

Knowledge Base Document

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Title: Mentor 12 Pulse and 24 Pulse Systems

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Summary of Contents

Application note for Mentor 12 Pulse and 24 Pulse Systems

MENTOR DRIVES IN 12- PULSE CONFIGURATION

Thyristor DC drives for very large outputs can be obtained by using Mentor modules in a 12-pulse configuration. This results in a drive which can have up to twice the power rating of a single module. Other advantages are that large 5th and 7th harmonic currents drawn by individual 6-pulse drives are absent from a 12-pulse configuration and motor current is a lot smoother.

In all 12-pulse systems a transformer with two secondary windings is necessary in order to develop two thyristor stack supplies which are equal in voltage but mutually separated by 30 degrees in phase. This is normally achieved by connecting one secondary in star and the other in delta. The primary will normally have a delta connection and will be wound for connection to high voltage distribution system.

1. PARALLEL 12-PULSE CONFIGURATION

A parallel 12-pulse drive, as its name implies, consists of two stacks with outputs connected in parallel feeding a single armature. Since the stacks will have different instantaneous output voltages it is necessary to insert an inter bridge reactor (IBT) between the stacks in order to ensure current sharing. The motor armature is fed from a centre tap of this reactor.

Parallel 12-pulse drives can develop nominally the same output voltage as a 6-pulse drive. The maximum armature voltage possible is 550V for the standard voltage module and 760V for high voltage modules. The transformer secondary voltages feeding the stacks must be at least 0.83 times the armature voltage at maximum load conditions. Currents upto 3700A continuous and 5550A peak may be obtained with parallel 12-pulse drives.

Drive Set-Up

To set the drives up in a parallel 12 pulse, speed control system they should be programmed so that the master drive is set-up in speed control and the slave drive is programmed in torque control. The final current demand (parameter 04.02) on the master drive has to be fed in to the slave drive torque reference (parameter 04.08). This current demand signal can be transferred between the drives either using an analogue input and output or by using the drive-to-drive serial communications using mode 2 and 3.

Additional bridge interlocking signals are shared between the two modules when a four quadrant system is required to ensure that the same bridge on both drives is firing and also that the current has reached zero on both stacks before current reversal is attempted. When the parameters 05.21 and 05.25 are set to 1 on both drives the ST5 digital output and F10 digital input are dedicated to providing the bridge interlocking signals. The ST5 output on the master should be connected to the F10 input on the slave and the ST5 output on the slave should be connected to F10 on the master.

The 0V terminals of each drive should be connected together.

Master (assuming analogue signals are used for slaving)

04.12 and 04.13 = 0 ;to set speed control mode.
05.21 = 1 ;to set enable the bridge interlocking. Only required if the drives are four quadrant.
05.25 = 1 ;to enable parallel 12 pulse operation.
07.08 = 402 ;to configure DAC1 analogue output to current demand.

Master (assuming serial comms are used for slaving)

04.12 and 04.13 = 0 ;to set speed control mode.
05.21 = 1 ;to set enable the bridge interlocking. Only required if the drives are four quadrant.
05.25 = 1 ;to enable parallel 12 pulse operation.
11.13 = 2 ;to select comms mode 2
11.19 = 402 ;to select source parameter for comms.

Slave (assuming analogue signals are used for slaving)

04.12 = 1 and 04.13 = 0 ;to select torque mode.
05.21 = 1 ;to set enable the bridge interlocking. Only required if the drives are four quadrant.
05.25 = 1 ;to enable parallel 12 pulse operation.
07.11 = 4.08 ;to configure GP1 analogue input to current reference.
05.18 = 0 ;to disable standstill logic

Slave (assuming serial comms are used for slaving)

04.12 = 1 and 04.13 = 0 ;to select torque mode.
05.21 = 1 ;to set enable the bridge interlocking. Only required if the drives are four quadrant.
05.25 = 1 ;to enable parallel 12 pulse operation.
11.13 = 3 ;to select comms mode 3.
11.19 = 408 ;to select destination for serial comms.
05.18 = 0 ;to disable standstill logic

