Chapter 12

Induction Motor Drives: Speed Control

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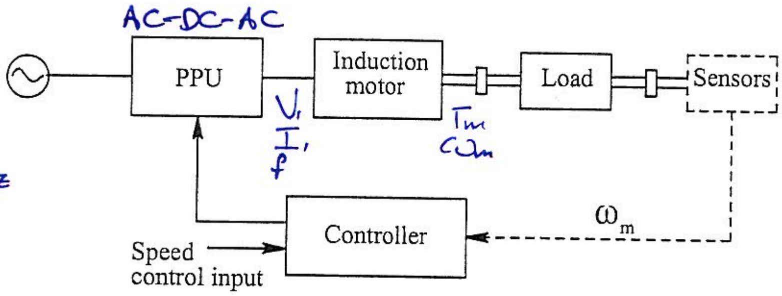
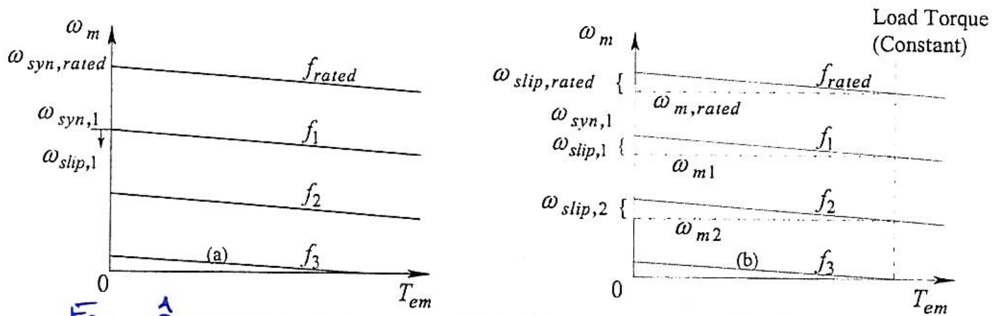


3-φ
400V, 50Hz
(Typical in Ireland)

- ❑ Efficient speed control over a wide range
  - Reduced voltage control (inefficient) * See thyristor soft start fig. 11.27
  - Frequency control (efficient) ✓
- ❑ PPU drives induction motor with variable frequency to maintain low slip
- ❑ As frequency decreases, voltage must also decrease to avoid magnetic saturation

Operating Characteristics with $\hat{B}_{ms} = (\hat{B}_{ms})_{rated}$

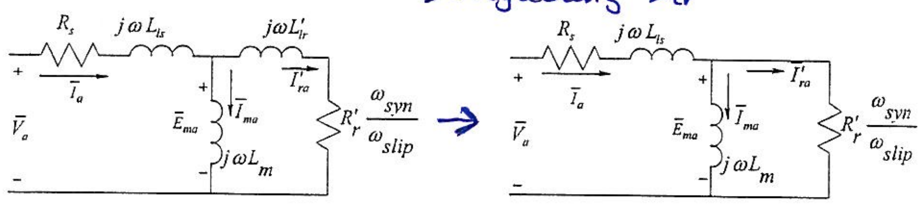


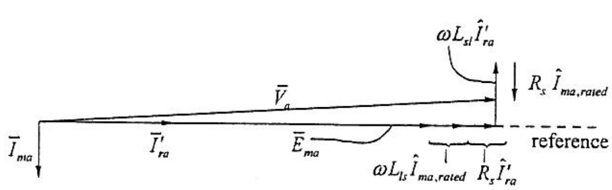
For $\hat{B}_{ms} = \text{const} \Rightarrow T \propto f_{slip}$ even if f_e is varied

- If flux is kept constant, slope will be the same at every frequency
- Load torque and speed are met by adjusting frequency See Ex. 12-1

Maintaining $\hat{B}_{ms,rated}$ Over Operating Frequencies and Current Levels by Adjusting Voltage

