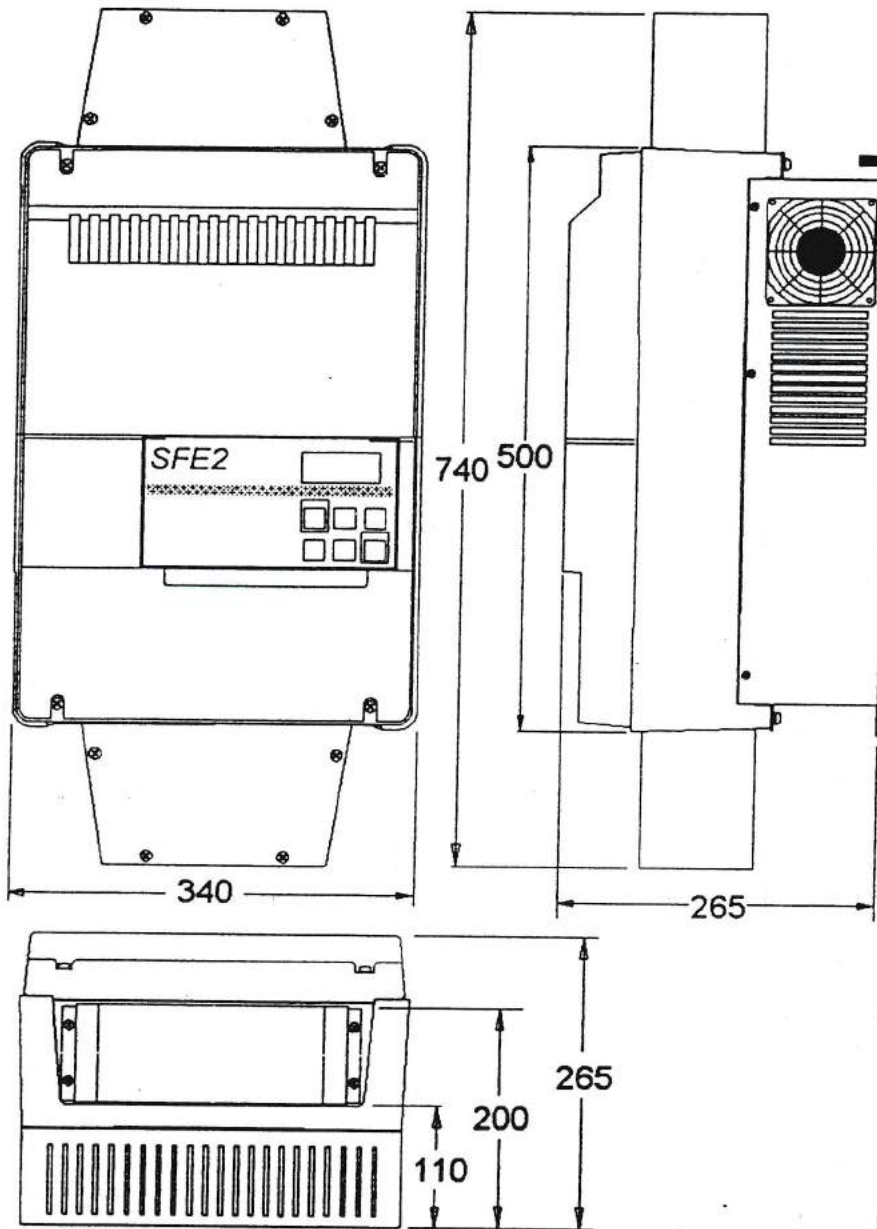


DIMENSIONS IN mm

SFE2 Model Number	Weight (Kg)	Baseplate Mounting Holes	
		Top	Bottom
- 5	4	2 holes; diameter of each hole is suitable for M6 fixings	2 open slots; each slot is suitable for M6 fixings
- 9	4		
- 16	5		
- 23	5		
- 30	5		
- 44	5		
- 59	5		
- 72	5		

SFE2 Chassis Size 1 units comply with IP20 specification.

1.5.2 Mechanical Outline - Chassis Size 2

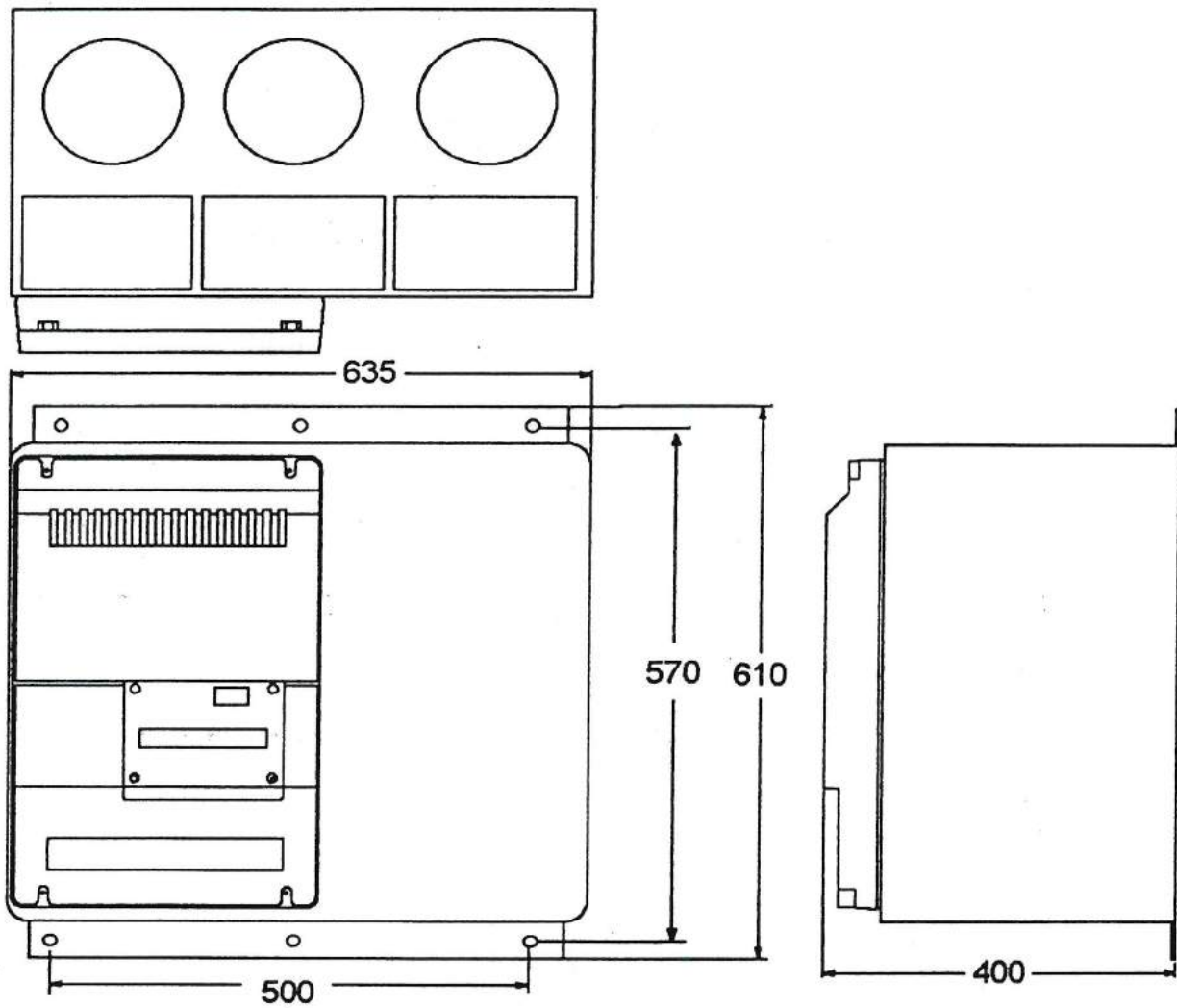


DIMENSIONS IN mm

SFE2 Model Number	Weight (Kg)	Baseplate Mounting Holes	
		Top	Bottom
- 117	15	2 keyholes; size of each keyhole is suitable for M6 fixings	2 open slots, each slot is suitable for M6 fixings
- 146	15		
- 174	15.7		
- 202	15.7		
- 242	18		
- 300	18		
- 370	18		

SFE2 Chassis Size 2 units comply with IP20 specification.

1.5.3 Mechanical Outline - Chassis Size 3



Choice of earth stud, top or bottom of the unit

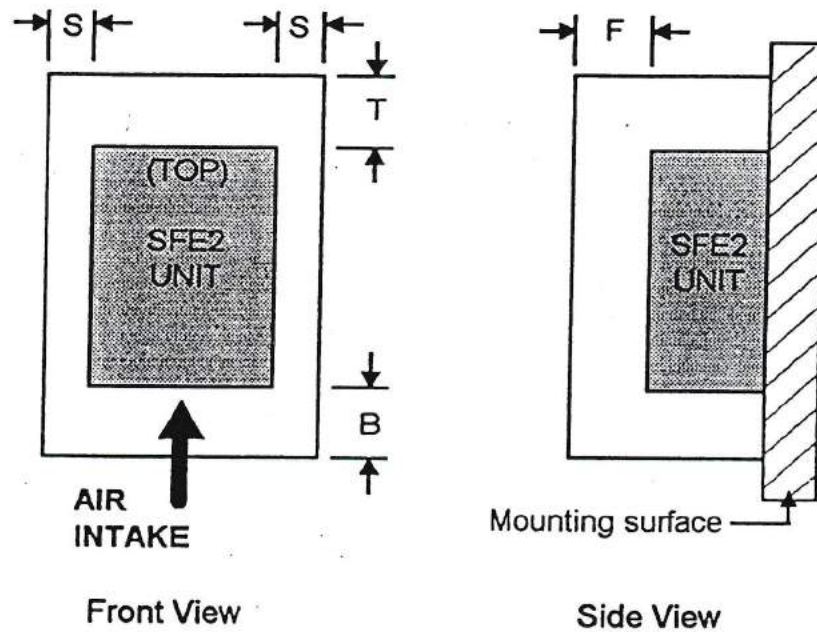
DIMENSIONS IN mm

SFE2 Model Number	Weight (Kg)	Baseplate Mounting Holes	
		Top	Bottom
- 500	25	3 holes, diameter of each hole is suitable for M10 fixings	3 holes, diameter of each hole is suitable for M10 fixings
- 600	25		
- 750	28		
- 900	28		

SFE2 Chassis Size 3 units comply with IP20 specification.

**1.5.4 Ventilation**

To maintain adequate ventilation, each model of SFE2 requires a minimum clearance to adjacent equipment and partitions. These clearances are specified in the table below.



Chassis	Ventilation Method	Minimum Clearance (mm)			
		Top (T)	Bottom (B)	Side (S)	Front (F)
Size 1 *	Natural convection	75	75	15	25
Size 1	Forced-air with built-in fan unit	75	75	75	25
Size 2		25	75	75	25
Size 3		200	200	25	25

\* Note: Fan unit not fitted to SFE2 models -5, -9, -16 and -23.

**1.5.5 Altitude**

	Maximum height above sea-level (m)
Operating (without derating)	1000
Operating (with maximum derating)	2000
<i>Derating:</i> Above 1000m, derate linearly by 1% Unit FLC per 100m to a maximum of 2000m. For altitudes greater than 2000m, consult the supplier.	

**1.5.6 Temperature**

The values shown below apply to the environment immediately surrounding the unit.

	Unit Temperature (deg. C)	
	MIN	MAX
Storage, continuous	- 25	+55
Storage, not exceeding 24 hours	- 25	+70
Operating (without de-rating)	0	+40
Operating (with maximum de-rating)	0	+60
<i>De-rating:</i> Above 40 C, de-rate linearly by 2% of Unit FLC/ C to maximum of 40% at 60 C		

**1.5.7 Electrical Supply [ Power terminals L1, L2, L3 ]**

All units will operate from a balanced 3-phase, 3-wire AC supply voltage that is within the limits specified below.

	Nominal Supply Voltage Range	
Rated Operational Voltage (U <sub>e</sub> ) 230V/460V -standard for all models	230 -15%	460 + 10%
Rated Frequency (Hz)	50	60
Phase sequence: The unit will operate with any 3-phase input sequence. However, it is important that the correct connections are made when using the SFE2 unit in an in-delta connected motor scheme. The user should ensure that the connections are suitable for the correct rotation of the motor shaft rotation before a sensitive load is coupled.		