2. SERIES 12-PULSE CONFIGURATION

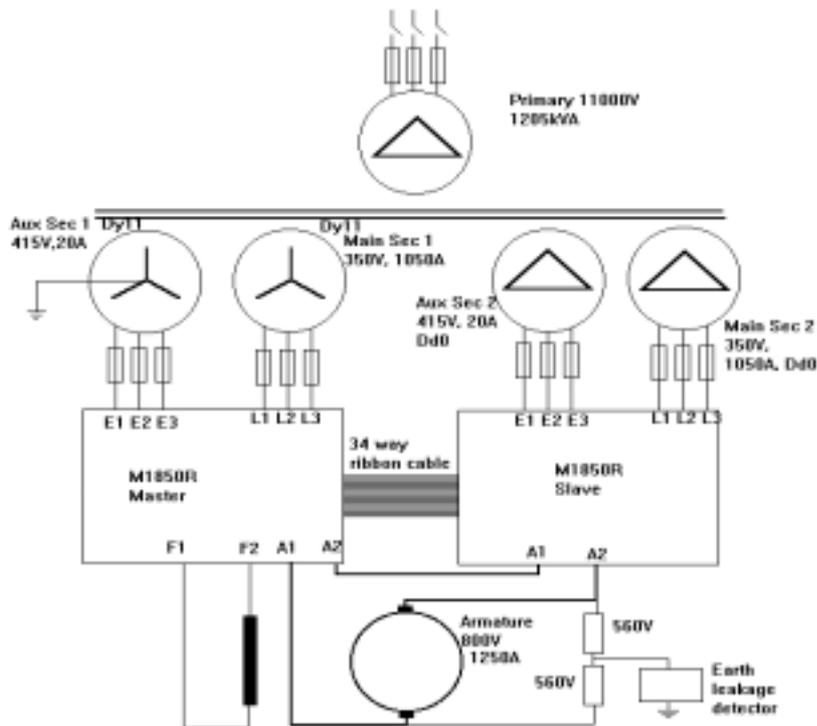
This configuration consists essentially of two 6-pulse modules connected in series. The armature current flows through both stacks and the total armature voltage is the series total of the two. No inter bridge reactors are necessary in this arrangement.

The maximum armature voltage possible is 1100V using the 220V/480V stack. Use of the 660V stack would enable higher voltages to be obtained but are not expected to be required. Output currents upto 1850A mean (2775A peak) may be obtained using standard Mentor modules.

The implementation of a similar 1000 kW drive system as a series 12-pulse arrangement is shown in Fig 2. Control of the thyristor stacks requires only one set of control electronics for both stacks. The main control card, MDA1, must be ordered with the additional connector fitted to provide delayed firing pulses for the slave stack. Bridge interlocking is provided by the same zero current detection as on a 6-pulse stack.

Series 12 pulse mode is phase sensitive. The phase rotation must be in the sequence L1, L2, L3 (parameter 10.11 = 1)

Fig. 2.
Series 12 Pulse System



Drive Set-Up

To set the drives up in a series 12 pulse, speed control system the master drive should be programmed as follows

- | | |
|-------------------|--|
| 04.12 = 04.13 = 0 | ;to set speed control mode. |
| 05.10 = 1 | ;to select the reduced firing angle end-stop to limit the maximum voltage during regeneration. |
| 05.24 = 1 | ;to enable series 12 pulse operation. |
| 05.23 = 1 | ;to enable single quadrant series 12 pulse operation. |