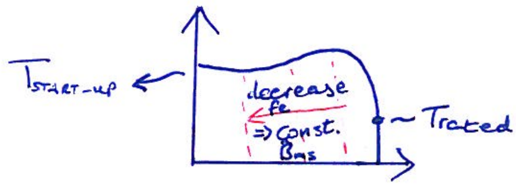
⇒ Neglecting L'_{lr}

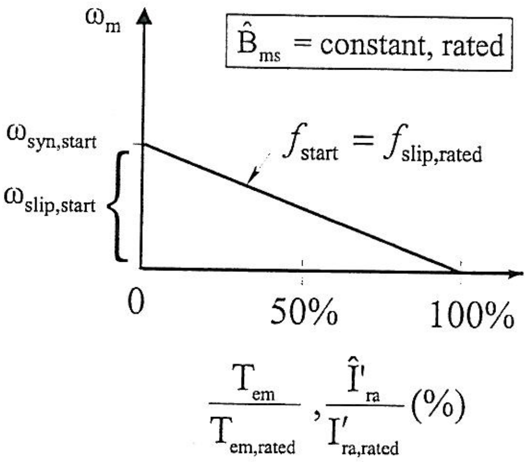


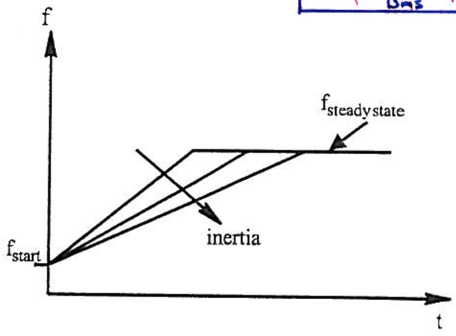


$$V_{ph} \approx 2\pi f_e (L_{ls} + L_m) I_m + R_s I_r$$

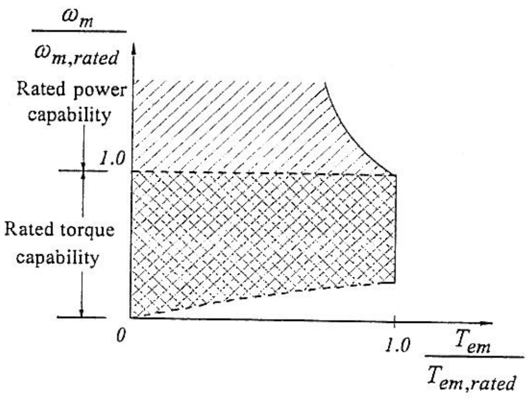
Start-up Considerations





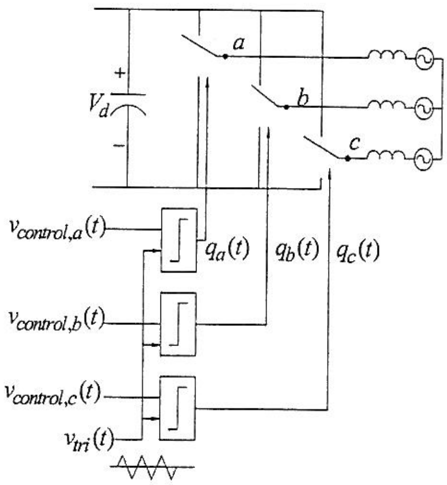


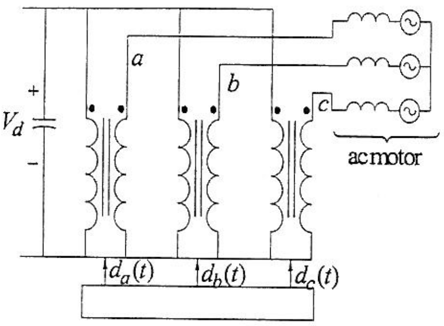
Capability Below and Above Rated Speed



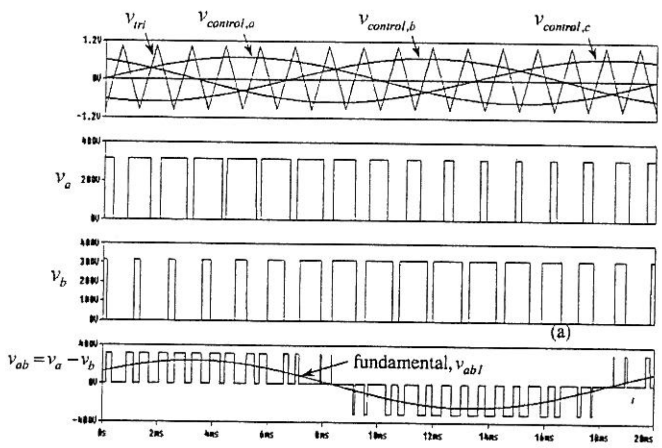
- ❑ Voltages limited to rated values, therefore $\hat{B}_{ms}$ must be reduced at higher speeds (Flux Weakening)
- ❑ Currents limited to rated values, therefore torque limited when $\hat{B}_{ms}$ is limited

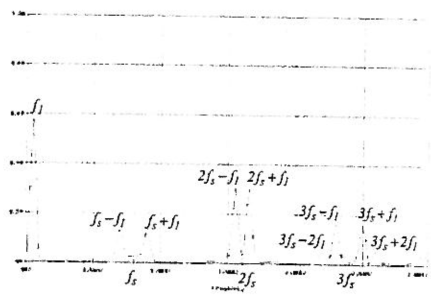
Pulse Width Modulated Power Processing Unit





Harmonics in PPU





- PPU with switching frequency of 800 Hz generating a fundamental sine wave of 50 Hz
- Frequency spectrum shows large 50 Hz component and smaller components at higher frequencies due to switching
- These higher frequency components add to the losses in the motor

EE4001 Study Questions – ED Chapter 12

Summer 2005
Problem 1
(a) Sketch the wiring diagram of the star-delta starter for inrush control of the induction machine.

[3 *marks*]

(b) The specification table for Westinghouse induction motors is provided as an attachment (see page 6). Consider the 22 kW, four-pole machine with 400 V (line-line), 50 Hz applied. What is the direct-on-line starting current when a star-delta starter is used?

[3 *marks*]