**1.5.8 Motor Characteristics [ The motor connects to terminals T1, T2, T3 ]**

All SFE2 units will control any standard 3-phase squirrel-cage induction motor capable of operating satisfactorily when connected to the main supply with its normal load coupled. See the applications information in section 2.1 for more detailed information of special considerations.

The number of poles that the motor possesses is not significant.

**1.5.9 Control Supply [ Control terminals X1, X2 ]**

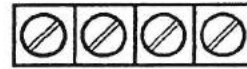
All units require a separate 2-wire supply for their internal control circuitry. At the Control Terminal Panel, the user can select either 110V or 230V operation for this control supply. (Note: This control supply needs external fuse protection.)

Nominal Control Supply Voltage (U <sub>s</sub> )	Control Supply Voltage Range		Nominal Power Consumption
	Minimum	Maximum	
110V selected	93.5V	121V	15VA
230V selected	195.5V	253V	15VA

Control Voltage Selector Links: (connector J10 on the control terminal panel)



110V operation



230V operation

**1.5.10 Power Rating**

SFE2 Model Number	Nominal Electrical Supply Voltage					
	230V		400V		460V	
	Power Output		Power Output		Power Output	
	kW	HP	kW	HP	kW	HP
-5	1.1	1.5	2.2	3.0	2.2	3.0
-9	2.2	3.0	4.0	5.5	4.0	5.5
-16	3.7	5.0	7.5	10	7.5	10
-23	6.3	8.5	11	15	11	15
-30	7.5	10	15	20	16	22
-44	11	15	22	30	22	30
-59	16	22	30	40	32	42
-72	20	27	37	50	40	54
-117	37	50	60	80	63	85
-146	45	60	75	100	80	106
-174	55	75	90	125	110	150
-202	63	85	110	150	132	175
-242	75	100	132	175	150	200
-300	90	125	160	220	185	250
-370	110	150	200	270	220	300
-500	160	220	250	350	300	400
-600	185	250	320	400	375	500
-750	250	350	400	540	450	600
-900	300	400	500	670	560	750

**1.5.11 Current Ratings- Full-Load, Current Limit and Short-Circuit Protection**

SFE2 Model Number	Rated Operational Current $I_o$ (Unit FLC) (A rms)	Short-Circuit Protection Device (SCPD)		
		Fuse Type (FE Code)	Current Rating (A)	Total $I^2t$ Clearing at 660V (A <sup>2</sup> s)
-5	5.5	FUSE.32	63	770
-9	9.0	FUSE.32	63	770
-16	16	FUSE.32	63	770
-23	23	FUSE.34	125	3700
-30	30	FUSE.34	125	3700
-44	44	FUSE.35	160	7500
-59	59	FUSE.37	250	28500
-72	72	FUSE.37	250	28500
-117	117	FUSE.39	400	105000
-146	146	FUSE.39	400	105000
-174	174	FUSE.41	500	180000
-202	202	FUSE.41	500	180000
-242	242	FUSE.42	500	170000
-300	300	FUSE.42	500	170000
-370	370	FUSE.43	630	350000
-500	500	FUSE.44	900	670000
-600	600	FUSE.44	900	670000
-750	750	FUSE.45	1250	1950000
-900	900	FUSE.45	1250	1950000
ALL	Current Limit (range of setting from keypad module, user selected) Minimum: 100% Unit FLC Maximum: 500% Unit FLC			

*Note:* The recommended fuses for SFE2 models -5 to -72 must be fitted externally to the unit. For SFE2 models -117 to -900, the recommended fuses are fitted internally, in place of the removable links.

**1.5.12 External Fuse Requirements**

The rating of fuse protection for the motor circuit should be at least twice the rated current of the motor. When high inertia loads (e.g. fans) are being started, special consideration should be given to fuse ratings due to the extended ramping times. For semiconductor protection fusing, refer to the table in section 1.5.11 above.

**1.5.13 Overload Current Profile and Duty Cycle, IEC 947-4-2 Motor Utilisation Category: AC-53a**

The table below specifies: (IEC 947-4-2 designations in brackets)

- (1) The duration of an overload ( $T_x$ , in seconds) for selected multiples of unit full-load current ( $X$ , multiple of  $I_e$ )
- (2) The ratio of the on-load period to the total period ( $F$ , percentage) for a selected number of operating cycles per hour ( $S$ )
- (3) To calculate times for a lower value of current, divide the square of the next highest given current multiplied by it's given time by the square of the required current. E.g. to find the time for  $X=2.5 I_e$ ,  $T_x = (3^2 \times 35)/(2.5^2) = 50$ seconds.

For other overload profiles, consult the supplier.

SFE2 Model Number	Overload Current ( $X$ , Multiple of $I_e$ )	Duration of Overload ( $T_x$ , seconds)	Ratio of on-load period to total load ( $F$ , %)	Number of Operating Cycles per hour ( $S$ )
-5 -9 -16 -23 -30 -44 -59 -72	3	35	99	10
	4	13	99	10
	5	4	99	10
-117 -146 -174 -202	3	35	99	10
	4	6	99	10
-242 -300 -370 -500 -600 -750 -900	3	35	60	3
	4	6	60	3

**EXAMPLE IEC RATING INDEX**

**30A : AC53a : 3 - 35 : 99 - 10**

↑  
Utilisation Category  
↑  
Rated Operational current ( $I_e$ )

For a 99% on-load factor, and 10 standard operating cycles per hour, the unit can accommodate  $3 \times I_e$  for 35 seconds.

**1.5.14 Overload Current Profile, IEC 947-4-2 Motor Utilisation Category: AC-53b**

The table below specifies: (IEC 947-4-2 designations in brackets)

- (1) The duration of an overload ( $T_x$ , in seconds) for multiples of unit full-load current ( $X$ , multiple of  $I_e$ )
- (2) The period that the motor is off (OFF-time)

For other overload profiles, consult the supplier.

SFE2 Model Number	Overload Current ( $X$ , Multiple of $I_e$ )	Duration of Overload ( $T_x$ , seconds)	Motor Off Time (OFF-time, seconds)
-5 -9 -16 -23 -30 -44 -59 -72	2	78	120
	3	35	120
	4	13	120
	5	4	120
-117 -146 -174 -202	2	78	120
	3	35	120
	4	6	120
-242 -300 -370 -500 -600 -750 -900	2	78	360
	3	35	360
	4	6	360

**EXAMPLE IEC RATING INDEX**

**30A** : **AC53b** : **4 - 13** : **47**



Utilisation Category

Rated operational current,  $I_e$ , for starting duty only

The unit can accommodate  $4 \times I_e$  for 13 seconds, but requires 47 seconds before initiating any subsequent start.

**1.5.15 Heat Output**

(At rated operational current,  $I_e$ , Unit Full-load current (FLC).)

Chassis Size 1		Chassis Size 2		Chassis Size 3	
Model Number	Heat Output (W)	Model Number	Heat Output (W)	Model Number	Heat Output (W)
-5	16	-117	350	-500	1600
-9	27	-146	440	-600	2000
-16	48	-174	520	-750	2500
-23	70	-202	610	-900	3000
-30	90	-242	650		
-44	120	-300	850		
-59	175	-370	970		
-72	210				

**1.5.16 Power, Control and Earth Terminations**

Chassis Size	Power Terminals [ L1, L2, L3 and T1, T2, T3 ]
1	IP20 rated clamping terminal suitable for solid or stranded conductor. Conductor size: 1.0 mm <sup>2</sup> (minimum), 25 mm <sup>2</sup> (maximum)
2	M8 metric threaded stud (Note: To use the stud, fit a suitable termination on the conductor.)
3	Two M10 fixings at 30mm centres, for busbar or cable terminations. Insulating panels provided for shrouding.
Control Terminals [ X1, X2 ]	
ALL	Screw clamp terminals suitable for solid or stranded conductor. Conductor size: 0.5 mm <sup>2</sup> (minimum), 2.5mm <sup>2</sup> (maximum)
Electrical Ground (Earth) Terminal	
1	Single M5 screw located by the control terminal panel
2	Single M8 x 25 metric threaded stud located on the baseplate at the top of the unit.
3	Two M10 x 30 metric threaded studs, one located on the baseplate at the bottom of the unit, the second located on the baseplate at the top of the unit. (User selects either terminal.)

1.5.17 Control Inputs

Connector/ Terminal	Identification	Description
J12/+t		Thermistor Input (2 terminals). Suitable for the connection of standard motor PTC thermistors to BS4999 or IEC 34-11.
J15/S1	PROG I/P	Programmable Input. Application of a voltage between S1 and 00, as specified below, will 'CLEAR' the bit parameter pointed to by parameter P21. (Refer to section 1.4.3 (d).) Removal of this voltage will 'SET' the bit parameter pointed to by parameter P21.  Input Voltage Range: 24VDC to 230VDC or 24VAC to 230VAC, 50Hz/60Hz
J15/S2	START	Start/Stop Input. Active only when the operator selects and enters, at the keypad, instruction CODE 3: Remote Control of Motor. (Refer to section 1.4.3 (d).) Application of a voltage between S2 and 00, as specified below, will cause the unit to initiate a START, and its removal will cause it a STOP.  Input Voltage Range: 24VDC to 230VDC or 24VAC to 230VAC, 50Hz/60Hz
J15/00	COMMON	Common (return) connection for terminals S1 and S2.
J16/OV(COMM) J16/4-20mA	OV 4-20mA	Current of 4-20mA provided by an external electronic device that the unit can monitor. May also be used for parameter mapping.
J18/OV(COMM) J19/0-21V		Monitoring input (e.g. set-point potentiometer). Can also be used for parameter mapping
J18/OV(COMM) J19/0-120V		<i>Note:</i> Only use the 0-21V input <i>or</i> the 0-120V input <i>but not both</i> .

**1.5.18 Control Outputs**

Located on the Control Terminal Panel.

Connector/ Terminal	Identification	Description
J11/11 J11/12 J11/14		Alarm relay, change-over contacts. J11/11 Pole J11/12 Normally-closed J11/14 Normally-open J11/11 connected to J11/14 indicates a detected fault. Contact rating: 230VAC, 3A AC11
J11/23 J11/24		Run relay, normally-open contacts. J11/23 connected to J11/24 indicates the motor should be running. Contact rating: 230VAC, 3A AC11
J11/31 J11/32 J11/34		Programmable relay, change-over contacts. J11/31 Pole J11/32 Normally-closed J11/34 Normally-open When the relay operates, J11/31 connects to J11/34. ( For setting details see 1.4.3 (d)). (The default function is Top of Ramp). Contact rating: 230VAC, 3A AC11
J18/0V(COMM) J18/12V		Connection for the 4 - 20mA input or the 0 - 21V input. Maximum current output: 100 mA
J20/0V(COMM) J20/AN2		Analogue output. A signal that represents the analogue value of the parameter pointed to by parameter P26. (Refer to section 1.4.3 (d).) Voltage Range: 0V to 10.0V Maximum Current: 10 mA
J23/0V(COMM) J23/AN1		Analogue output. A signal that represents the analogue value of the parameter pointed to by parameter P25. (Refer to section 1.4.3 (d).) Voltage Range: 0V to 10.0V Maximum Current: 10 mA