3. TANDEM DRIVE CONFIGURATION

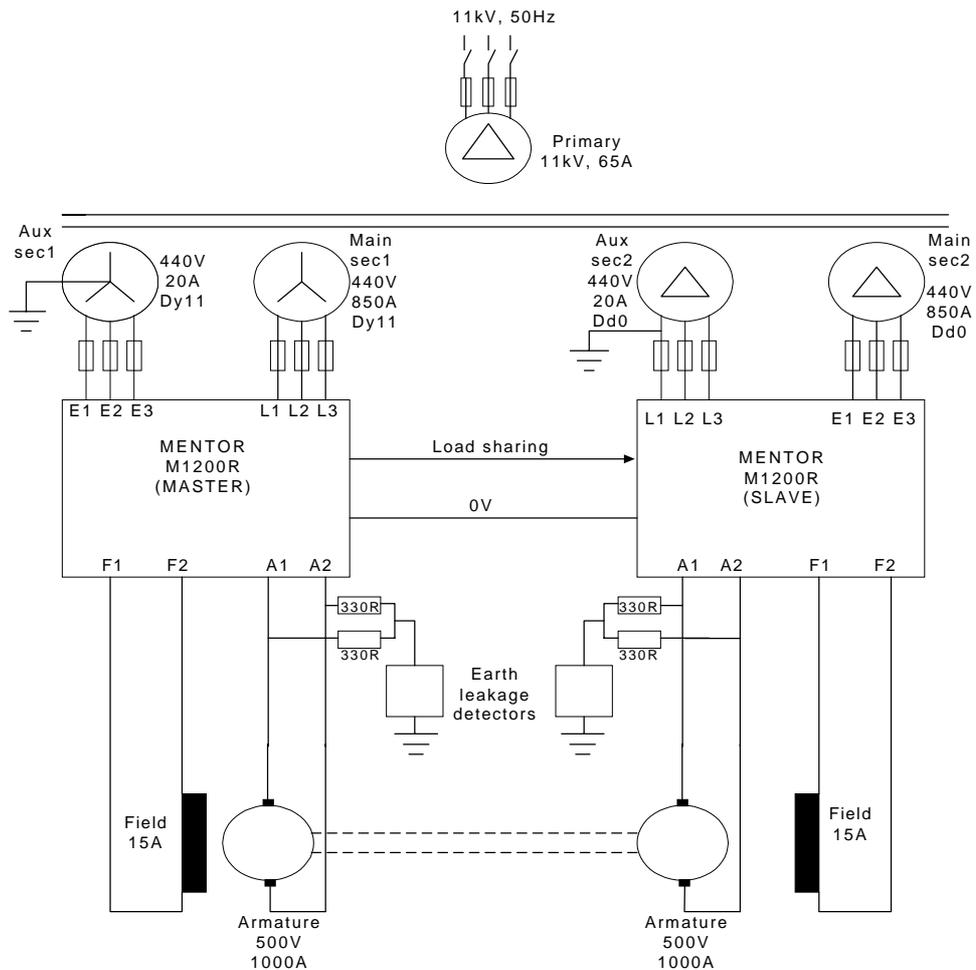
The equivalent of 12-pulse operation can be obtained by mechanically coupling two separate DC motors of equal rating and supplying the armatures from two separate stacks. The star/delta transformer must still be used. The two drive modules function as independent units in master/slave load sharing mode.

The advantage of this configuration is that no inter bridge reactor is necessary. Apart from the cost saving this results in less inductance in the armature loop thus permitting faster rates of change of current to occur which may allow a faster dynamic response to be obtained.

A typical implementation of a 1000 kW drive using two 500 kW motors is shown in Fig. 3. Both modules are completely standard and independent units.

The tandem drive concept can be extended to any number of motors and drives. For example, a 18-pulse system can be derived with 3 motors and a 24-pulse system may be derived with 4 motors. Harmonic cancellation is dependent on correctly phased transformer secondary windings.

As with the parallel 12-pulse system, the phase sequence and transformer winding disposition is of no consequence with a tandem drive.



Example of a Tandem Drive System

Fig.3

4. TRANSFORMERS FOR 12-PULSE SYSTEMS

A delta connected primary should be specified for the appropriate supply voltage. Taps for +10% and -10% should be requested. Taps at +5% and -5% may be required in addition.

Secondary voltages must be at least 0.83 times (ideally 0.88 times) the armature voltage for parallel or tandem configuration and 0.415 times (ideally 0.44 times) the armature voltage for the series configuration) These figures should be regarded as the voltages required at maximum load including any short term overload. Selection of secondary voltages towards the lower limit keeps the transformer kVA to a minimum and the power factor to a maximum. Higher secondary voltage reduces risk of regeneration faults in the event of low line conditions.

Leakage reactance of the transformer should be no greater than 6% total with respect to the maximum load condition which may include the short term overload.

Differences between leakage reactance for the two secondary windings can be tolerated but should not be large.