(c) A four-pole star-connected motor outputs 40 Nm at 1746 RPM when supplied by a 60 Hz line-line voltage of 440 V and a phase current of 10.39 A lagging at a power factor of 0.866. The series resistance is 1.5 Ω.

(i) By maintaining a constant field flux, what are the electrical line voltage, current, frequency, and power factor sourced from the inverter, when developing 50% of the rated torque at 50% of the rated speed?

(ii) Incorporating low-voltage boost, determine approximate values for the starting frequency, current, and voltage in order to supply 150% of rated torque at startup.

(iii) Determine values for the slip frequency, line current and power factor required to ensure constant-power operation of the machine at twice the rated speed.

Use the formula $slope = \dfrac{V_{ph,rated} - R_S \cdot I'_{R,rated}}{f_{rated}}$ for low-voltage boost.

[*14 marks*]

[Ans. (b) 162A, (c) (i) 220.1 V, 30 Hz, 6.88 A, 0.654, (ii) 2.7 Hz, 14.5 A, 51.2 (iii) 1.8 Hz, 9.37 A, 0.96]

Summer 2004
Problem 2
(a) Sketch the wiring diagram of the star-delta starter for inrush control of the induction machine.

[4 *marks*]

(b) A four-pole star-connected induction motor interfaces a mechanical load to the 400 V (line-line) 50 Hz power grid (via gearing, contactor and breaker). The machine has the following per-phase equivalent circuit parameters: $R_S = 20$ mΩ, $L_{LS} = 0.2$ mH, $L_M = 7.2$ mH, $L'_{LR} = 0.3$ mH, and $R'_R = 35$ mΩ.

(i) Which motor parameters limit the startup current and what value of peak startup current do you expect?

(ii) How much greater would the startup current be if the machine was started in a delta configuration.