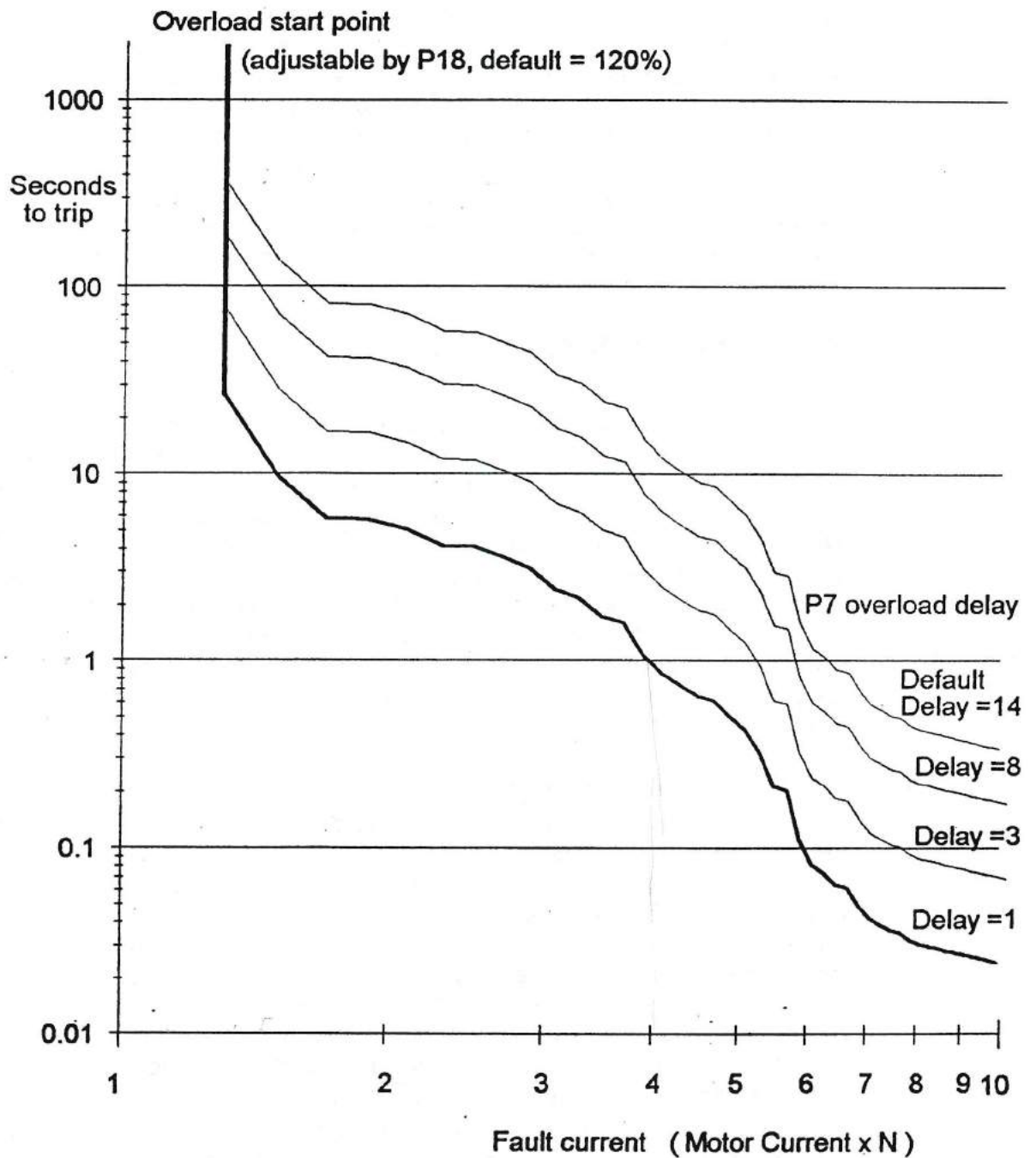
### 1.5.19 Indicators

Keypad Module:	Refer to section 1.4.1.
Control Terminal Panel:	LD1, Control Supply On LED indicator. When illuminated, LD1 indicates the presence of the control supply voltage.

### 1.5.20 Electro-Magnetic Compatibility (EMC)

As supplied, all SFE units meet the standards of emission and immunity levels defined in the IEC 947-4-2:1995 and EN 60947-4-2 product standards for AC Semiconductor Motor Controllers and Starters. However, the emc performance of the controller can be significantly affected by the manner in which it is incorporated into the system in which it is intended to operate. To prevent inadvertent degradation of emc performance, attention must be given to motor cable lengths, wiring configurations, the nature of the power supply, etc., at the design, construction and implementation stages of a project. A statutory obligation is placed product suppliers in Europe to provide information (guidelines) on how the original emc performance can be maintained after installation, and this can be found in sections 2.3.7 and 2.3.8. It is essential that the guidelines are followed closely.

1.5.21 Overcurrent Trip Graph



$$\text{Setting for the Overload Level, (P18)} = \frac{\text{Motor Current Rating}}{\text{Unit Current Rating (parameters P8, P9)}} \times 120\%$$

*Note:* This formula applies to motors that have current rating less than the unit current rating.

### 2.1 APPLICATIONS GUIDELINES

The SFE2 soft-starter is based on the "Fairford System" of microprocessor-based optimising soft-starters which have been used world-wide in more than 100,000 critical and non-critical systems. Since 1983, Fairford system soft-starters have successfully operated with almost every type of load and environment from the Antarctic to the Jungle. The design has proven to be most reliable and adaptable, and gives the user a powerful new mechanism with which to control the fixed-speed induction motor. However, due to the intrinsic differences between electronic and electro-mechanical starting systems, there are a number of simple rules and observations to follow when using an SFE2 soft-starter unit. This section introduces guidelines for the user and those incorporating the unit as part of their system design.

#### 2.1.1 General Rules for All Applications

##### 2.1.1(a) Suitability

In principle, any equipment incorporating an induction motor can be started by a soft starter. However, there are a few considerations which have to be taken into account before selecting a soft starter since the motor performance and load characteristics can alter the rating of the SFE-2 that should be applied. Normally, the breakaway torque of the load should be less than the full load torque of the motor, unless a motor with a high locked rotor torque characteristic is employed. As a quick assessment, any load which has a low or no-load start with a moderate starting time, or which can be started with a star-delta starter, auto transformer or other forms of reduced-voltage starting, can be considered to be a potential application for an SFE-2 soft starter. This means that the majority of applications are suitable.

##### 2.1.1(b) Induction Motor Characteristics

Induction motors are required to provide sufficient torque to accelerate the motor and its load from standstill to full speed and to maintain full speed efficiently at all torque levels up to the design full load torque. Most modern induction motors have characteristics which are wholly suitable for use with soft starters. However, the characteristics vary considerably between different manufacturers and design types. It is important that the motor is capable of providing sufficient torque at all speeds between standstill and rated speed to enable the SFE-2 to function properly and it is particularly important that the motor to be soft started does not have a low pull-up or saddle torque (see section 3.1.2 for more information on motor characteristics), otherwise the load may not be accelerated correctly.

Very small motors, (less than 0.75kW) which are operated at light loads may draw insufficient current to maintain conduction in the thyristors. This can give rise to erratic or rough operation. An SFE-2 soft starter is unlikely to be suitable for such a load.

The primary function of the SFE-2 soft starter is to act as a torque regulating device and cannot apply a torque greater than that which the motor generates. For this reason, problematic applications for which many different starting methods have been tried but failed, may need analysis of the motor or load performance before a soft starter can be successfully applied.

**2.1.1(c) Rating**

For most applications, the starting demands are so small, and the inertia of the rotating masses so insignificant, that no special consideration needs to be given to the rating of the SFE soft starter other than to ensure that it is equal or marginally greater than the rated voltage and current of the motor which is to be controlled.

Alternatively, if the number of poles of the motor and the moments of inertia of the load ( $J_{load}$ ) and motor rotor ( $J_{motor}$ ) are known, an SFE2 soft-starter can be selected on the basis of the motor rated current as follows:

Number of Poles	2	4	6	8
Synchronous speed (rpm)	3000	1500	1000	750
$(J_{load}) / (J_{motor})$	5	15	20	25

A table of the more common applications is given at the end of this section.

**2.1.1(d) Maximum Motor Cable Length**

The length of the cable between the output terminals of the starter and the motor should not normally be greater than 150 metres.

**2.1.1(e) Power Factor Correction Capacitors (PFC)**

Power factor correction capacitors applied individually to a motor MUST always be connected by a separate contactor placed on the SUPPLY side of the soft-starter controller. Capacitors should be switched in after the top-of-ramp condition is reached and switched out of circuit before a stop is initiated.

***It is important that any total system PFC scheme that automatically corrects for a range of inductive loads is not operated in such a way as to leave it heavily over compensated since this might introduce oscillations leading to damaging over-voltages.***

**2.1.1(f) Lightly Loaded, Small Motors**

Lightly loaded, small-sized (less than 2kW), star connected motors can produce high voltages at the motor terminals when shut down by the simple tripping of a line contactor. As these voltages can damage the soft-starter, it is safer to control the opening of the line contactor through the controller run relay contacts.

**2.1.1(g) Motors Fitted with Integral Brakes**

Motors that include an integral, electrically operated brake, internally connected to the motor input terminals, can only be soft-started when the brake is re-connected to the supply through its own contactor.

**2.1.1(h) Older Motors**

The action of the fully-controlled soft-starter introduces harmonic currents and voltages to the motor. It is therefore, important to ensure that the motor employs techniques such as rotor skewing in its construction to suppress the effects of harmonic fluxes and avoid rough starting. This is rarely a problem with modern motors because nearly all motors designed in the last 20 years employ these techniques.

### 2.1.1(i) Wound-rotor or Slip-ring Motors

Slip-ring induction motors ALWAYS need some resistance in the rotor circuit to ensure that sufficient rotational torque is generated to overcome any alignment torque which is present at start-up. The resistance can be safely shorted out in the normal fashion with a contactor controlled by the programmable relay set as 'top-of-ramp' contacts.

### 2.1.1(j) Enclosures

Thyristors are not perfect conductors, and the passage of current through them causes heat dissipation in the body of the device, which in turn causes the heatsink temperature to increase. Typically, the heat generated is 1 watt/amp/phase, which equates to a dissipation of 30 watts from the heatsink for a line current of 10 amps. Therefore, all cabinets or enclosures that house soft-starters should have adequate ventilation. Please refer to the installation procedures, section 1.2.3 for more detailed information.

### 2.1.1(k) Efficiency

Although the use of the soft-starter introduces a power loss, the system still retains an overall efficiency of 99.5%. If the optimising function has been selected, then the gain in motor efficiency at part loads is far greater than the loss of efficiency arising from thyristor heating effects. If prolonged operation at full load is expected, the thyristor loss can be eliminated (as in some matched motor/pump drives) by closing a bypass contactor around the soft-starter. (This contactor is readily controlled by the programmable relay set as 'top-of-ramp' contacts as the circuit in section 2.2.1 shows.)

### 2.1.1(l) High-Efficiency Motors

Due to an inherently steep front to the speed/torque curve, high efficiency motors can exhibit instability when lightly loaded. Using the optimising function is not recommended in this case although they can still benefit from the soft-starting feature.

### 2.1.1(m) EU Compliance with the EMC Directive

Subsequent to the fitting of the unit, users and installers in European countries must comply with the EMC Directive 89/336/EEC. The manufacturer of the soft-starter has a statutory obligation to provide a guide for compliance with this directive; this guidance is given in sections 1.3.6 and 2.3. It is essential that users and installers understand and comply with the requirements described in these sections.

### 2.1.1(n) Fuses

Circuit protection fuses should be rated at twice the motor rated current for normal low-inertia applications.

## **2.1.2 Rules for Specific Applications**

### **2.1.2(a) In-Delta Operation**

The SFE2 allows the soft-starter to be placed within the delta connections which can permit the use of a lower-current rated module. However, this form of operation is phase rotation sensitive, so an incorrect phase rotation results in the SFE2 refusing to start the motor. Simply changing the motor connections remedies this situation and enables motor starting to occur. If motor rotation is incorrect, the supply connections should be changed. It should be recognised that **six** connections between the motor and soft-starter are necessary to execute this form of working. Before using the SFE2 soft-starter in delta mode, controller parameter P27 must be set. Please refer to section 1.4.3(i) and 1.4.4.

### **2.1.2(b) High Inertia Loads**

High inertia loads such as centrifugal and axial fans, grinders, flywheel presses, etc., may require a larger size of soft-starter for the motor fitted to the drive. For example, a 15kW starter for 11kW motor. This is necessary to accommodate the extended starting time and the effect of prolonged over-currents on the thyristors. If very high inertia loads are involved, then an analysis of the ramp times should be made for different current levels. This will require accurate data on the motor speed-torque and speed-current characteristics as well as the load characteristics. For further information, consult the supplier or manufacturer. Consideration must also be given to fuse and thermal overload protection systems when extended ramp times are involved, since these may operate or be aged during the ramping process. In these circumstances, it is recommended that electronic overload systems are employed which allow for dual settings during ramping and normal operation at full speed.

### **2.1.2(c) Phase Control Operation**

Certain applications such as voltage regulators, transformers, heaters, lighting banks require the load to be controlled manually or from a 4 - 20mA input. The SFE2 soft starter is not designed for these applications. However, a special version of the SFE controller is available for this type of application. Please refer to your supplier for further information.

### **2.1.2(d) Resistive Loads**

Resistive loads such as heaters, etc. may require different forms of control such as burst-firing. The SFE2 soft-starter is not designed for these applications. However, a special version of the SFE controller is available for this type of application. Please refer to your supplier for further information.

### **2.1.2(e) Frequent Starting**

High starting frequencies require careful consideration of the SFE2 soft-starter thermal capabilities, and may show that a larger soft starter should be fitted.

### **2.1.2(f) Optimising**

Drives which operate for long periods of time at less than 35% of their rated capacity can benefit from the energy saving function (optimising) which will adjust the thyristor triggering to reduce the excitation losses of the motor. This will lower the running temperature of the machine and help to extend its life.