The transformer secondary current ratings may be calculated from the motor armature current. A form factor of 1.03 may be applied to allow for ripple which will be at a frequency of predominantly 12 times supply frequency. A factor of 0.816 converts the quasi-square secondary current waveform amplitude to rms. value.

Secondary winding rms. current for parallel 12-pulse drives is therefore given by:

$$I_{rms} = 0.816 \times 1.03 \times I_A/2$$

For series 12-pulse and tandem drives the secondary current is given by:

$$I_{rms} = 0.816 \times 1.03 \times I_A$$

The total transformer kVA will be less than the sum of that of the two secondary windings by a factor of 0.935. This is a result of harmonic cancellation between the two windings. Other auxiliary windings must be treated separately.

For parallel 12-pulse drives an auxiliary secondary winding of the same connection as the main winding should be provided for each drive module for the purpose of synchronization and electronics supply. The field supply may also be derived from this winding.

For series 12-pulse drives it is important to maintain the correct phase sequence and the correct phase relationship between the two main secondary windings and the auxiliary supply.

The following table shows which combinations are permissible.

Phase Sequence	Secondary 1 (Main bridge)	Secondary 2 (Delayed bridge)	Auxiliary (sync)
<u>Preferred</u>			
ABC	Dy11	Dd0	Dy11
<u>Non Preferred</u>			
ABC	Dd0	Dy1	Dd0
ACB	Dy1	Dd0	Dy1
ACB	Dd0	Dy11	Dd0

The preferred connection should be adhered to if possible as most star connected transformers are Dy11. In all configurations the phases on secondary 2 will lag the corresponding phases on secondary 1 by 30 degrees.

5. INTER BRIDGE REACTORS FOR PARALLEL 12-PULSE DRIVES.

The inter bridge reactor consists of a simple air-gapped iron core with a centre tapped winding. Its main purpose is to allow for the two thyristor bridges to have different instantaneous output voltages without major differences in current arising between them. The most arduous operating condition occurs at or near standstill (zero back emf) where the voltage waveform between the ends of the reactor approximates to a square wave of 0.707 times the supply voltage at a frequency of six times supply frequency. The inductance of the reactor is chosen so that the peak current due to this square wave (the magnetizing current) is no greater than 5% of the motor full load current.

It is also necessary to allow a further 5% differential for imperfect matching of bridge currents. This may arise as a combination of steady state errors and also mismatch due to the following error of the slave bridge during rapid current changes. The total allowance for magnetizing current is therefore 10% of motor full load current.

The current in each half of the reactor will have a DC component of upto 55% of the motor full load current. Since it will normally be possible to maintain better balance under steady state conditions it is not normally necessary to make further allowance for ripple except where conductors are so large that their AC resistance at 300 Hz (or 360 Hz) is significantly greater than at line frequency.

The construction of the reactor is not critical and a two limb U+I core with one winding section on each limb is the most convenient to manufacture. A marginally faster dynamic response can sometimes be obtained by reducing the leakage reactance between the two halves by splitting each half between the two limbs or by using a E+I core.

The presence of the inter bridge reactor will typically double the amount of inductance in the armature circuit. Since the frequency of the armature current ripple is also doubled it will be found that the continuous current mode of operation is reached at much lower levels of current. During the discontinuous mode each bridge produces independent current pulses of less than 30 degrees width. At levels of around 5 to 10% of full load current each bridge will conduct continuously. Levels of ripple in the armature will be typically 1/4 of that occurring with 6-pulse drives.

The following formulae can be used as a simple guide to design of inter bridge reactors:

Reactor magnetizing inductance,

$$L_M = 0.707V / (12 f \times 0.1 I_A)$$

Reactor magnetizing current (ripple + imbalance)

$$I_M = 0.1 I_A$$

Reactor rms. current

$$I_{rms} = 0.55 I_A$$

The size of the inter bridge reactor in equivalent kVA at line frequency will be approximately 6% of the main transformer kVA. In the example the characteristics for the reactor are $L_M = 2.6$ mH, $I_M = 200$ A and $I_{rms} = 1100$ A.

