Electrical Calculations

L.M.Photonics Ltd 2006

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Printed: January 2006 in Christchurch New Zealand

Publisher

L.M.Photonics Ltd

Managing Editor

Mark Empson

Table of Contents

Part I

1 Introduction

This software package is designed to provide a suite of useful calculations for the electrical engineer.
It includes Busbar and cable calculations, Powerfactor Correction, Motor Starter Selection, and metric/imperial conversions.

The Busbar and cable calculations provide maximum current ratings and voltage drop figures under varying conditions. The Busbar calculations provide for both Aluminium and Copper Busbars. Busbar Power dissipation for given currents are also calculated.

The Power Factor Correction calculations provide for an accurate sizing of static power factor correction of AC Induction motors. Most selection tables are highly inaccurate as the variations in individual motor designs result in a wide variation of magnetizing current.

The Motor Starter Selection calculations allows the correct starter to be matched to any specific motor and load provided the speed torque curves for the motor and load are available.

Metric to imperial and imperial to metric conversions are included for many of the commonly used units in the electrical industry under the topics of Area, Length, Mass, Pressure, Torque and Volume. More conversions will be added in later releases of this software.

This software is under constant development. If you have any comments of suggestions, please post these at:
http://www.lmphotonics.com/contact.php or post them on our forum at http://www.lmpforum.com/forumdisplay.php?fid=71
For discussions and announcments, watch http://www.lmpforum.com/forumdisplay.php?fid=60

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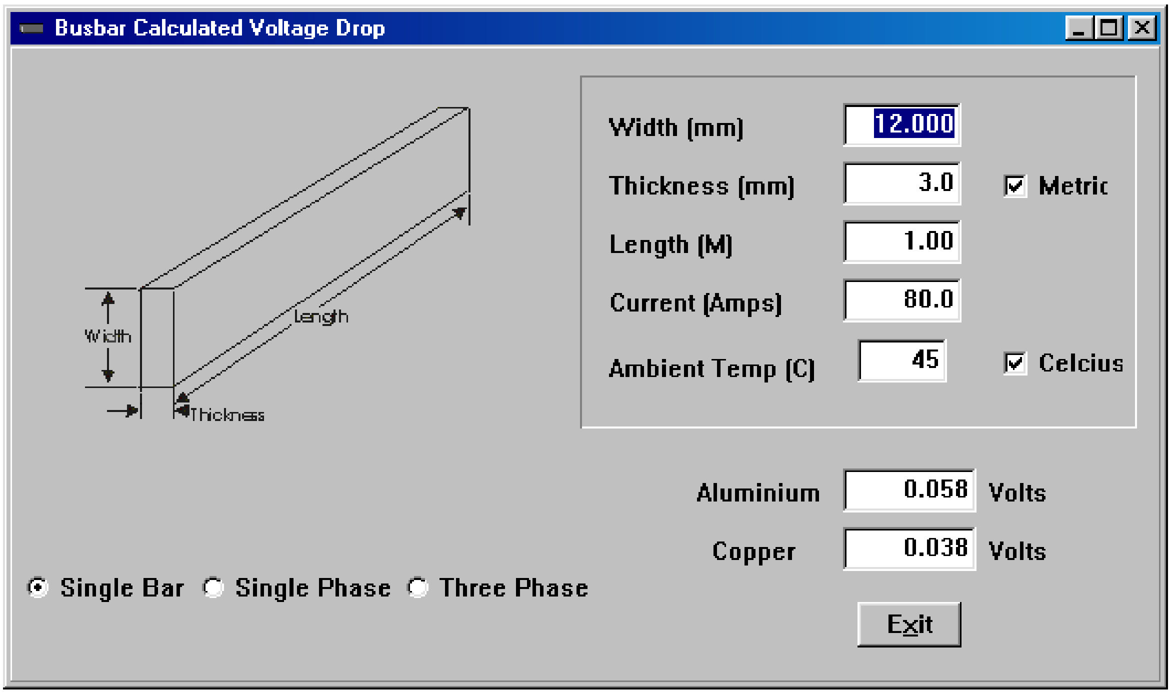
Part II

2 Busbar Calculations

2.1 Busbar Voltage Drop

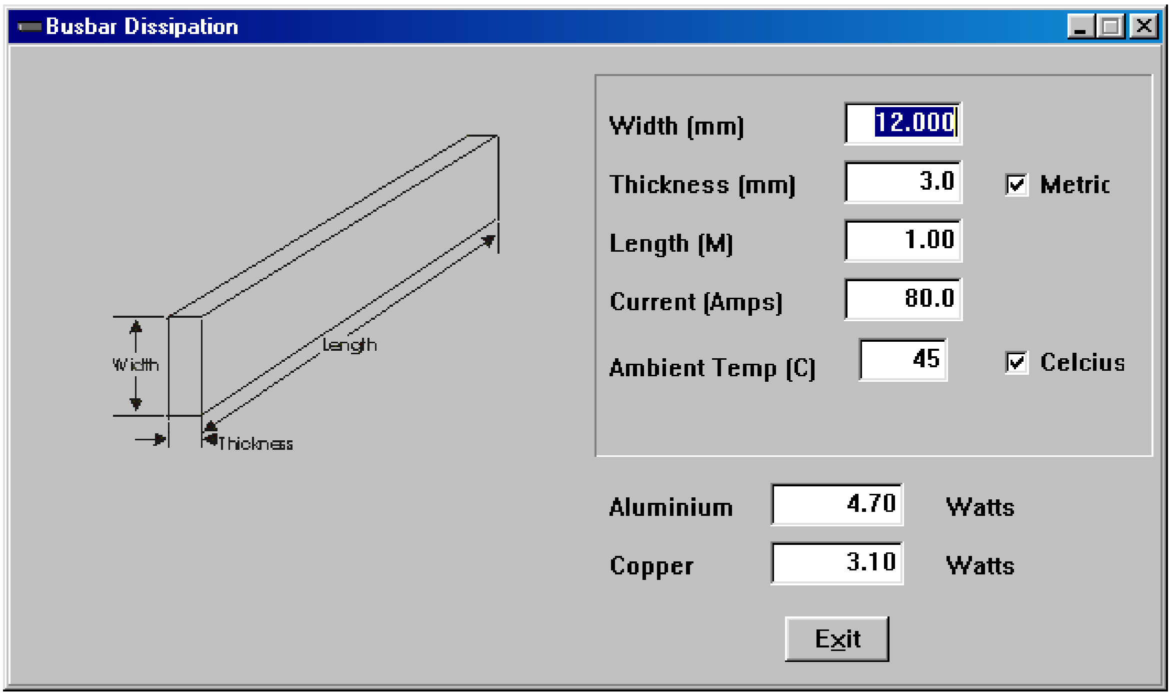
The Busbar voltage drop is the expected resistive voltage drop on a busbar circuit, based on the length and cross sectional area of the bar. There may be an additional voltage drop due to the inductance of the bar. This can become particularly important at high frequencies and high currents. Where there are a number of bars in parallel, assume the bar width is the actual width multiplied by the number of bars in parallel. i.e. 5 bars of 50 x 6 mm in parallel would give the same resistive voltage drop as a single bar of 50 x 30mm.