A power electronics inverter is now integrated into the system and the motor is connected in star. The motor develops an electromagnetic torque (including friction and windage) of 865 Nm at 1453.5 rpm when supplied by a voltage-source PWM inverter supplying a 50 Hz line-line voltage of 400 V and line current of 225 A lagging at a power factor of 0.89.

(iii) Calculate the minimum dc link voltage for the voltage-source inverter.

(iv) By maintaining a constant airgap flux, what are the electrical line voltage, current, and frequency, and power factor sourced from the inverter, when developing 25 % of the rated torque at 25 % of the rated speed? Also calculate the modulation index for this operating point.

(iv) Determine approximate values for the starting electrical line voltage, current, and frequency in order to supply 150% of rated torque at startup.

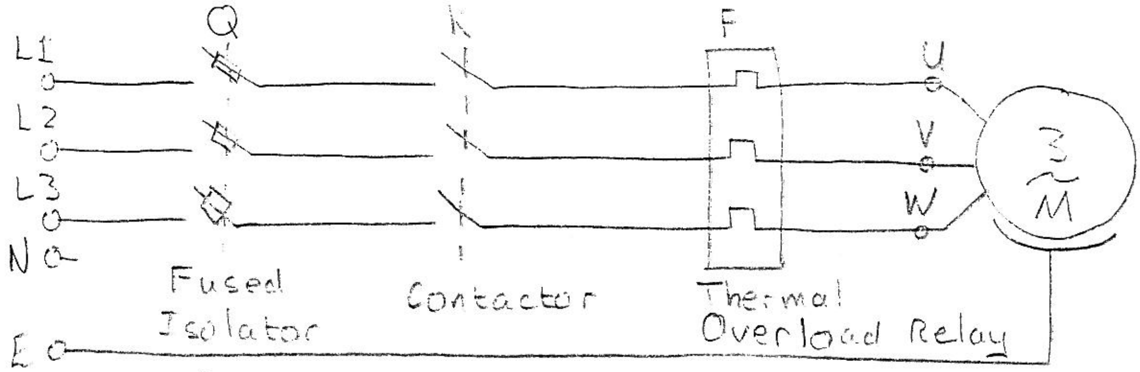
Use the formula $slope = \dfrac{V_{ph,rated} - R_S \cdot I'_{R,rated}}{f_{rated}}$ for low-voltage boost.

[*16 marks*]