6. EARTHING ARRANGEMENTS

It is important to ensure that adequate ground fault protection is made in all drive systems and 12-pulse systems sometimes require special arrangements. In the series 12-pulse system it is possible to develop higher than normal armature voltages and it is necessary to take special precautions to prevent excessive voltage stress on components used for voltage isolation and to ensure that voltage monitoring circuits function correctly.

For very high power drive systems direct bonding to earth alone is not recommended since in the event of a fault the earth current must reach a level high enough to blow the supply fuses or operate the circuit breaker. Considerable damage at the point of the fault plus damage to semiconductors can easily occur. An alternative and suitably safe practice is to ground the system via a sensitive earth leakage trip interlocked with the supply circuit breaker. If a detector with a sensitivity of 100 mA is used the total resistance of the detector plus any series resistance may be upto 500 ohms before 50V is exceeded at the threshold of operation. In the event of a ground fault a resistance of this order limits fault current to a level which is unlikely to result in serious damage.

Power circuit earth connection

In parallel 12-pulse systems the most convenient point for earthing is the neutral point of the star connected secondary. A series 12-pulse system may be earthed via the mid point of the two bridges or by a potential divider across the motor armature. It is important to avoid earthing one of the armature terminals as this will place one of the bridges at a very high potential relative to earth.

Auxiliary supply earth connection

It must also be remembered that auxiliary transformer windings must also be earthed. For star connected auxiliary windings the neutral point should be bonded directly to earth. For delta connected windings the same should be done with one phase thus leaving the other two at line to line voltage relative to earth. Co-ordination with suitable HRC fuses is necessary.

Control circuit earth connection

In order to avoid problems with earth loops Mentor DC drives have control circuits which are not solidly bonded to earth. Various points in the power circuit are monitored by the control circuits via high impedance differential amplifiers. For these circuits to function correctly no AC or DC terminal of the stack may exceed 600V relative to the control circuit ground. This will not be a problem if the recommendations for earthing the power circuit are followed and the system ground for all control devices is also earthed.

7. COMMISSIONING 12-PULSE DRIVES

In most respects the normal procedure for commissioning 6-pulse drives should be followed. However, particular attention should be paid to the relative phasing of transformers, stacks and auxiliary supplies in the case of the series 12-pulse system.

It is very important for drives to have identical burden resistors in their current feedback circuits and for there to be only one 12 pulse system (two drives) on any one transformer for the drives to share the load equally.

In parallel and tandem drive systems it is possible to operate each stack independently as a 6-pulse drive before operation as a full 12-pulse drive is attempted. However, the inter bridge reactor in a parallel system will saturate at about 10% full load current. The subsequent change in inductance may result in poor current loop performance but will not result in any damage.

When 12-pulse operation is established it is recommended that the current feedback levels for each drive are compared for various load conditions to ensure that currents are balanced.

When setting up a four quadrant system it is necessary to use the final current demand (4.02) of the master drive as the torque reference (4.08) for the slave drive so that the interlocking of the bridge changeover and autotune routine can operate correctly.

If the autotune routine is to be used to set up the current loop gains of a parallel system you should follow this procedure

1. Enable 12 pulse operation on both drives
2. Set autotune parameter 5.09 on the master drive.
3. Enable both drives.
4. Copy over the gains to the slave drives
5. Repeat the autotune by setting 5.09 on the master.