To calculate the resistive voltage drop of a length of busbar, enter in the width, length and thickness of the bar. Select the units as either metric or imperial. and the current passing through the bar. The circuit configuration also needs to be specified. "Single bar" refers to the voltage drop along a single length of bar, while "Single Phase" refers to the voltage drop of two equal lengths of bar, one in the active circuit and one in the neutral circuit. "Three Phase" calculates the voltage drop between the supply and a three phase load where three equal bars are used for the three phase circuits. Enter the ambient temperature around the bar as Celsius or Fahrenheit and the program will check the suitability of the bar for that current. The program displays the resistive voltage drop for both an aluminium bar of these dimensions and a copper bar of these dimensions.

2.2 Busbar Power Dissipation

The total Power Dissipated in the busbar is dependent on the resistance of the bar, it's length and the square of the RMS current flowing through it.



The power dissipated in the busbar is proportional to the square of the current, so if the busbar has a cyclic load, the current should be the RMS current rather than the average. If the maximum current flows for a considerable period of time, this must be used as the current to determine the maximum busbar temperature, but the power dissipation is based on the square root of the maximum current squared times the period for which it flows plus the lower current squared times the period it flows all divided by the square root of the total time. For example, a busbar carries a current of 600 Amps for thirty seconds, then a current of 100 amps for 3000 seconds, then zero current for 3000 seconds. The power dissipation is based on an RMS current of sqrt(600x600x30 + 100x100x3000 + 0 x 3000)/sqrt(30 + 3000 + 3000) = 82.25 Amps.

To calculate the Power Dissipation of a busbar, enter in the width, length and thickness of the bar, and the RMS Current passing through it. Select the units as either metric or imperial. The program displays the Power Dissipated in both an aluminium bar of these dimensions and a copper bar of these dimensions. Enter the ambient temperature around the bar in either Celsius or Fahrenheit and the program will check the suitability of the bar for this application.

2.3 Busbar Ratings

Busbar ratings are based on the expected surface temperature rise of the busbar. This is a function of the thermal resistance of the busbar and the power it dissipates. The thermal resistance of the busbar is a function of the surface area of the busbar, the orientation of the busbar, the material from which it is made, and the movement of air around it. The power dissipated by the bus bar is dependent on the square of the current passing through it, its length, and the material from which it is made.

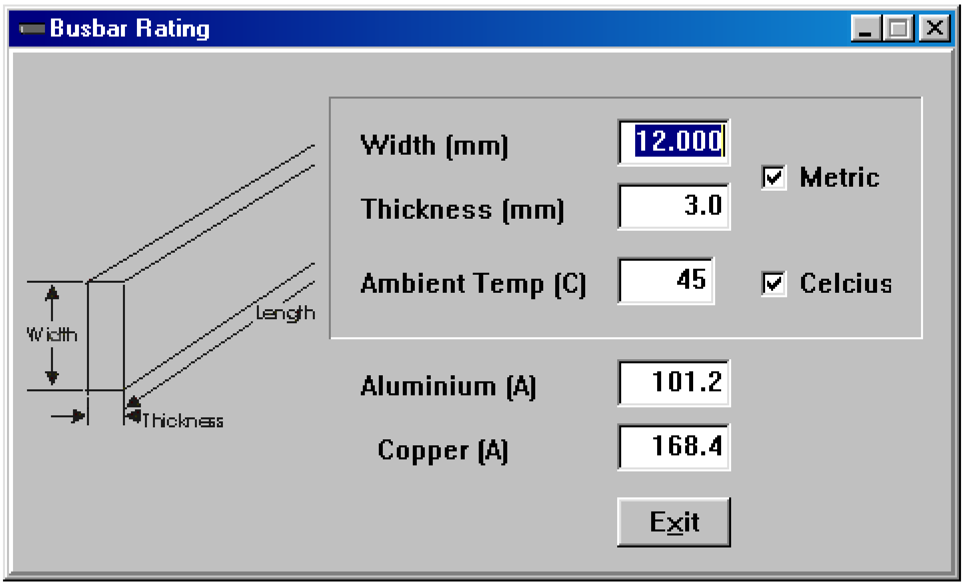
Optimal ratings are achieved when the bar runs horizontally with the face of the bar in the vertical plane. i.e. the bar is on its edge. There must be free air circulation around all of the bar in order to afford the maximum cooling to its surface. Restricted airflow around the bar will increase the surface temperature of the bar. If the bar is installed on its side, (largest area to the top) it will run at an elevated temperature and may need considerable derating. The actual derating required depends on the shape of the bar. Busbars with a high ratio between the width and the thickness, are more sensitive to their orientation than busbars that have an almost square cross section.