### 2.1.2(g) Soft-Stopping

Soft-stopping will reduce positive surge pressures in pipelines on shutdown, but it is necessary to make sure that the ramp-down time is long enough to remove the energy from the fluid before the pulsing of the thyristors is stopped, otherwise the surge pressure may still be present. Over-sized motors fitted to centrifugal pumps are sometimes difficult to control with soft-stopping.

Soft-stopping can be successfully fitted to high friction loads such as conveyer belt systems where sensitive loads such as bottles are being transported.

### 2.1.2(h) Reversing Drives and Plug-braking

SFE2 soft-starters used in conjunction with contactor controlled reversing and plug-braked motors show considerable benefits to the user by reducing mechanical and electrical stresses, particularly when utilising the current limited start feature. However, it is good practice to insert a 150 - 350 millisecond delay between the opening of one contactor and the closing of the other, to allow any residual flux in the rotor to die away. When plug-braking is employed there should be some form of zero-speed detector to trip the drive after braking has been completed, otherwise the drive will accelerate in the reverse direction. The SFE has a dual setting feature which is particularly useful in plug-braking where the braking settings need to be different from the normal starting ramp time and current levels. (See also section 2.2.4: Motor Reversing.)

### 2.1.2(i) Replacement of Fluid Couplings

Soft-starters can replace fluid couplings yielding benefits of higher efficiency running and lower costs to the user. However, if the coupling is used to magnify the available breakaway torque, it may be necessary to replace the fitted motor with another of larger size or one with a high starting torque characteristic before the soft-starter can be employed.

### 2.1.2(j) Two-speed Motor Applications

Two speed motors, whether Dahlander connected or with dual windings, can be soft started at each speed, provided that the start is given when the actual motor speed is less than the synchronous speed for the winding selected. This is particularly important when changing from high to low speeds. Of particular benefit in the SFE2 is the ability to have different operating settings for high and low speeds and the ability to switch rapidly between them.

### 2.1.2(k) Multiple Motor Starting

Refer to section 2.2.2: Multiple Motor Starting

### 2.1.3 Application Table

The table below shows many common motor applications that suit the SFE2 soft-starter. It lists typical breakaway torque requirements as a percentage of motor full-load torque (FLT). For the most satisfactory soft-start in a given application, the motor should have a full-voltage locked-rotor-torque (LRT) that exceeds twice the breakaway torque. (E.g. For a reciprocating compressor, the motor LRT should be in the region of 200% FLT.) As a general rule, the higher the motor LRT is above the load breakaway torque, the greater the control over the starting process.

## 2.1.3 Applications Table

APPLICATION	BREAKAWAY TORQUE (%FLT)	REMARKS
Agitator	35	
Air compressors, rotary, unloaded start.	25 - 35	
Air compressors, reciprocating, unloaded start.	50 - 100	Also for refrigeration applications, short ramp times
Air compressors, screw type, unloaded start.	30	Usually two-pole motor
Ball mill.	30 - 50	Eccentric load, needs high starting torque motor.
Carding machine	100	Often high inertia
Centrifuge	50 - 90	Usually high inertia
Centrifugal fan, dampers closed	10 - 25	High inertia, long ramp times may be required
Centrifugal fan, dampers open	10 - 25	High inertia, long ramp times may be required
Centrifugal blower, valve closed	25 - 35	
Centrifugal blower, valve open	30 - 40	Can have long ramp time
Chillers (rotary)	10 - 25	Usually started unloaded, two-pole motor
Conveyor, horizontal, unloaded.	10 - 50	
Conveyor, horizontal, loaded.	100 - 150	Loaded conveyor applications benefit from use of high starting torque motors.
Conveyor, vertical lifting, unloaded.	50 - 85	
Conveyor, vertical lifting, loaded.	100 - 175	
Conveyor, vertical lowering, unloaded.	10 - 40	
Conveyor, vertical lowering, loaded.	10 - 25	
Crushers, (not rock), unloaded.	25 - 75	Can be high inertia
Drilling machines, unloaded.	10	
Escalators, unloaded.	25 - 50	Optimising feature can be effective
Fan, axial-flow propeller	20 - 40	
Feeders, screw.	100 - 175	Needs high starting torque motor.
Feeders, vibrating, motor driven.	100 - 150	Needs high starting torque motor.
Grinders, unloaded.	10 - 25	Usually high inertia
Hammer mill.	20 - 125	Eccentric load, needs high starting torque motor.
Mills, flour etc.	30 - 50	
Mixers, dry contents	35 - 75	
Mixers, fluid contents	10 - 40	
Mixers, plastic contents	75 - 125	High torque motor offers advantage
Mixers, powder contents	75 - 125	High torque motor offers advantage
Pelletsers	50 - 100	
Press, flywheel.	50 - 150	Needs high starting torque motor.
Pump, centrifugal	10 - 25	Soft stopping useful
Pump, positive displacement, piston type	100 - 175	Needs high starting torque motor.
Pump, vane type, positive displacement	100 - 150	Needs high starting torque motor.
Rolling mill	30 - 50	
Saw, band	10 - 35	
Saw, circular	25 - 50	May be high inertia. Plug brake may be useful
Screen, vibrating	30 - 60	
Travelators, walkways	25	Unloaded starting
Transformers, voltage regulators	Nil	Change firing mode
Tumblers	30 - 100	Eccentric load, may need high torque motor
Washing machines, rotary, all types.	30 - 100	Usually highly geared, soft start very effective.



### **2.2.2 Multiple Motor Starting**

The SFE2 unit is capable of starting parallel-connected motors simultaneously provided each motor has similar characteristics and load. For such configurations, the rating of the SFE2 unit should meet or exceed the total power rating for all the motors.

Alternatively, the SFE2 unit can start motors sequentially using bypass contactors under the control of the programmable relay set as a 'Top of Ramp' relay. The dual setting feature of the SFE2 enables the control of individual groups of motors with differing start-up requirements. For further details on multiple motor applications, consult the supplier.

### **2.2.3 External Motor Protection Relay**

The rating for a motor protection relay should be as for Direct-on-Line (DOL) starting, and if it is an electronic relay, then the user should confirm its suitability for use with a soft-starter. If the motor load is high inertia (extended start time), then a longer trip time may be required.

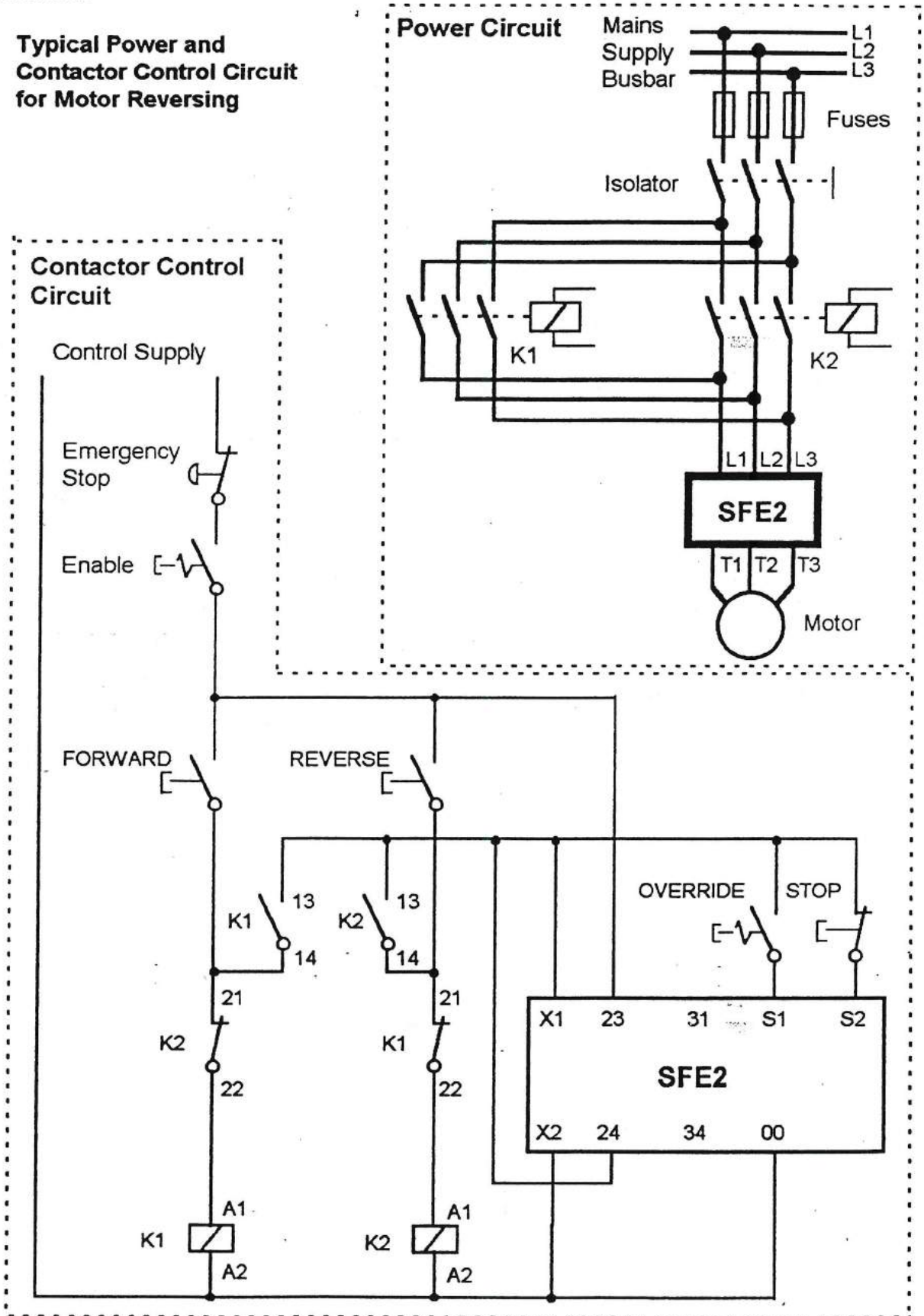
### **2.2.4 Motor Reversing**

The diagram on the next page shows a typical motor reversing circuit using two contactors, K1 and K2, to interchange two phases of the 3-phase supply connections. For this application, it is recommended that:

- A period of 150 - 350 ms elapses between the FORWARD and REVERSE commands
- If the reversing rate is high, the SFE2 rating may need to be selected on the basis of the starting duty; refer to sections 1.5.13 and 1.5.14.

2.2.4 continued

**Typical Power and Contactor Control Circuit for Motor Reversing**



## **2.3 ELECTRO-MAGNETIC COMPATIBILITY (EMC)**

### **2.3.1 Introduction**

It is widely accepted that electro-magnetic compatibility between electronic and electrical products is a desirable objective. To this end, technical standards are increasingly stipulating levels of EMC performance which compliant products are required to meet. In particular, the decision by the European Union (EU) to implement a community-wide directive covering EMC caused considerable activity amongst electrical and electronic equipment manufacturers and suppliers to identify, understand and mitigate the sources of electro-magnetic interference within their products and systems.

### **2.3.2 Applicable Standard within the EU**

The product standard which defines EMC performance for soft-starters is EN 60947-4-2 'AC Semiconductor Motor Controllers and Starters'. (The Official Journal of the EC will list this standard as EN 60947-4-2.) The SFE2 has been type tested in accordance with the test procedures and levels laid down in the product standard.

### **2.3.3 Mandatory Requirements within the EU**

(Applicable to any person involved in the installation and operation of the equipment.)

The EC document on EMC, Directive 89/336/EEC, describes the mandatory aspects of equipment use necessary to meet and retain compliance with the electro-magnetic compatibility levels it specifies. It imposes an obligation on the manufacturer of the soft-starter to provide sufficient information for installers, system integrators, users and anyone else connected with the installation and operation of the equipment. This section provides the technical information to support the obligation of the manufacturer.

From the manufacturer the provision and maintenance of compatibility extends to the panel-builder, assembler, system integrator, and ultimately, to the installer and user. Anyone involved in the installation and operation of the equipment, through a lack of knowledge, misdirection or for other reasons, can completely negate the initial EMC performance of the equipment.

### **2.3.4 Guidance for Installation Personnel and System Designers**

- (1) For safety reasons, all SFE2 products are intended to be installed and set to work by skilled personnel who are capable of interpreting and following EMC guidelines correctly. Any person not fully trained in the appropriate technology should not attempt the installation.
- (2) If you do not understand, or if you are unclear, about any part of these guidelines, then please consult your supplier. Often, consultation with the supplier can avoid unnecessary problems in specifying and installing the correct combination of equipment.