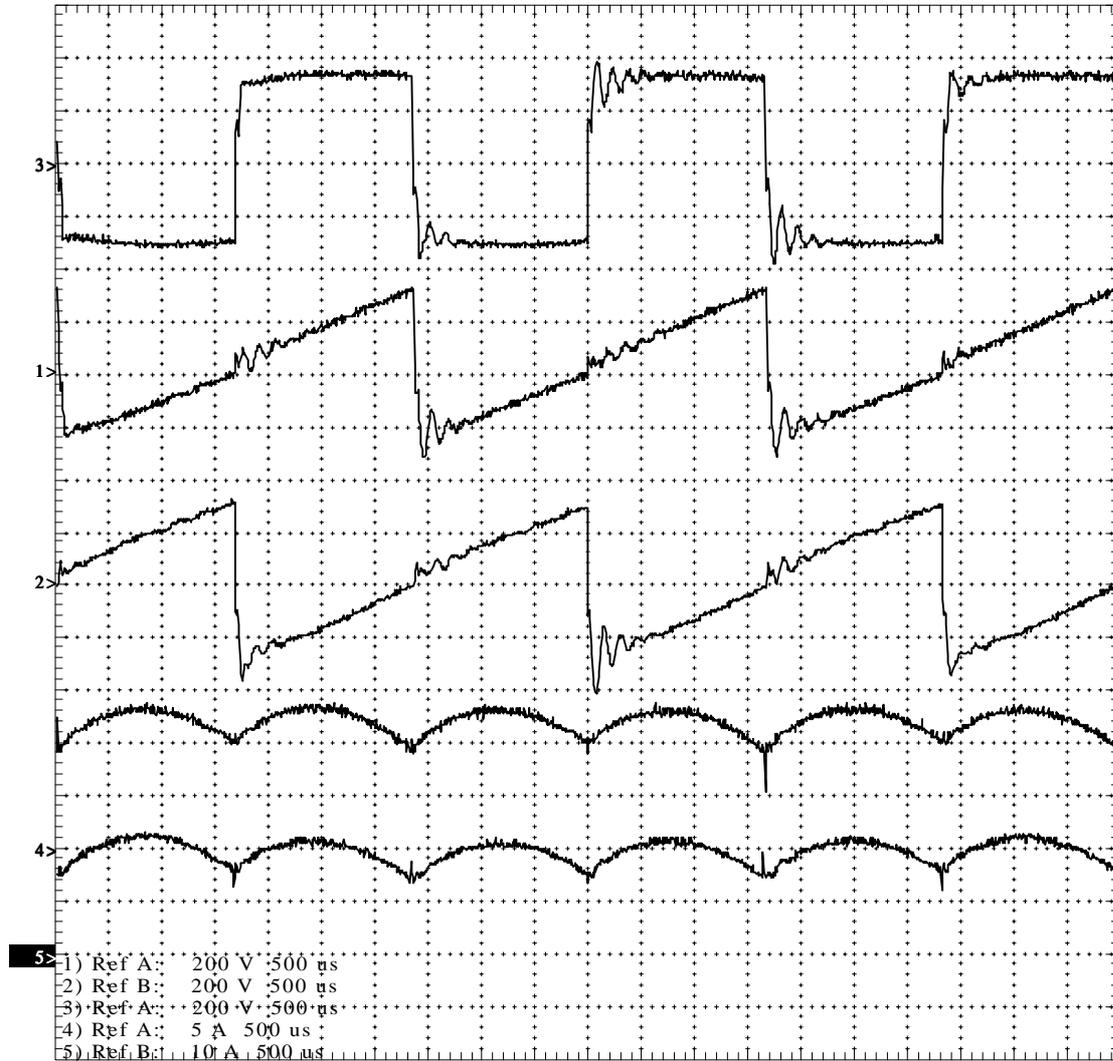
8. TYPICAL HARMONIC CURRENT LEVELS

The table below clearly shows that the 5th and 7th harmonics are practically eliminated by using the 12 pulse arrangement.

Order of Harmonic	6-Pulse System Percentage of fundamental	12-Pulse System Percentage of fundamental
5	27	0.3
7	6.5	0.75
11	8.9	12.2
13	4.5	2.6
17	5.3	*
19	3.3	*
23	3.7	4.5
25	2.6	2.2
29	2.9	*
31	2.2	*
35	2.3	3.1
37	1.8	2
41	1.9	*
43	1.6	*
47	1.6	2.2
49	1.5	1.6