Vertical busbars will run much hotter at the top of the bar than at the bottom, and should be

derated in order to reduce the maximum temperature within allowable limits.
Maximum Busbar ratings are not the temperature at which the busbar is expected to fail, rather it is the maximum temperature at which it is considered safe to operate the busbar due to other factors such as the temperature rating of insulation materials which may be in contact with, or close to, the busbar. Busbars which are sleeved in an insulation material such as a heatshrink material, may need to be derated because of the potential aging and premature failure of the insulation material.

The Maximum Current rating of Aluminium Busbars is based on a maximum surface temperature of 90 degrees C (or a 60 degree C temperature rise at an ambient temperature of 30 degrees C). If a lower maximum temperature rating is desired, increase the ambient temperature used for the calculations. i.e. If the actual ambient temperature is 40 degrees C and the desired maximum bar temperature is 80 degrees C, then set the ambient temperature in the calculations to 40 + (90-80) = 50 degrees C.

The Maximum Current rating of Copper Busbars is based on a maximum surface temperature of 105 degrees C (or a 75 degree C temperature rise at an ambient temperature of 30 degrees C).



The Busbar Width is the distance across the widest side of the busbar, edge to edge.

The Busbar Thickness is the thickness of the material from which the Busbar is fabricated. If the busbar is manufactured from a laminated material, then this is the overall thickness of the bar rather than the thickness of the individual elements.

The Busbar Length is the total length of busbar used.

The Busbar Current is the maximum continuous current flowing through the busbar. The power dissipated in the busbar is proportional to the square of the current, so if the busbar has a cyclic load, the current should be the RMS current rather than the average. If the maximum current flows for a considerable period of time, this must be used as the current to determine the maximum busbar temperature, but the power dissipation is based on the square root of the maximum current squared times the period for which it flows plus the lower current squared times the period it flows all divided by the square root of the total time. For example, a busbar carries a current of 600 Amps for thirty seconds, then a current of 100 amps for 3000 seconds, then zero current for 3000 seconds. The power dissipation is based on an RMS current of sqrt(600x600x30 + 100x100x3000

+ 0 x 3000)/ssqrt30 + 3000 + 3000) = 82.25 Amps.

The Ambient Temperature is the temperature of the air in contact with the busbar. If the air is in an enclosed space, then the power dissipated by the busbar will cause an increase in the ambient temperature within the enclosure.

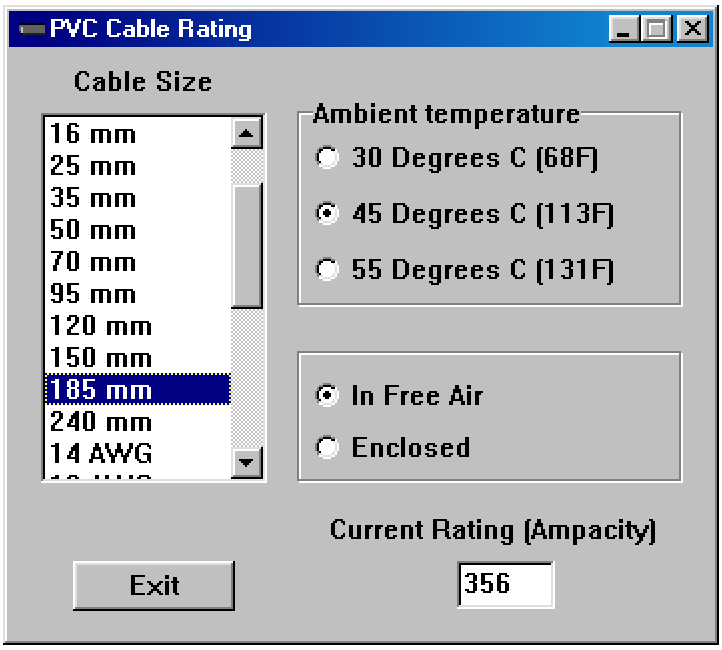
To calculate the rating of a busbar, enter in the width and thickness of the bar, and the ambient temperature around the bar. Select the units as either metric or imperial, and the temperature as Celsius or Fahrenheit. The program displays both the current rating of an aluminium bar of these dimensions and a copper bar of these dimensions.

Part III

3 Cable Calculations

3.1 Cable Current Ratings

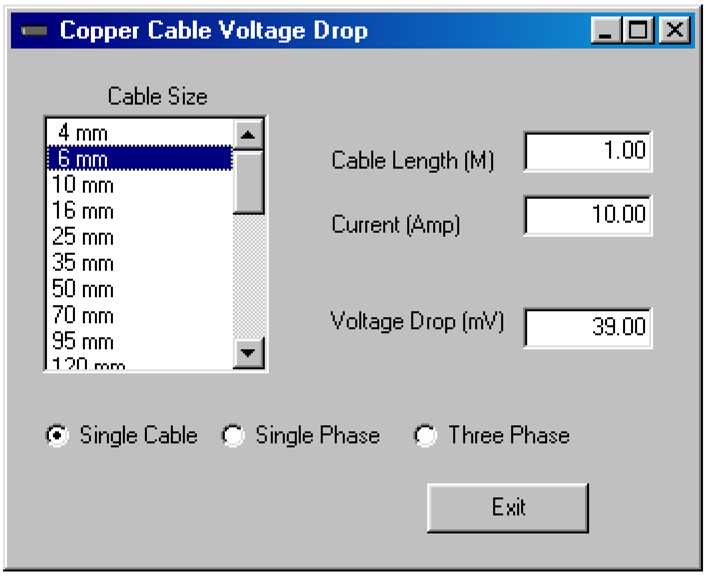
Cable ratings are based on the resistance of the cable, the surface area of the cable, and the temperature rating of the insulating material. The rating applied to a cable is at a given ambient temperature. Variation in ambient temperature will result in a variation of the cable rating.
The resistance of the cable is a function of the material from which the conductor is manufactured, i.e. copper or aluminium, and the cross sectional area of the conductor.
The Cable size can be nominated in either square millimeters, or in the US American Wire Gauge. The European metric ratings are based on figures from VDE 0100 and the American Wire Gauge figures are taken from the National Electrical Code. (NEC)
Ambient Temperature. The air temperature around the cable.
Ventilation. Free air movement around the cable will allow more cooling than cables enclosed in conduit or trunking.