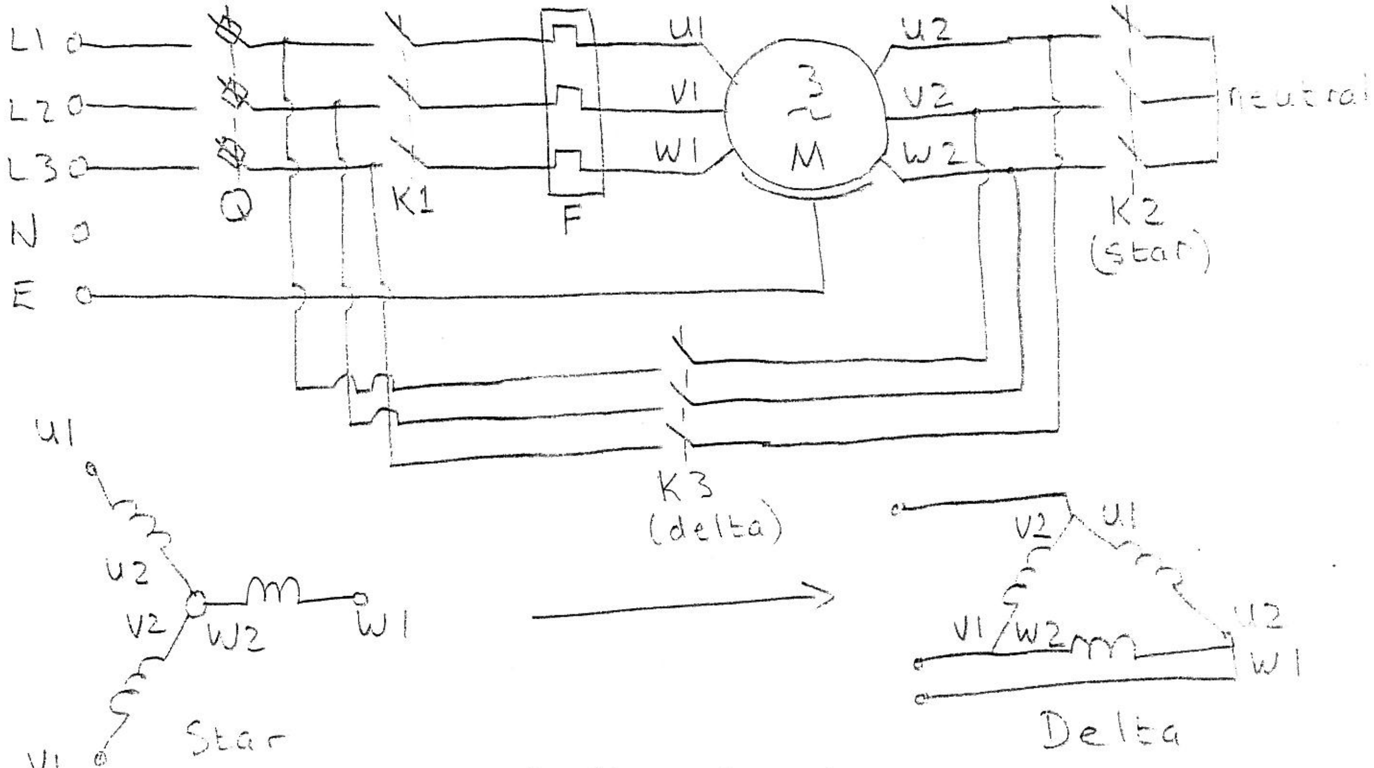
[Ans: 1390 Arms (about 7 times rated!); 2408 Arms; 654 Vdc, 100 V, 114.2 A, 12.5 Hz,0.439, 28.7 V, 317 A, 2.326 Hz]

Problem 3
Note various wiring circuits for soft-start, volts/hertz control, etc.

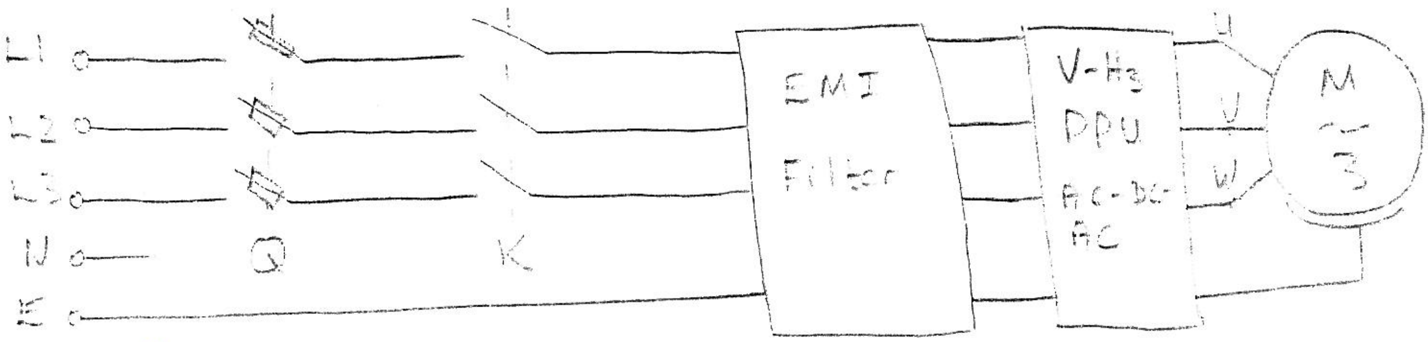
A four-pole motor outputs 40 Nm at 1440 rpm when supplied by a 50 Hz line-line voltage of 400 V and phase current of 10 A lagging at a power factor of 0.88. The series resistance is 1.5 Ω. Neglecting voltage boost and maintaining a constant field flux, what are the approximate slip and electrical frequencies when outputting 20 Nm at 800 rpm. Calculate the minimum dc link voltage for the voltage-source inverter.
Incorporating voltage boost, determine approximate values for the starting frequency, current, and voltage in order to supply 150% of rated torque at startup. Calculate the modulation index (ratio of peak control voltage to peak triangular voltage) at this voltage.