* indicates that the level was less than 1%

Fig.4 12- Pulse Waveforms at Zero Speed For Parallel System



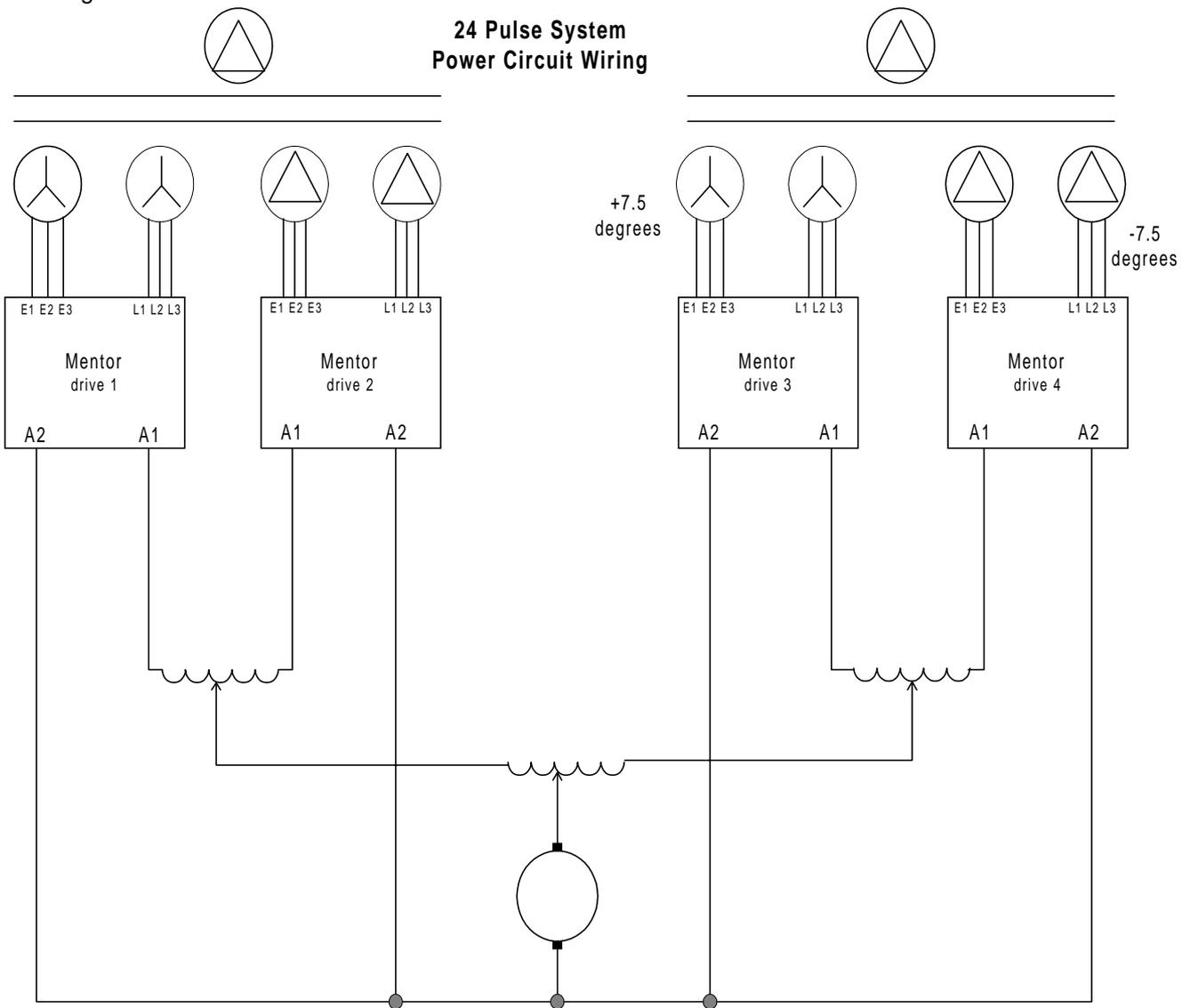
Waveform 1 Voltage across choke (200V/div.)
Waveform 2 Output voltage of MASTER drive (200V/div.)
Waveform 3 Output voltage of SLAVE drive (200V/div.)
Waveform 4 Output current of MASTER drive (5A/div.)
Waveform 5 Armature current (10A/div.)
Time base = 0.5 ms/div.