To calculate the current rating of a cable, select the cable size and the ambient temperature around the cable in degrees Celsius or Fahrenheit and the ventilation. ("In Free Air" or "Enclosed" in conduit or trunking.) The current rating of a copper cable is displayed.

3.2 Cable Voltage Drop

The Cable voltage drop is the expected voltage drop on a cable circuit, based on the length and cross sectional area of the bar. Where there are a number of cables in parallel, assume the cable cross sectional area is the actual area multiplied by the number of cables in parallel. i.e. 5 cables of 6 mm in parallel would give the same resistive voltage drop as a single cable of 30mm.



To calculate the voltage drop of a length of cable, select the cable size and the current passing through the cable. The circuit configuration also needs to be specified. "Single Cable" refers to the voltage drop along a single length of cable, while "Single Phase" refers to the voltage drop of two equal lengths of cable, one in the active circuit and one in the neutral circuit. "Three Phase" calculates the voltage drop between the supply and a three phase load where three equal cables are used for the three phase circuits. The program displays the voltage drop for a copper cable.

3.3 Cable Power Dissipation

The total Power Dissipated in the cable is dependent on the resistance of the cable, it's length and the square of the RMS current flowing through it.

The power dissipated in the cable is proportional to the square of the current, so if the cable has a cyclic load, the current should be the RMS current rather than the average. If the maximum current flows for a considerable period of time, this must be used as the current to determine the maximum cable temperature, but the power dissipation is based on the square root of the maximum current squared times the period for which it flows plus the lower current squared times the period it flows all divided by the square root of the total time. For example, a cable carries a current of 600 Amps for thirty seconds, then a current of 100 amps for 3000 seconds, then zero current for 3000 seconds. The power dissipation is based on an RMS current of sqrt(600x600x30 + 100x100x3000 + 0 x 3000)/sqrt(30 + 3000 + 3000) = 82.25 Amps.

Part IV

4 Circuits

4.1 Delta Star conversions

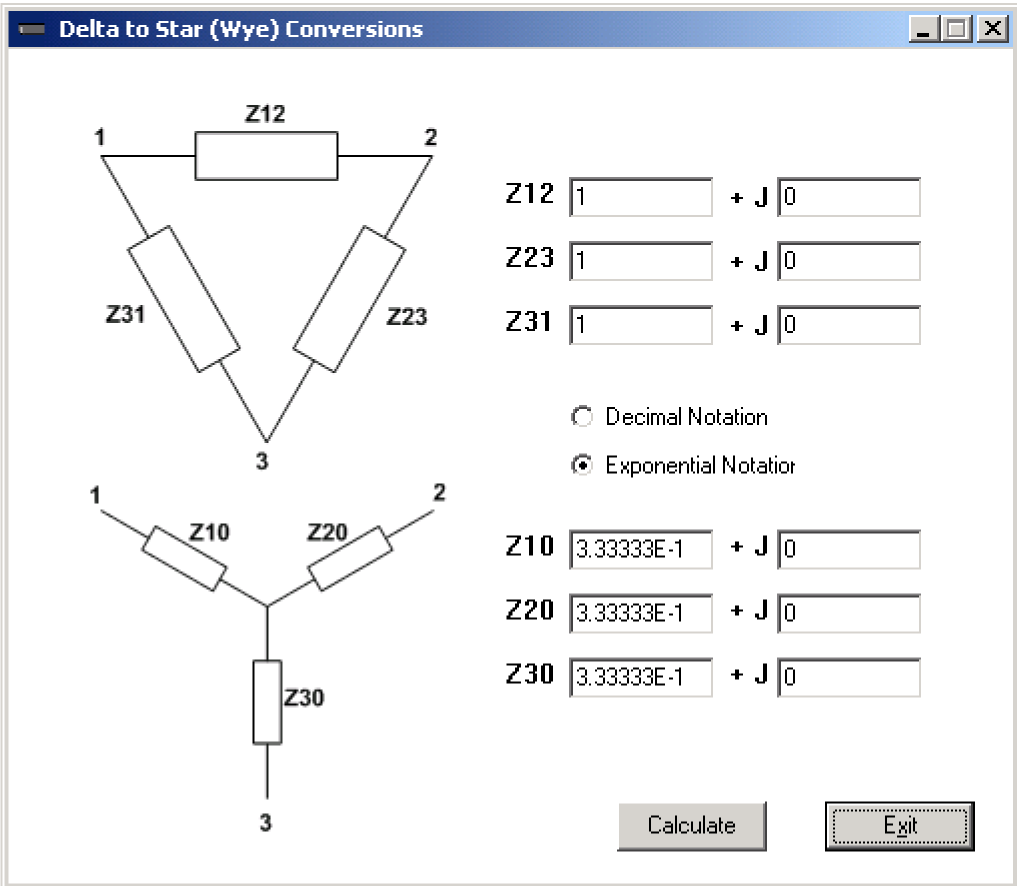
In three phase applications, Delta connected circuits can be replaced by star connected circuits with the same resultant impedance. The Delta impedances are Z12, Z23 and Z31. These can be replaced by star impedances Z10, Z20 and Z30.

For the calculations, the impedance Zxx is expressed as R + JX where R is the resistive component and X is the reactive component.

For an inductor, X = 2 x pi x F x L and
for a capacitor, X = -1/(2 x pi x F x C) NB X value for capacitor is negative!!

where:
pi = 3.142
F = operating frequency
L = inductance
C = Capacitance.

The values can be entered and diplayed in either decimal format or in exponential format.
1e-3 = 0.001
1.45e2 = 145



4.2 Star Delta conversions

In three phase applications, Star connected circuits can be replaced by Delta connected circuits with the same resultant impedance. The Star impedances are Z10, Z20 and Z30. These can be replaced by Delta impedances Z12, Z23 and Z31.