Direct-on-line start



Start Delta Starter

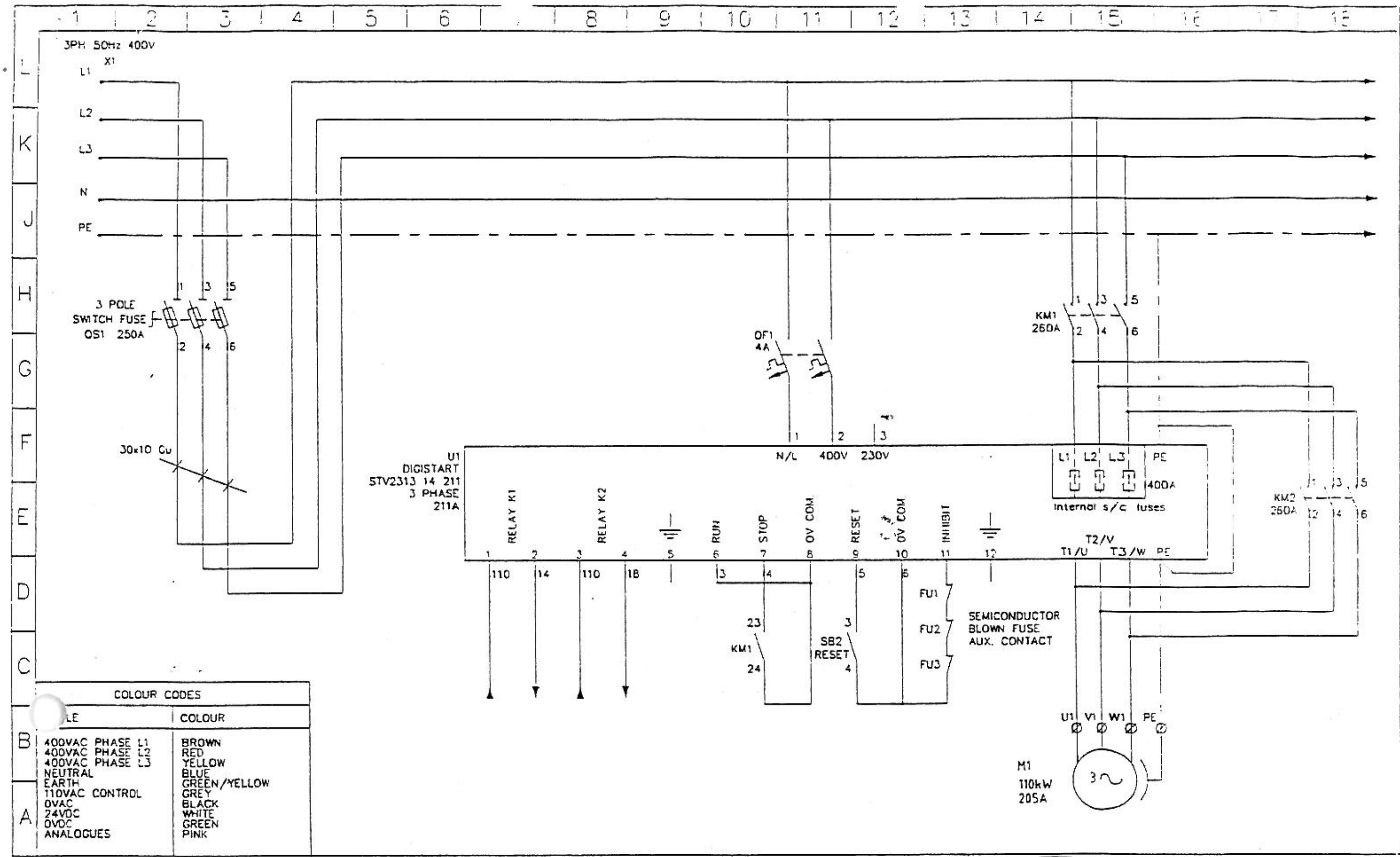


$V_{ph\,Y} = \frac{V_{ph\,\Delta}}{3}$

$I_{ph\,Y} = \frac{I_{ph\,\Delta}}{3}$

Variable-speed System

(1) Control not included above: power only