### 2.3.5 EMC - Basic Criteria

The electro-magnetic compatibility of a product is defined by two criteria:

- (1) Immunity to electromagnetic disturbances generated externally to the product
- (2) The type and amount of conducted and radiated electromagnetic emissions emanating from the product.

Ascertaining the nature of the product's power supply is of primary consideration when deciding on appropriate EMC requirements. Products installed in heavy industrial environments (fed from their own isolated low voltage power supply) differ from those installed in residential, commercial, light industry and health-care applications (directly connected to a public low-voltage network).

Generally, industrial installations require higher immunity levels and permit higher levels of conducted and radiated emissions than those for non-industrial installations. On the other hand, lower levels of emissions output, and lower immunity levels, are specified for installations connected directly to the public low-voltage network.

### 2.3.6 Purchasing Implications of Meeting an EMC Standard

Before purchasing components for the installation, the specifier must evaluate the expected source of power for the soft-starter and understand exactly the implications for meeting EMC requirements. It is likely that failure to do so will result in the purchase and installation of inappropriate equipment. Close consultation with your supplier will avoid these unnecessary problems, particularly when you do not understand, or are unclear about any part of the guidelines given later in this section.

**If you have any doubt, please ask.**

#### **IMPORTANT:**

***The information and guidance given in sections 2.3.7 and 2.3.8 form part of the statutory requirements of the European Union Directive 89/336/EC on EMC.***

### 2.3.7 Basic EMC Considerations

#### 2.3.7(a) Immunity

The product standard for immunity requirements is EN 60947-4-2:1996. All SFE2 soft-starter products meet, or exceed the industrial level immunity requirements laid down in this standard.

#### 2.3.7(b) Emissions

Emissions are classified as low frequency, (below 9kHz), known as harmonics, and high or radio frequency, (above 9kHz). Both radio-frequency emissions and low frequency harmonics are generated by the action of an SFE2 soft-starter.

### 2.3.7(c) Emissions - Harmonics

Harmonics arise from the intentional delay, relative to the voltage wave zero, in the turn-on of the semiconductor switches in order to vary the voltage at the motor terminals. This introduces supply discontinuities and so generates harmonics. However, the configuration of the SFE2 soft-starter power circuits as a fully-controlled regulator (W3C), and the mode of pulsing used results in minimised harmonic effects. This means that only non-triplen, (integer multiples of the third harmonic), odd harmonic frequencies are created, starting with, and diminishing rapidly from the fifth harmonic, and virtually disappearing by the nineteenth harmonic.

*Note:* The generic limits for harmonics for soft-starters which operate with a power level greater than 1kW are under consideration. Until these have been defined, harmonic filters are not required for any SFE2 soft-starter.

### 2.3.7(d) Emissions - Radio Frequency (RF)

Radio frequency emissions are propagated in two ways:

- (1) Conduction along the leads supplying the soft-starter.
- (2) Radiation from the operating equipment.

They also have two sources:

- Source 1: The high frequency currents associated with the control electronics (this includes the microprocessor)
- Source 2: The action of the semiconductor devices forming the power switching elements located in the controller main circuits of the controller.

The radiation measurements made from operating versions of SFE2 soft-starters show levels lower than the allowed limits. Further, enclosures (or cubicles) of metallic construction provide additional shielding for SFE2 soft-starters mounted within them. The only radiated interference effect that might arise from a soft-starter would be if mobile telephones, walkie-talkies etc. were to be used in very close proximity to a unit which was operating with the enclosure door open. For this reason, any enclosure must display a label that brings the possibility of electro-magnetic interference to the attention of the operator under these circumstances.

### 2.3.7(e) Emissions - Conducted

Conducted emissions are able to travel great distances and may cause interference to any neighbouring consumers connected to the common low-voltage supply network.

Allowable levels for conducted emissions generated by semiconductor motor controllers and starters are influenced by the nature of the low-voltage power distribution network. The determining factor is whether the source of power is,

- either (a) A private supply with a single consumer whose Point of Common Coupling (PCC) is at a high or medium voltage transformer.
- or, (b) A public low-voltage network with more than one consumer, where the individual PCC is made directly to the network itself.

The first type of supply is identified as "Industrial" and requires the use of soft-starters compliant with EN 60947-4-2 Table 14: 'Equipment Class A Emission Levels'.

### 2.3.7(e) continued

The second type of supply is identified as "Residential" and requires the use of Equipment Class B Apparatus. SFE soft-starters are able to comply with either classification **provided** the appropriate action is taken. (Section 2.3.3 described the strategies for attaining and maintaining compliance.)

#### **Important Systems Information:**

The specification limits for both equipment classes assume systems are earthed at the star-point of the supply transformer through low impedance connections.

*Certain industries, particularly continuous process industries, employ distribution systems that operate either with an earth through a high impedance or without an earth at all. These systems may cause severe problems of operator safety when fitted with capacitive high frequency filters - such systems are not considered in this document.*

In the case of an isolated or high impedance earthed system, seek advice from your supplier before fitting a capacitive high frequency filter to an SFE soft-starter. It is essential that the specifying authority, user or installer has a clear knowledge of the type of network to which the product is to be fitted before making decisions as to which EMC strategy to adopt.

As supplied, all SFE2 products comply with the conducted emissions requirements for Equipment class A soft starters as defined by EN 60947-4-2:1996 Table 14. However, the length and type of cable connecting the motor to the starter module materially affects the level of emissions generated, and can amplify them greatly. The standard also allows different levels of emissions depending on motor rated current, which also affects the need to fit filters. The EN 60947-4-2:1996 standard only requires consideration of steady-state conditions for EMC purposes and expressly excludes varying conditions such as those during ramp-up and ramp-down. Therefore, closing a bypass contactor around the module during the run condition will remove the need for any high frequency filters. However, some of the features (protection, optimising etc.), which are active during the run state, are disabled when the bypass contactor is closed. Users need to assess the cost and merit of fitting a bypass contactor compared with the cost of a filter when it is required.

Finally, statistics show that the number of disturbances arising from soft-starters, operating in a very wide variety of applications and networks throughout the world, is insignificant. Where EMC disturbances occur, it is very unlikely that they can be genuinely attributed to a soft-starter.

### **2.3.8 Strategies in Attaining and Maintaining EMC Compliance**

Where possible, minimise the effect of electrical interference by incorporating the strategies listed below.

- (1) Locate the SFE2 soft-starter unit as close as reasonably possible (preferably within 5 metres) to the motor terminal box in order to minimise cable length.
- (2) Ensure that, within any enclosure, the control wiring does not run parallel to the power wiring. Where this is unavoidable, then maintain a 100 mm separation between control cables and power cables.

2.3.8 continued

- (3) Where possible, ensure that the control wiring crosses at right-angles to the power wiring; this reduces the cross-coupling between cables.
- (4) Cables carrying sensitive signals are screened. The digital control inputs to an SFE2 are opto-isolated and do not normally require buffering (e.g. through a small relay) or screening.
- (5) Compliance in residential environments (Equipment class B) can be achieved by one of two methods:
  - (a) Bypassing the soft-starter with an AC1 rated contactor controlled by the programmable relay set to the 'top-of-ramp'. (The ramp-up and ramp-down features remain effective in this configuration)
  - (b) Fitting a special purpose RF filter which can be supplied on request.(see also (10) below).
- (6) Where a special purpose system filter has been applied at the point of common coupling, additional filtering of individual drives is not necessary and may introduce undesirable effects due to resonance.
- (7) For systems that include motors greater than 100A **operating simultaneously** with motors rated less than 100A, then Filt06 filters need not be fitted to the smaller units. This is due to the EMC effects not being considered as cumulative.
- (8) For the purposes of EMC, the connection between the SFE2 controller and motor is considered to be an extension of the enclosure and should be contained within earthed metallic trucking or conduit or be correctly terminated armoured cable. Screened cable is not necessary.
- (9) For industrial environments, filters should be applied as follows:

Soft-start Current Rating ( $I_e$ )	EN55011 Class A Conducted Emission (Limit)	Motor Cable Length (L)	
		L < 10 m	L >10 m
$I_e < 100A$	Group 1	No filter required	Filter type Filt06
$I_e > 100A$	Group 2	No filter required	No filter required

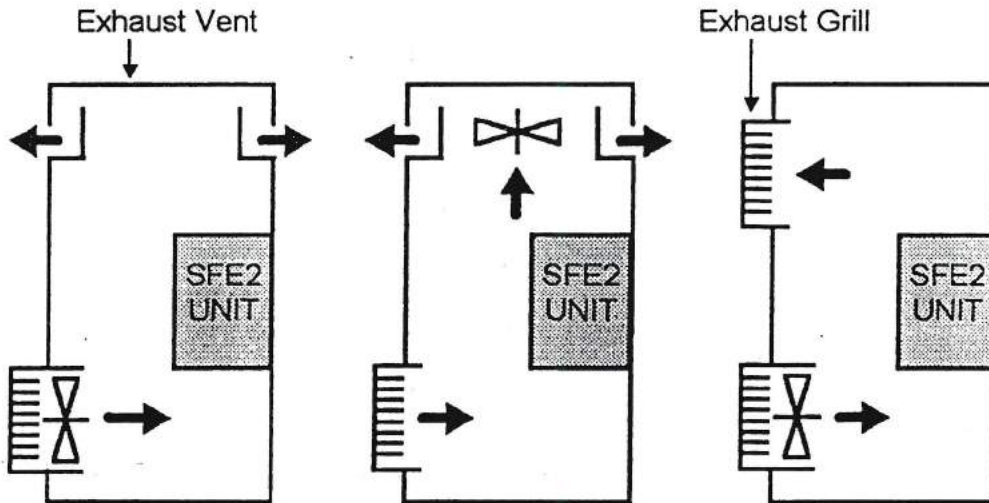
(For further information on the filter Filt06, refer to the supplier.)

- (10) An alternative method of achieving the residential environment EMC requirements is to insert a special purpose filter designed for use with variable-frequency drives. Care must be taken to ensure that the short-term current rating of the filter will allow for the starting currents experienced. If this method is adopted, it is essential that the motor/controller connections are kept within 10 metres.
- (11) All associated electrical and electronic equipment near to the controller complies with the emission and immunity requirements of the EMC Directive.

**2.4 ENCLOSURES WITH FORCED-AIR COOLING**

**2.4.1 Mounting of Fans and Exhaust Grills/Ducts**

Forced-air cooling is an important consideration for a unit mounted within an enclosure. Perhaps the enclosure is necessary to meet EMC requirements, but its use limits the natural convection cooling inside the enclosure. A fan fitted to an enclosure wall compensates for this lack and helps to ventilate all components mounted within the enclosure. Typical arrangements for fan-ventilated enclosures are shown below. As a general rule, it is better to locate the unit towards the bottom of the enclosure; this encourages internal convection and the distribution of heat.



**2.4.2 Operation in Warmer Climates**

In warmer climates it may be necessary to increase the air-flow in order to maintain the operating temperature within the limits of the equipment. Use the following formula to calculate the air-flow required:-

$$Q = \frac{W}{(t_{max} - t_{amb})}$$

Q = required volume of air (Cubic metres per hour)  
 W = power produced by the unit and other heat sources in the enclosure (Watts)  
 $t_{max}$  = maximum permissible temperature within the enclosure (deg. C)  
 $t_{amb}$  = temperature of the air entering the enclosure (deg. C)

(This formula also appears in section 1.2.3.)

**For 22 deg C ambient temperature**

$t_{max}$  = 40 deg.C  
 $t_{amb}$  = 22 deg.C  
 W = 610W (Heat output at full load)

Using the formula,  
 Q = 33.9 cu m/hr.