For the calculations, the impedance Zxx is expressed as R + JX where R is the resistive component and X is the reactive component.

For an inductor, X = 2 x pi x F x L and
for a capacitor, X = -1/(2 x pi x F x C) NB X value for capacitor is negative!!

where:
pi = 3.142
F = operating frequency
L = inductance
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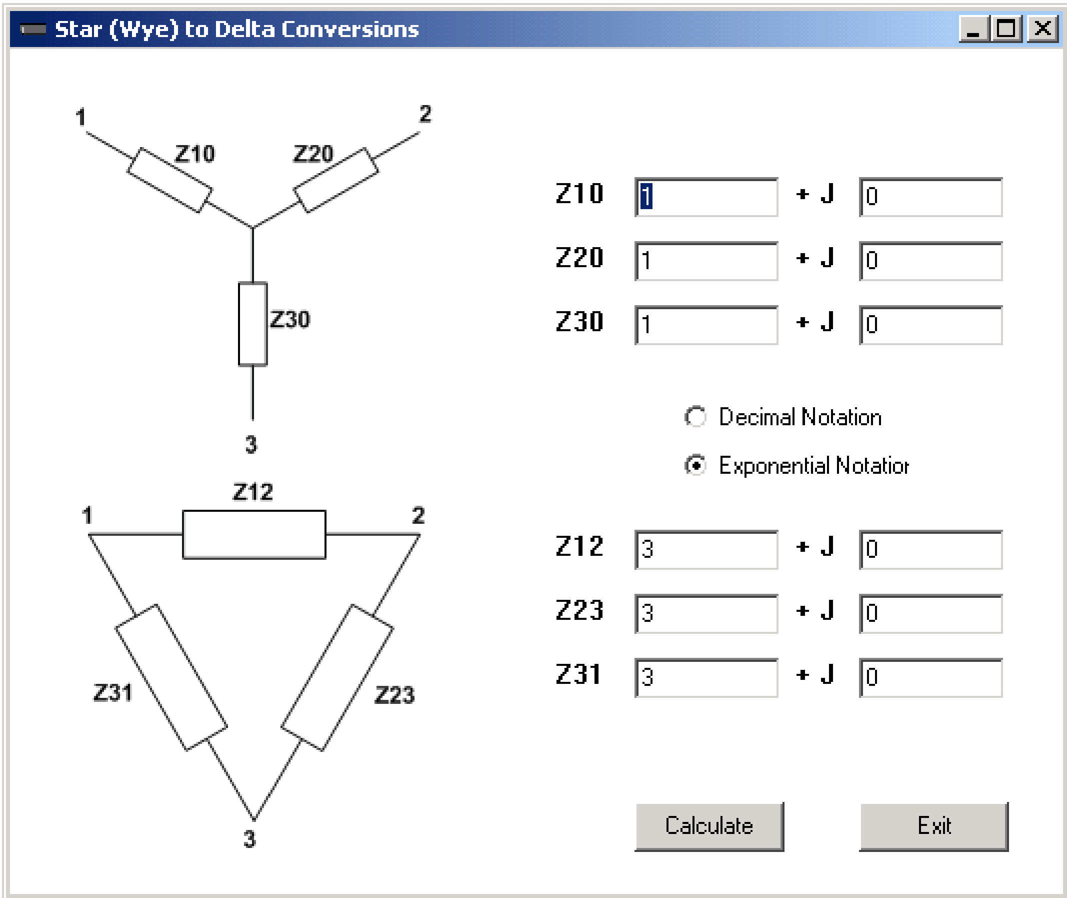
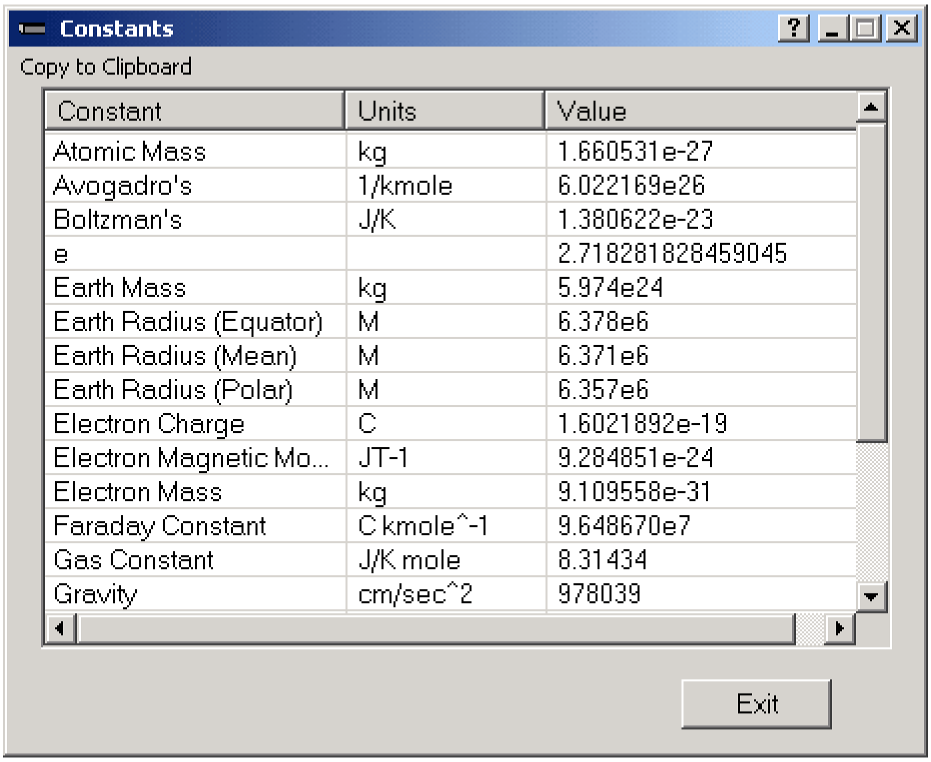


Part V

5 Constants

5.1 Constants

The Constants screen includes a wide range of engineering and scientific constants. Highlight the constant and select the "copy to clipboard" option to apply the constant in other applications.