9. 24 PULSE SYSTEMS

It is possible to extend the 12 pulse function to provide a 24 pulse system by supplying two parallel 12 pulse systems from a transformer with four phase shifted windings as shown in Fig 5 below

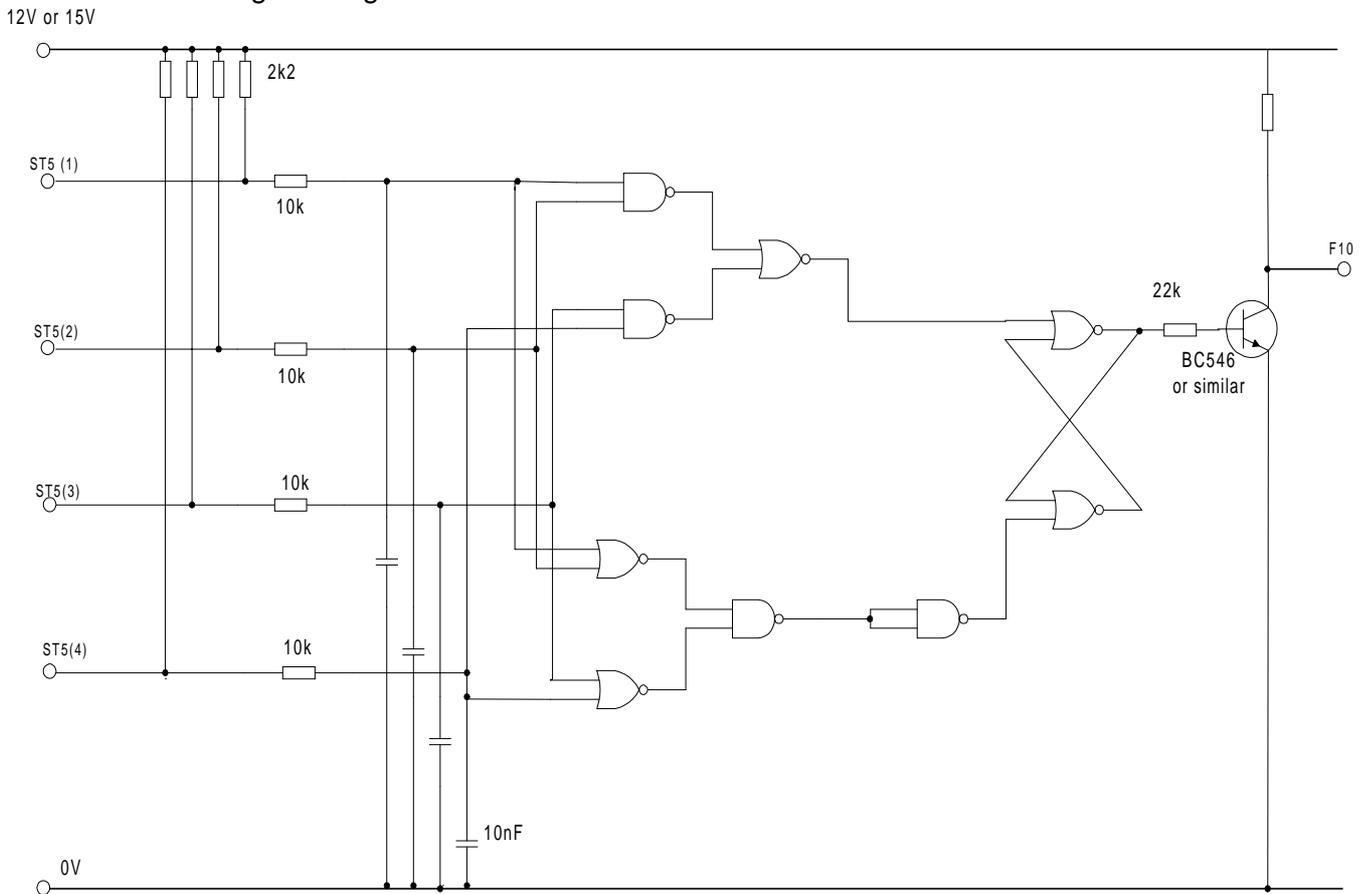
The earthing arrangement explained for the 12 pulse system should be used.

Fig.5



If the drives are 4 quadrant then some extra logic is needed to control the bridge interlocking. The required circuit is shown in Fig. 6 below.

Fig.6
4 Quadrant Bridge Changeover Interlock Circuit



The bridge interlocking board is connected to the Mentor drives as shown in Fig. 7 below

Fig. 7