**For 30 deg C ambient temperature**

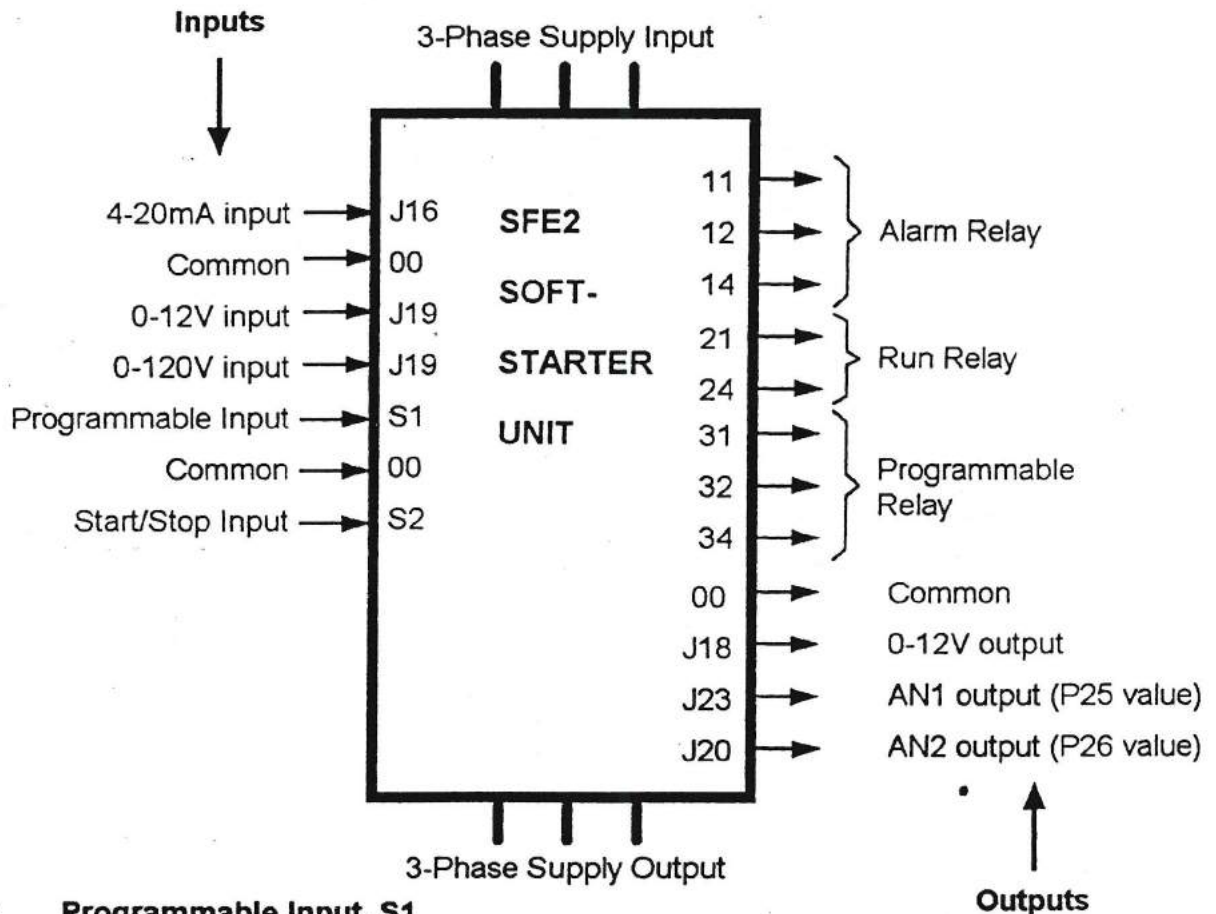
$t_{max}$  = 40 deg.C  
 $t_{amb}$  = 30 deg.C  
 W = 610W (Heat output at full load)

Using the formula,  
 Q = 61 cu m/hr.

## 2.5 USING THE PROGRAMMABLE INPUTS AND OUTPUTS

### 2.5.1 SFE2 as a Component within a System

Through access to its internal electronic control circuitry, the SFE2 unit can become a fully-integrated component within a system. The programmable inputs and outputs give the Systems Designer access to this control circuitry. A functional block diagram of the programmable inputs and outputs, together with the power inputs and outputs, is shown below. (Refer to sections 1.3.1, 1.4.3(d), 1.5.17 and 1.5.18.)



### 2.5.2 Programmable Input, S1

The programmable input will SET and CLEAR the parameter pointed to by parameter P21. A voltage applied between S1 and 00 will CLEAR the assigned parameter and override the existing state. If selected, this input remains active in this way irrespective of local or remote control. To select a parameter for this input, enter the appropriate number from the Bit Parameter - Read/Write table. The default value, which turns this input off, puts P21 to 0.

*Example Requiring Parameter Selection:* A customer requires shearpin protection for the first part of a crucial process and then requires that it be disabled upon completion of the process.

*Achieving Parameter Selection:* Attach the process via a Programmable Logic Controller (PLC) or a relay or a switch to the input S1. Assign the programmable input to b5: Shearpin Trip Selector by setting the data value of parameter P21 to 5.

### 2.5.3 Start/Stop Input, S2

If you select remote control, then a voltage applied between S2 and 00 causes the unit to initiate a START; its removal causes the unit to initiate a STOP.

#### IMPORTANT

The stop and start inputs should not be relied upon alone to ensure the safety of personnel. If a safety hazard could arise from the starting of the motor, then an interlock mechanism should be provided to prevent the motor from running except when it is safe.

### 2.5.4 Programmable Relay, (terminals 31, 32, 34)

You can assign any bit within the Read/Write or Read-only bit parameter tables to the programmable relay. Setting parameter b8 to BIT = 1 select the Read/Write table, whilst BIT = 0 selects the Read-only table. Setting parameter P20 selects the number of the assigned bit from its table.

*Example A:* A customer requires an external warning that the unit is overloading and is about to trip if the overload continues.

*Achieving Parameter Selection:* Attach the warning device (e.g. a light or an audible alarm) to the terminals 31 and 34. Assign the programmable relay to br10: Integrating Indicator by setting the data value of parameter P20 =10 and b8 to BIT = 0.

You can also assign the programmable relay directly to the programmable input. To achieve this, the user must assign the Programmable Input State bit (br1) to the parameter P20. (The bit br1 indicates the state of the bit pointed to by the programmable input P21.)

*Example B:* A customer requires an external signal when switching the energy saving input.

*Achieving Parameter Selection:* Assign the parameter P21 to point to the bit b2: Energy Saving Input. Select and enter bit b8 to BIT = 1 (Read/Write bit table). Finally, Assign the programmable relay to b2 by setting parameter P20 to 2.

If you assign the programmable relay to the programmable input, but do not want to change the state of a bit in either table, then disable the programmable input by setting parameter P21 to 0.

*Example C:* A customer requires a warning that an external process is operational, but wants the SFE2 unit to continue operation as normal.

*Achieving Parameter Selection:* Turn off the programmable input by setting P21 to 0. Select and enter bit b8 to BIT = 0 (Read-only bit table). Finally, assign parameter P20 to the parameter br1 (programmable input state). (These settings will cause the programmable input to change the state of the programmable relay without changing any bits in the Read/Write table.)

### 3.1 THE PRINCIPLES OF FIXED-SPEED INDUCTION MOTOR STARTING AND CONTROL.

Since its invention one hundred years ago, the standard 3-phase induction motor has become one of the most familiar items of industrial equipment ever known. Due to its simplicity of construction, low cost, reliability and relatively high efficiency, it is likely to remain the prime source of mechanical energy for the foreseeable future.

#### 3.1.1 Introduction

Energy conversion, from the electrical supply to rotating mechanical energy, is a characteristic of all motors. To regulate energy flow, most motor circuits require a mechanism to connect and disconnect them from their electrical power source; electro-mechanical switches, known as 'Contactors', are the standard means of achieving this control. Even today, more than one hundred years after their introduction, contactor-based systems remain the most widely used method of motor control.

Nevertheless, there is a definite trend towards more sophisticated electronic systems of control being applied to fixed-speed motor drives. This section will discuss these newest forms of control - namely, electronic, microprocessor-controlled, optimising soft-starters.

*Note: Since there is a wealth of detailed literature available in the technical press, it is not proposed to dwell too heavily on the specifics of realising the electronic control system, but rather, to offer an outline of its various capabilities.*

#### 3.1.2 The Induction Motor

In order to appreciate the benefits of using an electronic controller, it is important to have some understanding of the characteristics and limitations of the induction motor and the electro-mechanical systems currently used to control them.

The standard, fixed-speed induction motor fulfils two basic requirements:

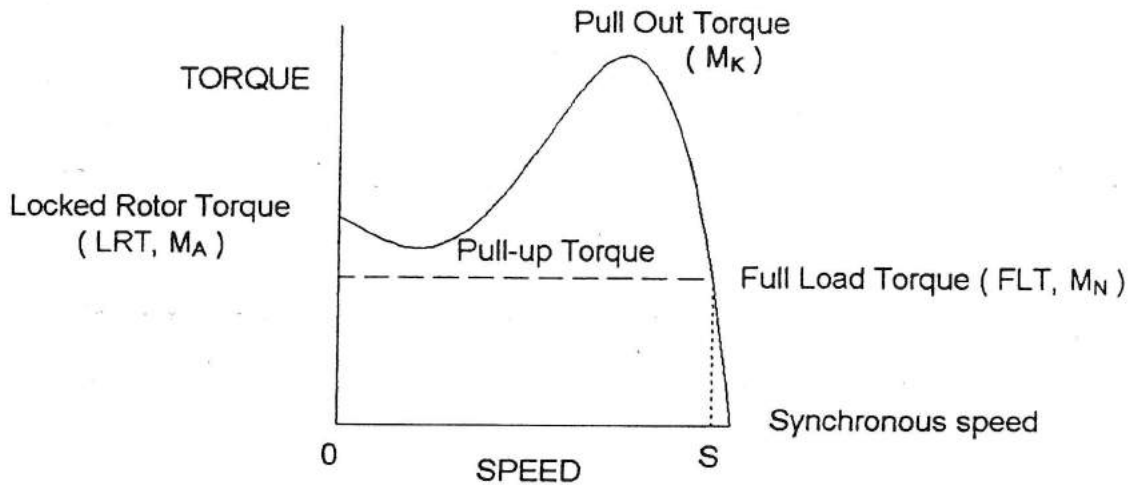
- \* to accelerate itself and its load to full speed (or speeds in the case of multi-speed motors)
- \* to maintain the load at full speed efficiently and effectively over the full range of loadings.

Due to the constraints of materials and design, it can be difficult to achieve both objectives effectively and economically in one machine.

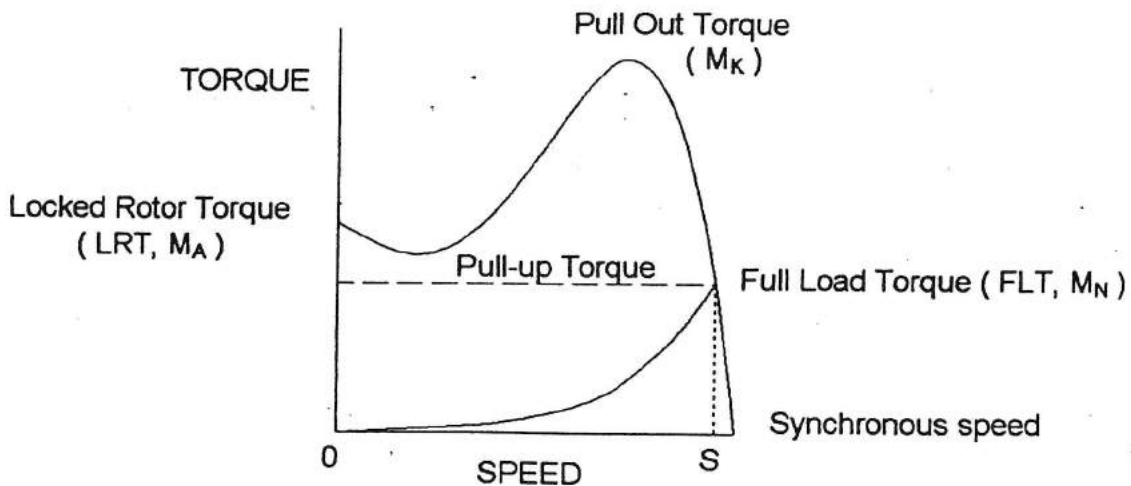
3.1.2 The Induction Motor (continued)

So, how does a motor start in the first place? As mentioned earlier, motors convert electrical energy drawn from the power supply into a mechanical form, usually as a shaft rotating at a speed fixed by the frequency of the supply. The power available from the shaft is equal to the torque (moment) multiplied by the shaft speed (rpm).

From an initial value at standstill, the torque alters, up or down, as the machine accelerates, reaching a peak at about two-thirds full speed, finally to become zero at synchronous speed. This characteristic means that induction motors always run at slightly less than synchronous speed in order to develop power - the 'slip speed' and, hence the term asynchronous. The graph below, which shows an induction motor torque/speed curve, illustrates this most important characteristic.