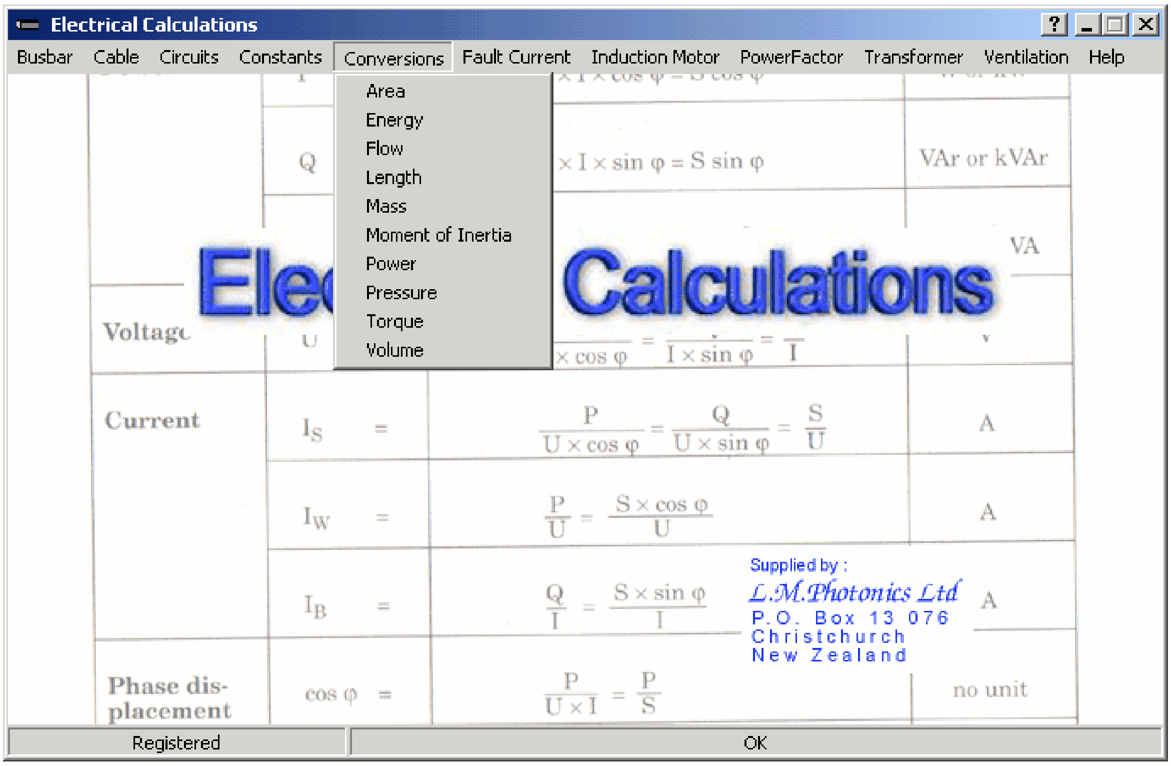


Part VI

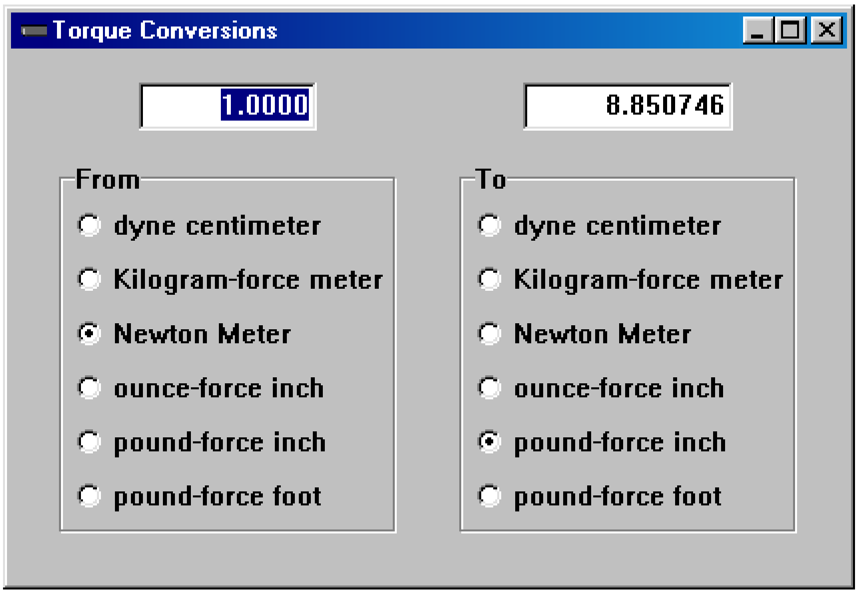
6 Conversions

6.1 Conversions

The conversions routines currently provide conversions for units of area, length, Mass, Pressure, Torque and Volume. Within these, there are a range of commonly used metric and imperial units to convert between.



To make a conversion, from the "Conversions" menu, select the required conversion.



Enter a value (Greater then 1) in the left hand window and select the units to convert from. Select the units to convert to on the right hand side and the result is displayed in the right hand window.