COLOUR CODES

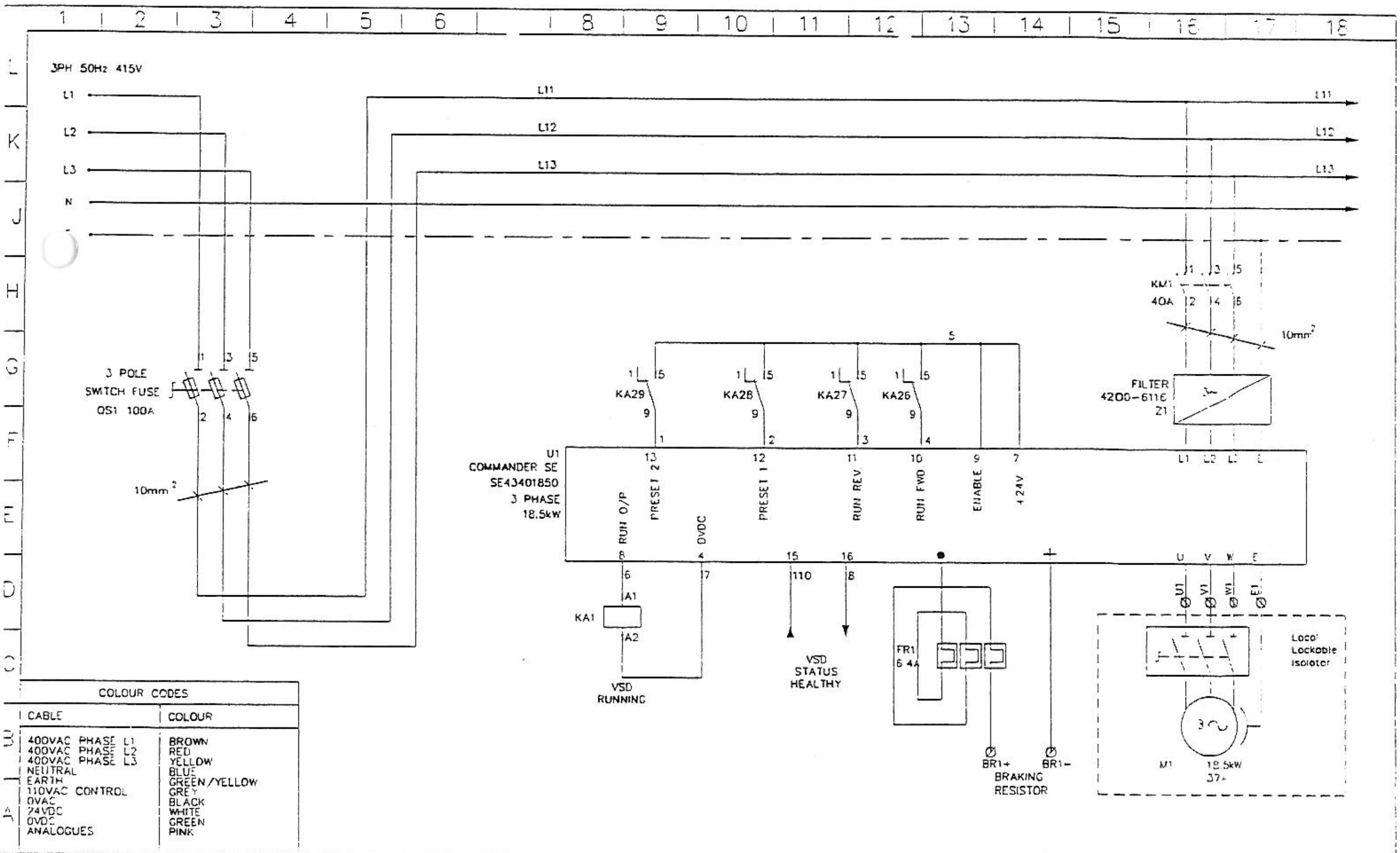
CABLE	COLOUR
400VAC PHASE L1	BROWN
400VAC PHASE L2	RED
400VAC PHASE L3	YELLOW
NEUTRAL	BLUE
EARTH	GREEN/YELLOW
110VAC CONTROL	GREY
0VAC	BLACK
24VDC	WHITE
0VDC	GREEN
ANALOGUES	PINK