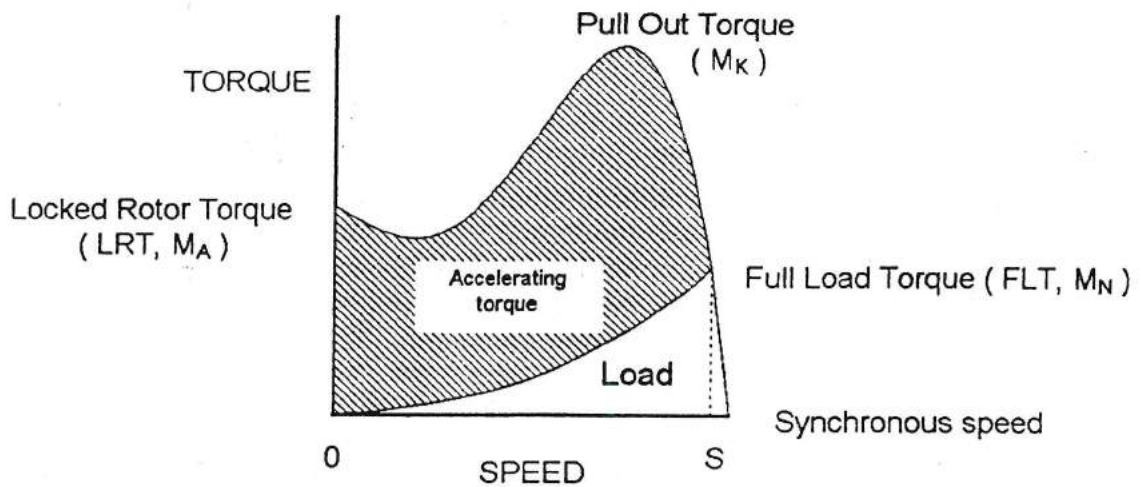


As for each type of motor, so each load coupled to an induction motor has its own speed/torque curve:



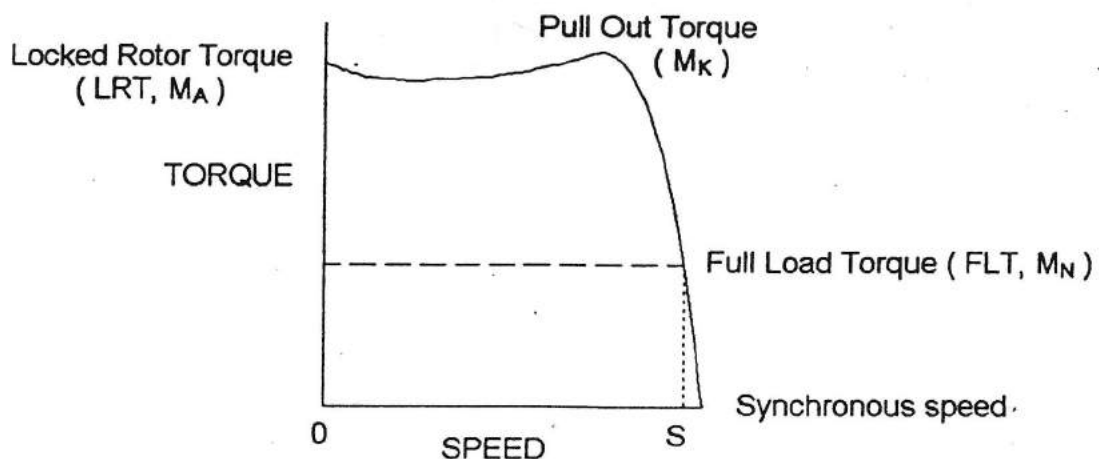
3.1.2 The Induction Motor (continued)

The acceleration of a motor-load system is caused by the difference between the developed torque (motor) and the absorbed torque (load) and is shown by the shaded area in the next figure:



Obviously, the larger the difference, the faster the acceleration and the quicker full speed is reached - and, coincidentally, the greater the stresses experienced by the supply and drive systems during the acceleration process. An "ideal" start would accelerate the load with just sufficient force to reach full speed smoothly in a reasonable time, and with minimum stress to the supply and drive mechanisms.

Broadly speaking, the motor speed/torque characteristic is controlled by the rotor resistance - a motor with high rotor resistance can generate its peak torque (pull-out torque) at standstill giving the high break-away torque characteristic, which reduces steadily as the speed increases and becoming zero at synchronous speed. At the other end of the scale, a motor with a very low rotor resistance will produce a low starting torque but will generate its peak torque closer to the synchronous speed. Consequently this type of motor runs at full power with higher operating efficiency and low slip speed. It is possible to combine the twin requirements of high starting torque and efficient full-speed operation within a single motor by techniques such as double-cage or deep bar design, and this usually is the motor characteristic chosen for lifting and hoisting applications:



### 3.1.2 The Induction Motor (continued)

However, most induction motors are designed to have a "standard" characteristic that provides a compromise between starting torque and operating efficiency. To summarise, an induction motor will only start and accelerate when it produces more torque than the connected load absorbs. This is true for all speeds - including standstill and full speed.

### 3.1.3 Starting Induction Motors

Starting a de-magnetised induction motor from standstill is a demanding and complex process. At the instant of switching all the energy necessary to magnetise the motor, to provide the acceleration force, and to supply the kinetic energy of the rotor and load, must be present together with the energy to overcome the mechanical and electrical losses. To do so at full supply voltage places considerable stresses on the supply, the motor windings, and the iron cores of the stator and rotor. Excessive acceleration of a rotor when the mechanical load is small can produce torque oscillations in the shaft causing severe wear to transmissions, gears and drives. Excessive acceleration when the load inertia is high such as in centrifugal fans, causes belts to slip in the pulleys, producing rapid wear and early failure.

### 3.1.4 Electro-Mechanical Methods Of Starting

#### Method A: Direct-on-Line

The most simple means of controlling energy flow to an induction motor is to interrupt the power supply by a single, solenoid operated, 3-phase switch, known as a contactor. Very widely applied, the method is known variously as "direct-on-line", "across-the-line", "direct" etc., and is the usual form of control where low cost is the first, and most important consideration. As a result, it is most often used on small motor sizes (7.5 - 22kW), or where the supply is strong enough to withstand the inrush and starting current surges without causing unacceptable voltage drops.

The harsh, damaging effects described earlier are all imposed by direct-on-line starting and, as a control method, it is the most destructive of equipment. Its simplicity and apparent low cost, although attractive at first sight, hide large cost penalties in the shape of increased maintenance, reduced transmission equipment life and higher risk of motor failure, particularly when frequent stopping and starting is needed. In larger sized motors special strengthening is necessary, at higher cost, before they can be safely used with direct-on-line starting.

However, the shortcomings of the direct-on-line starter have been recognised ever since motors have been used and alternative systems have been developed over the years to reduce the damaging effects of this form of control.

3.1.4 *Electro-mechanical Methods of Starting (continued)*

**Method B: Star-Delta and other Reduced Voltage Starting Systems**

Reduced voltage starting makes use of the fact that motor torque is proportional to the square of the terminal voltage; the most familiar type of reduced-voltage starter is the star-delta starter.

Consisting of three contactors and a time switch (which can be mechanical, pneumatic, electrical or electronic), the star-delta starter changes the motor winding configuration from an initial star connection to a delta as the motor accelerates. The change-over or transition point is controlled by the time switch and is usually arranged to be approximately at 80% of full speed. The effect of starting in star is to alter the voltage across each stator winding to 58% of normal. This reduces the starting torque to a third of locked rotor torque (LRT) with a consequent reduction in starting currents and acceleration forces.

Although an apparent improvement over the direct system, significant disadvantages still remain. The transfer from star to delta momentarily removes the motor from the supply. During this time the motor is under the mechanical influence of the rotating load and, at the instant of disconnection, current will still flow in the rotor bars due to the time delay necessary for the magnetic flux to die away. Therefore, there is a residual flux "frozen" on the surface of the rotating rotor, which cuts the stator windings, generating a voltage whose frequency depends on the rotor speed. If the load inertia is small, such as in a pump, or if the friction is high, there could be a significant loss of speed during the time the supply is disconnected.

In this case, when the reconnection to delta is made, a large phase differential can exist between the supply and the rotor fluxes. This can give rise to very large current surges (as much or more than full-voltage locked rotor current), together with massive transient torque oscillations. (These oscillations can peak at fifteen-times full-load torque.) Although the effects described are only present for a very short period of time (about one fifth of a second), they are sources of great stress and damage to the whole drive system, and where frequent starting is necessary, invoke high maintenance costs.

There are methods of control, for example, the Wauchope starter, which eliminate or reduce the reconnection transients. However, such starters are expensive and have reliability implications; for these reasons they are not widely applied.

The star-delta starter also has disadvantages due to the restricted starting torque available (if you need 40% LRT to break-away, you can only increase the motor size, or revert to direct-on-line). Combined with the severe effects of the re-switching surges, and the additional costs of bringing six conductors from the motor to the starter instead of only three, star-delta only offers an imperfect solution to the problem of starting the induction motor.

### 3.1.4 *Electro-mechanical Methods of Starting (continued)*

#### **Method C: Primary Resistance Starter**

It has long been recognised that the transition step in the star-delta system was a source of problems such as welded contactors, sheared drive shafts etc., and for many years a method of stepless control has been available in the form of the primary resistance starter.

This type of controller inserts a resistance in one, or more often in each, of the phase connections to the stator at start-up, after which it is progressively reduced and shorted out at the end of the acceleration process. Frequently, the resistances are movable blades that are gradually inserted into an electrolyte liquid. The mechanism is usually large and expensive, both to purchase and to maintain, and considerable heat is created by the passage of current through the electrolyte resistor. This limits the starting frequency (because the electrolyte has to condense back to liquid before a new start can proceed), and these restrictions prevent this starter from being a popular option when selecting a control system. However, it has the distinction of being the smoothest and least stressful method of accelerating an induction motor and its load.

#### **Method D: Other Electro-Mechanical Systems**

Other control methods such as auto-transformer starting (popular in North America), primary reactance starting etc., are employed to a greater or lesser extent, to compensate for some of the disadvantages of each type of starter discussed. Nevertheless, the fundamental problems of electro-mechanical starters remain, and it is only in the last decade or two that their dominance has been challenged by the introduction of power semiconductors controlled by electronics.

### 3.1.5 **The Semiconductor Motor Controller**

During the 1950's, much effort was put into the development of a four-layer transistor device which had the power to switch large currents at high voltages when triggered by a very small pulse of current. This device became known as the silicon controlled rectifier (SCR), or in Europe, the 'Thyristor'; it is the basis on which all soft starting systems are built. The characteristic of most interest is the ability of the thyristor to switch rapidly (in about 5 millionths of a second) from "OFF" to "ON" when pulsed, and to remain "ON" until the current through the device falls to zero, - which conveniently, happens at the end of each half-cycle in alternating current supplies.

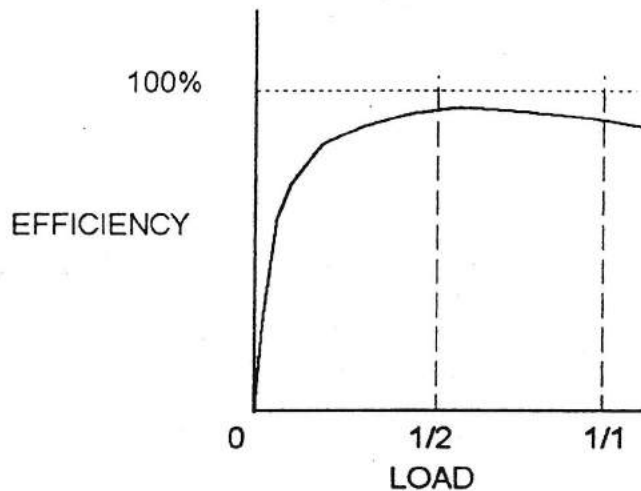
By controlling the switch-on point of a thyristor relative to the voltage zero crossing in each half wave of an alternating current, it is possible to regulate the energy passing through the device. The closer the turn-on point is to the voltage zero crossing point, the longer the energy is allowed to flow during the half-cycle. Conversely, delaying the turn-on point reduces the time for the energy to flow. Putting two thyristors back-to-back (or anti-parallel) in each of the phase connections to a motor, and by precisely controlling their turn-on points, an electronic soft starter continuously adjusts the passage of energy from the supply so that it is just sufficient for the motor to perform satisfactorily.