Part VII

7 Enclosure Ventilation and Cooling

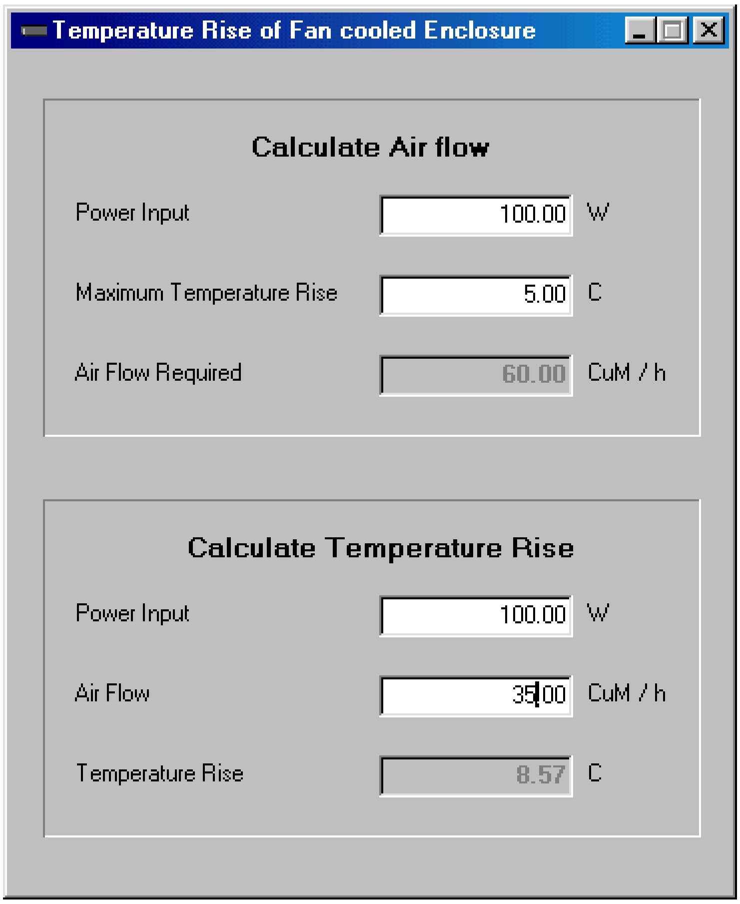
7.1 Fan cooled enclosure

The temperature rise within the enclosure is directly proportional to the thermal resistance of the enclose and the total power dissipated within the enclosure. The thermal resistance is a function of the shape and size of the enclosure, and also to the amount of exposed surface area. Given the dimensions of the enclosure, and the environment within which it is mounted, it is possible to approximate the enclosure thermal resistance for a sealed enclosure.
The addition of ventilation grills will reduce the thermal resistance, but not by a significant amount. (Typically less than 10%)
If the thermal resistance of the enclosure needs to be reduced significantly, the only way to accurately control the temperature rise is by the addition of forced ventilation fans. With forced ventilation, the amount of airflow required for a given temperature rise is proportional to the total power dissipated.
When fans are used, adequate open area for air input and air output must be provided. If the open area equals the size of the fan, the velocity of the air flow will be equal to the velocity of the air through the fan. If the open area is too small, the airflow velocity will increase, the pressure across the fan will increase and the airflow will reduce.
Inlet and exhaust ports can provide a much higher resistance to air flow, and thereby restriction in ventilation than is generally appreciated. Wherever possible, it is preferable to keep the smallest dimension of the open area at no less than 10 mm. If the smallest dimension is reduced below this figure, the boundary effect around the edges of the opening will reduce the effective open area. A good rule is to try for twice the area of the fans in open area for the inlet and exhaust ports with the minimum dimension of the opening at 10mm or greater.
If the smallest dimension is halved, then allow for double the open area.
A further reduction in the minimum opening dimension should be compensated for by and increase in the open area. Failure to do this will result in reduced air flow and increased temperature rise. One solution where very fine mesh is employed is to double the fan capacity. Air filters can severely restrict the air flow, but will often be accompanied by flow/pressure curves.
Where these curves are available, they can be superimposed on to the fan curves and the actual expected flow can be easily predicted. NB Small box fans very quickly lose airflow when a constrictive filter is applied.

Typical Air flow figures for small fans:

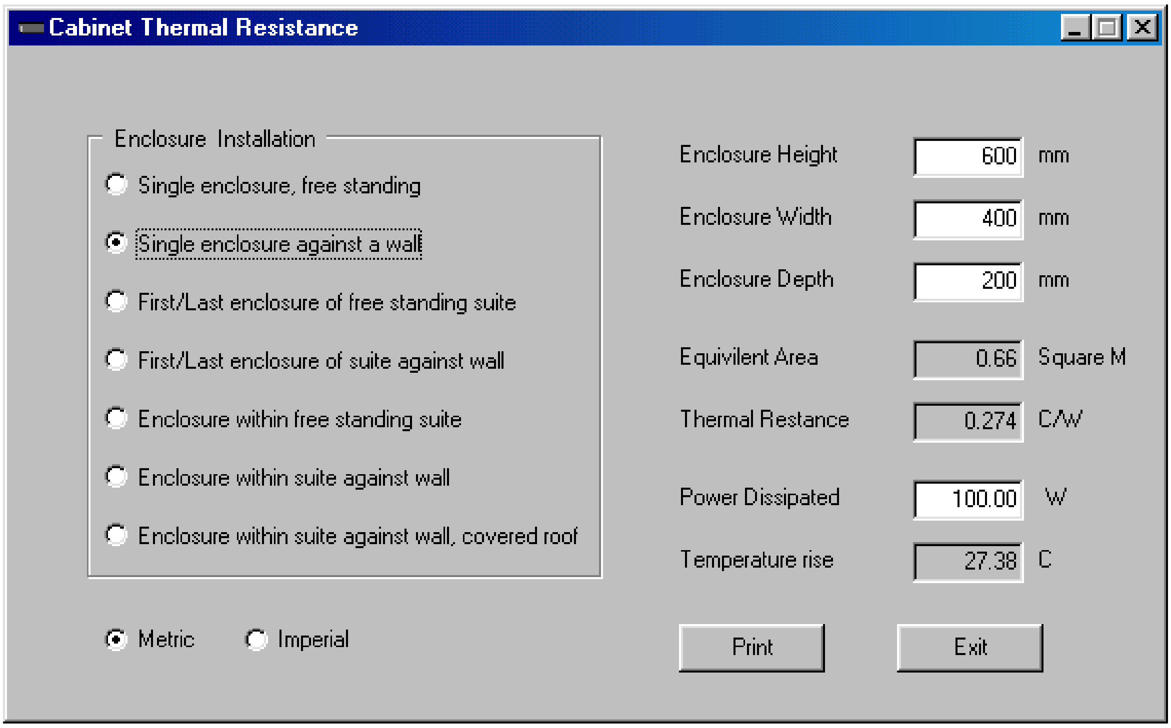
Size (mm)	Speed	(cfm)
119 x 25	High	80
119 x 38	Low	50
119 x 38	Medium	75
119 x 38	High	100
172 x 51	High	280

The required airflow can be calculated from the total power dissipated in the enclosure and the maximum allowable temperature rise. Likewise, the temperature rise can be calculated for known Power dissipation in the enclosure and airflow.