A	PAGE 1	DESC.
B	REVISION 0	CUST.
C	APPROVAL	PROJ.

CONTROL CIRCUIT DIAGRAM
CANTWELL ELECT. ENG. LTD.
110kW SOFTSTART

DATE 2003-05-28
JOB No 0777
DRAWN BY DK
DWG NO. 30777100

CONTROL TECHNIQUES
Newbridge Industrial Estate
Newbridge Co. Kildare
Tel: 00 353 (0) 45 448200
Fax: 00 353 (0) 45 433622



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A	PAGE 1	DESC.
B	REVISION 2	CUST.
C	APPROVAL	PROJ.

CONTROL CIRCUIT DIAGRAM
MCSHERRY ELECTRICAL LTD
BRIDGE LIFT CONTROL PANEL

DATE 2003-06-17
JOB No 0784
DRAWN BY DK
DWG NO 30784100

CONTROL TECHNIQUES
Newbridge Industrial Estate
Newbridge Co. Kildare
Tel: 00 353 (0) 45 448200
Fax: 00 353 (0) 45 433622

@ 50% $T_{EM,RATED}$ and 50% N_{RATED}

$\Rightarrow$ $N_{SLIP,rated} = 54$ RPM

$\Rightarrow$ $f_{SLIP,rated} = 0.9$ Hz

$\Rightarrow$ @ 50% $T_{EM,RATED}$

$f_{SLIP} = 0.45 \text{ Hz} = (27 \text{ RPM})$

$N_{RATED} = 1746$ RPM

50% of $N_{RATED} = 873$ RPM

$\Rightarrow$ $N_{syn} = 900$ RPM

$\Rightarrow$ $f_e = 30$ Hz

Also $I_{R'} = 0.5 \, I_{R',RATED}$

$= 4.5$ A

$\Rightarrow$ $V_{ph} = \text{slope} \times f_e + R_s \times I_{R'}$

$= 4.01 \times 30 + 1.5 \times 4.5$ V

$= 127.05$ V

$V_L = 220.1$ V

$I_M = I_{ph,RATED} \sin\phi$

$= 10.39 \text{ A} \times \sin[\cos^{-1} 0.866]$

$= 5.2$ A

$\Rightarrow$ $I_{ph} = \sqrt{I_m^2 + I_{R'}}$

$= \sqrt{5.2^2 + 4.5^2}$

$= 6.88$ A

$\cos\phi = \dfrac{I_{R'}}{I_{ph}}$

$= 0.654$

@ $f = 2\, f_{RATED}$

$\Rightarrow \quad f_{slip} = 2\, f_{SLIP,\,RATED}$

$= 1.8\ Hz \quad (108\ RPM)$

$\Rightarrow \quad I_M = \frac{1}{2}\, I_{M,\,RATED}$

$= 2.6\ A$

$I_{R'} = I_{R',\,RATED}$

$= 9\ A$

$\Rightarrow \quad I_{ph} = \sqrt{2.6^2 + 9^2}$

$= 9.37\ A$

$\cos\phi = \frac{9}{9.37}$

$= 0.96$