### 3.1.5 The Semiconductor Motor Controller (continued)

So, for instance, by starting with a large delay to the turn on point in each half cycle, and progressively reducing it over a selected time period, the voltage applied to the motor starts from a relatively low value and increases to full voltage. Due to the motor torque being proportional to the square of the applied voltage, the starting torque follows the same pattern giving the characteristic smooth, stepless start of the soft-starter.

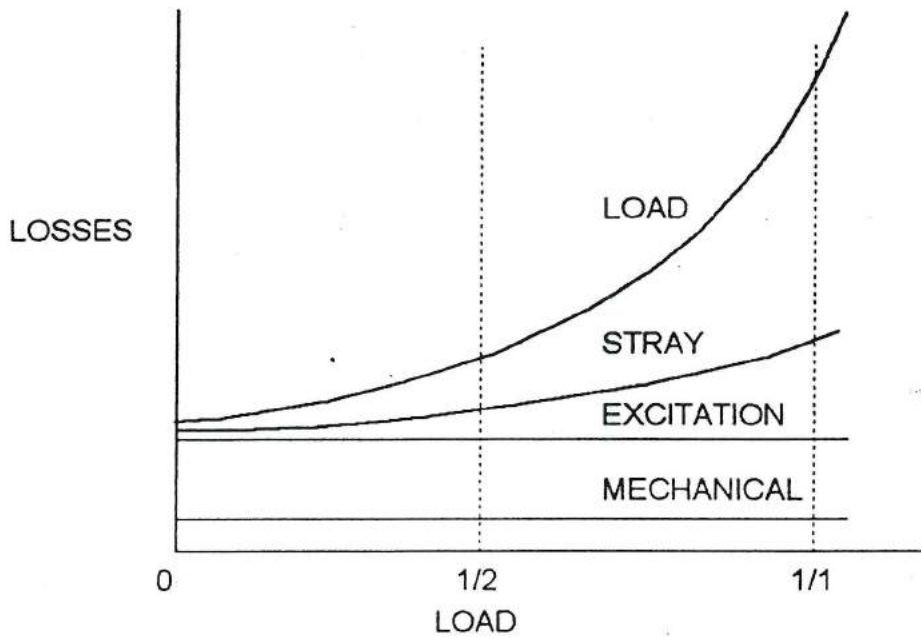
### 3.1.6 Running Induction Motors

Once a start has been completed the motor operating efficiency becomes of interest. When working at or near full load, the typical 3-phase induction motor is relatively efficient, readily achieving efficiencies of 85% to 95%. However, as shown below, motor efficiency falls dramatically when the load falls to less than 50% of rated output.



In fact, very few motors actually experience consistent fully rated operation, the vast majority operate at much lower loads due to either over-sizing (a very frequent situation), or natural load variations. For Fan and Pumping applications, the affinity laws will allow the inverter drive to show very considerable energy savings over virtually all other methods of control through varying the speed of the motor in response to changes in load. Where motor speeds cannot be varied, the optimising version of the semiconductor motor controller will also produce energy savings in lightly loaded motors. Less sophisticated systems of soft-starter remain at full conduction and the motor then behaves as if it were connected directly to the mains supply. However, at light loads and mains voltages, induction motors always have excess magnetic flux, and efficiency loss and power factor degradation result. By detecting the load at any instant, and adjusting the motor terminal voltage accordingly, it is possible to save some of the excitation energy and load loss, and improve motor power factor when the motor is running inefficiently at light loads.

3.1.6 Running Induction Motors (continued)



All SFE2 soft-starters are microprocessor controlled, and this gives them a number of advantages. Firstly, there are no adjustments to be made for the energy saving function: all calculations necessary to find the best degree of phase-back of the thyristors for any load condition is made by the micro-computer. Secondly, the start always synchronises with the supply voltage and a special structure of turn-on pulses virtually eliminates the inrush currents normally associated with motor start-up; this happens every time. Lastly, there is the absolutely stepless starting process, found only with the primary resistance or reactance electro-mechanical starters - but without the wasted energy, and with the opportunity to control the maximum current allowed to flow during the starting process. Other features such as soft stopping are included, or are available, to give considerable control over all modes of induction motor operation.

**3.1.7 Reliability Considerations**

An aspect of electronic controllers for induction motors which is of increasing concern is that of reliability. There is little point in installing an expensive item of electronic equipment to save potentially considerable amounts of money if the device is unreliable to the point that vital processes are constantly interrupted.

There are electronic products in the market place which appear to offer soft starting cheaply. They almost always rely on less advantageous technologies such as analogue control, or half-control, where one of the two thyristors in the phases is replaced with a diode. There are systems which only control the energy flow in one phase while the other two are directly connected. Owing to the variable quality and performance of many so-called inverters and soft-starters available to the unsuspecting purchaser, international standards for these products have been, or are being, developed.

So far, IEC 947-4-2 (1995) - 'AC Semiconductor Motor Controllers and Starters' defines the soft-starter in every important respect, including thermal and overload performance as well as electromagnetic compatibility. By ensuring that any motor controller equipment purchased conforms to IEC 947-4-2, a user should be reasonably safeguarded from shoddy or inadequate products when specifying equipment for future installations.

A particular advantage of the use of the optimising soft starter is its impact on the maintenance requirements of associated electro-mechanical equipment. Optimising lowers the surface temperature of the motor by reducing the losses within the motor. This prolongs the motor life - and reduces heating of the surrounding atmosphere in the process. If the atmosphere is subject to air conditioning, reducing the heat input will reduce the air conditioning costs. Reduced starting and running currents reduces cable losses and, contactor switching operations are carried out under the most advantageous conditions. No current flows on switch-on since all switching is carried out by the thyristors - virtually eliminating the need for contact replacement. Indeed, there are a growing number of installations where contactors are no longer employed, being replaced by controllable circuit breakers or isolators instead.

In summary, electronic controllers for most fixed-speed applications are opening new ways of increasing the efficient operation of induction motors, as well as offering significant benefits in control. Intending users need to ensure themselves of the quality and performance of any products they expect to fit and this can be reasonably expected if compliance with the appropriate IEC standards is demanded.

### 3.2 PRINCIPLES OF THE OPTIMISING MODE

When the motor has reached full speed and driving the load at the torque demanded, it enters the 'motor running' stage. Under user control, from the SFE2 keypad or through external circuitry, the motor may also operate in 'Optimising Mode'. This is an operating condition that may, at light or partial load conditions, provide the benefit of energy saving and if selected, is continuous from the dwell period until a STOP command is initiated or the mode is disabled.

During start-up, the system software computes and stores by a patented method, a reference value for the power factor. When the motor enters its running stage, with the optimising mode selected, the reference power factor is continuously compared with the running power factor. From the comparison, the software continuously computes and adjusts the firing points of the power thyristors so that the best power factor is maintained. This method of continuous control minimises the energy wastage caused by overfluxing the motor. It also maintains the power factor at the most appropriate value for every condition of load demand. This can effect a significant reduction in the kVA demand.

The method of power factor management described does not affect motor performance, neither does it detract from the motor's capability to respond to changes in load demand. This feature of the SFE2 soft-starter is a purely electrical function which has the effect of ensuring that, at all times, the motor delivers the torque demanded, but allows it to draw only the precise amount of magnetising current required to support that torque output. Without this feature the motor would draw the maximum magnetising current regardless of load. The

## Concepts

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effect of the energy-optimising function is a cumulative economy in the consumption of electrical energy.

*Note:* The energy optimising function cannot improve the power factor beyond what it would ordinarily be at full load, but it does make the optimum improvement possible at any part-load.

**Appendix A: Glossary of Terms**

<b>Breakaway Torque</b>	The minimum torque required to achieve rotor movement for the motor with its load.
<b>Current Limit</b>	The maximum current that a unit will deliver. For SFE2, current limit is only active during start-up where it contributes to the motor control function. This feature is particularly useful when starting high-inertia loads that require an extended start-up period. (See also Overload Level.)
<b>Direct-On-Line (DOL)</b>	The direct connection and disconnection of a motor from the AC mains supply by means of a contactor or switch. Acceleration and operation is at full mains voltage only..
<b>Drop voltage</b>	The value to which the motor voltage falls to when the unit initiates a STOP with soft-stop selected. Drop voltage is usually expressed as a percentage of the mains supply voltage.
<b>End of Table</b>	'End of Table' signifies the number of the last parameter in a parameter table.
<b>Inrush Current or Locked Rotor Current</b>	The current that flows at the instant of connection of a motor to the power source. It is limited by the impedance presented by a de-energised motor. And the applied voltage. Usually expressed as a multiple of motor full-load current.
<b>Kickstart</b>	Kickstart voltage is the percentage of supply voltage applied before commencing ramp-up when a load has a high breakaway torque and the standard settings of pedestal voltage may not allow sufficient torque to be developed by the motor to cause acceleration.
<b>Overload Level</b>	The level of current at which the controller overload begins to integrate. For SFE2, the overload detector is always active and provides protection against prolonged over-current operation.
<b>Parameter Table</b>	The various parameters associated with the unit performing motor control are categorised into four tables. Each table is termed a 'Parameter Table', two of which the operator can change settings and the remaining two being 'read-only'.
<b>Pedestal Voltage</b>	The voltage that the unit applies to the motor at start-up. It is expressed as a percentage of the rated supply voltage.
<b>Power Factor</b>	The ratio, expressed as a trigonometric cosine, of the real power consumption to the apparent power consumption.
<b>Soft-start</b>	Soft-start is the regulation by electronic means, of the supply voltage from an initial low value to full voltage during the starting process. This over-comes the inherent drawbacks of a switched supply. The motor torque is modified in proportion to the square of the voltage applied.
<b>Trip</b>	A trip occurs when the unit removes power to the motor because its operation equals the limit imposed by one of its self-protection features.
<b>Top of Ramp (TOR)</b>	The unit achieves Top of Ramp (TOR) when it completes the start-up stage of motor control. This occurs when the voltage applied to the motor first equals the mains supply voltage.)

**Appendix B: Typower Zilox Fuses for SFE2**

SFE2 Model Number	Typower Zilox Fuse Details				Fairford Electronics Code
	Fuse Rating (A rms)	Body Size	Part Number	Total I <sup>2</sup> t Clearing at 660V (A <sup>2</sup> s)	
- 5 - 9 - 16	63	1*	170M3110	770	FUSE.32
- 23 - 30	125	1*	170M3113	3700	FUSE.34
- 44	160	1*	170M3114	7500	FUSE.35
- 59 - 72	250	1*	170M3116	28500	FUSE.37
- 117 - 146	400	1*	170M3119	105000	FUSE.39
- 174 - 202	500	1*	170M3121	180000	FUSE.41
- 242 - 300	500	1	170M4114	170000	FUSE.42
- 370	630	1	170M4116	350000	FUSE.43
- 500 - 600	900	3	170M6113	670000	FUSE.44
- 750 - 900	1250	3	170M6116	1950000	FUSE.45

Fuse information taken from Cooper Bussman Publication No. 170Q0101E 09.90

**Appendix C: Power Factor Conversion Chart**

The Value Parameter - Read-only table contains the parameters r2 (current power factor) and r3 (reference power factor). The keypad display will show each of these parameters in angular degrees. The table below enables the conversion of this value ( $\theta$ , in degrees) to the power factor ( $\cos \theta$ ).

Degrees	Power Factor	Degrees	Power Factor	Degrees	Power Factor
0	1.00	30	0.87	60	0.50
1	1.00	31	0.86	61	0.48
2	1.00	32	0.85	62	0.47
3	1.00	33	0.84	63	0.45
4	1.00	34	0.83	64	0.44
5	1.00	35	0.82	65	0.42
6	0.99	36	0.81	66	0.41
7	0.99	37	0.80	67	0.39
8	0.99	38	0.79	68	0.37
9	0.99	39	0.78	69	0.36
10	0.98	40	0.77	70	0.34
11	0.98	41	0.75	71	0.33
12	0.98	42	0.74	72	0.31
13	0.97	43	0.73	73	0.29
14	0.97	44	0.72	74	0.28
15	0.97	45	0.71	75	0.26
16	0.96	46	0.69	76	0.24
17	0.96	47	0.68	77	0.22
18	0.95	48	0.67	78	0.21
19	0.95	49	0.66	79	0.19
20	0.94	50	0.64	80	0.17
21	0.93	51	0.63	81	0.16
22	0.93	52	0.62	82	0.14
23	0.92	53	0.60	83	0.12
24	0.91	54	0.59	84	0.10
25	0.91	55	0.57	85	0.09
26	0.90	56	0.56	86	0.07
27	0.89	57	0.54	87	0.05
28	0.88	58	0.53	88	0.03
29	0.87	59	0.52	89	0.02



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