7.2 Sealed Enclosure

A sealed enclosure containing electrical apparatus will have an internal temperature rise that is dependent on the thermal resistance of the enclosure and the total power dissipated within that enclosure.
The thermal resistance of the enclosure is a function of the size of the enclosure, the shape of the enclosure and the exposed surface area of the enclosure. If the enclosure is free standing with air able to freely circulate over all vertical surfaces, then it will have a lower thermal resistance than an enclosure where the air flow over one or more surfaces is restricted. Likewise, increasing width is far more effective in reducing the thermal resistance of an enclosure than increasing height.
Adding ventilation louvers without fans will only slightly reduce the thermal resistance of the enclosure. (usually less than 10% reduction in thermal resistance or temperature rise!)
The thermal resistance can be calculated for a given height, width and depth of enclosure provided the installation conditions are specified. From the thermal resistance and total power dissipated within the enclosure, the temperature rise can be calculated.



7.3 Power dissipated in Enclosure

The total Power dissipated in the enclosure is the sum of all power dissipated by all components mounted within the enclosure.

In order to calculate/approximate the ventilation required for an enclosure, the power dissipated within the enclosure must be known.

Here are some guidelines for calculating the total power dissipated in the enclosure.

Soft Starter. Allow 4.5 Watts per amp. i.e. MSX 0175 operating at 150 amps, allow 150 x 4.5 = 675 Watts.

Speed Drive. Allow 20 Watts per amp.

Contactor AC3. If dissipation not known, allow 0.15 Watts per Amp contact dissipation, plus 0.1 Watts per amp coil dissipation.

Contactor AC1. If dissipation not known, allow 0.6 Watts per Amp contact dissipation, plus 0.1 Watts per amp coil dissipation.

Thermal overload. If not known, allow:

10 watts if Ie < 32A

18 watts if 32A < Ie < 70A

22 watts if 70A < Ie < 500A

50 watts if Ie > 500A.

Fans. (Not part of starter. i.e. cabinet ventilation fans)

Allow 10 watts for 25mm x 120 mm.

Allow 18 watts for 38mm x 120 mm.

Allow 30 watts for 51mm x 172 mm.

Lamps. Allow 2.5 watts

Fuses.

Type F06. Allow 2 watts per fuse.

Semiconductor Fuses.

Fuse	Soft Starter	Speed Drive
40AFE	2W	10W
80AFE	3W	20W
200FM	7W	40W
350FM	10W	55W
700FMM	22W	120W

Isolators. If not known, allow 0.6 watts per line amp.

Power factor correction capacitors. Refer to data sheet and/or supplier.

Part VIII

8 Induction Motor Starting

8.1 Introduction

An induction motor is part of a system comprising the driven load, the induction motor, the starter and the supply. The best starting conditions can only be met if all components of the system are correctly engineered as a group. The driven load requires torque to accelerate to full speed. If insufficient torque is applied to the driven load, it can not reach full speed. The Induction motor converts current into torque to accelerate the motor. If there is insufficient start current available, the motor can not develop enough torque, and the load can not reach full speed.

To engineer the system, it is important to firstly establish the starting torque requirements of the driven load. Next the starting characteristics of the induction motor should be analyzed in order to establish the start current required by the motor to develop the required starting torque. A starter can now be designed/selected to meet the start current requirement, and an appropriate supply connected.

Induction motors exhibit a very low impedance at speeds less than their rated speed. This results in a very high start current when Direct On Line started. The Direct On Line starting current is independent of the motor load and is dependent only on the motor design, rotor speed and the applied voltage. Variations in motor loading will affect the start duration only. Typically, the Direct On Line starting current falls somewhere between 550% Full Load Current and 900% Full Load Current. The actual start current of a given design is determined primarily by the design of the rotor. Shallow bar rotor designs are generally referred to as Design 'A' rotors and are characterized by a high start current (650% - 900%) and a low starting torque (60% - 150%). Design 'B' rotors are deeper bar rotors and typically exhibit a starting current of (550% - 650%) and a starting torque of (150% - 300%).

In many installations, the maximum starting torque is not required, and the very high starting current places stress on the supply causes voltage disturbances and interference to other users on the supply. Reduced voltage starting is a means of reducing the start current, however a reduction in the start voltage will also reduce the starting torque.
In order to achieve a useful start at a reduced starting current, it is important that the motor is able to develop sufficient torque at all speeds up to full speed to exceed the load torque at those speeds. If the reduced torque developed by the motor is less than the load torque at any speed, the motor will not accelerate to full speed. Stepping the starter to full voltage at less than full speed will result in a high current and little if any advantage over using a Direct On Line starter. The selection of a start voltage that is too low will result in an inferior start characteristic.

Star/Delta (Wye/Delta) starters are open transition. When the transition is made from the reduced voltage to full voltage, there is a period of time when the motor is effectively open circuited from the supply. During this period, the motor is effectively acting as a generator at a frequency proportional to it's actual shaft speed. When the starter reconnects the motor to the supply in Delta, there is a very high transient current and resulting transient torque which is much more severe and damaging than the Direct On Line starting conditions.

Other reduced voltage starters commonly employed are the Autotransformer Starter and the Solid State Soft Starter.

8.2 Induction Motor Characteristics

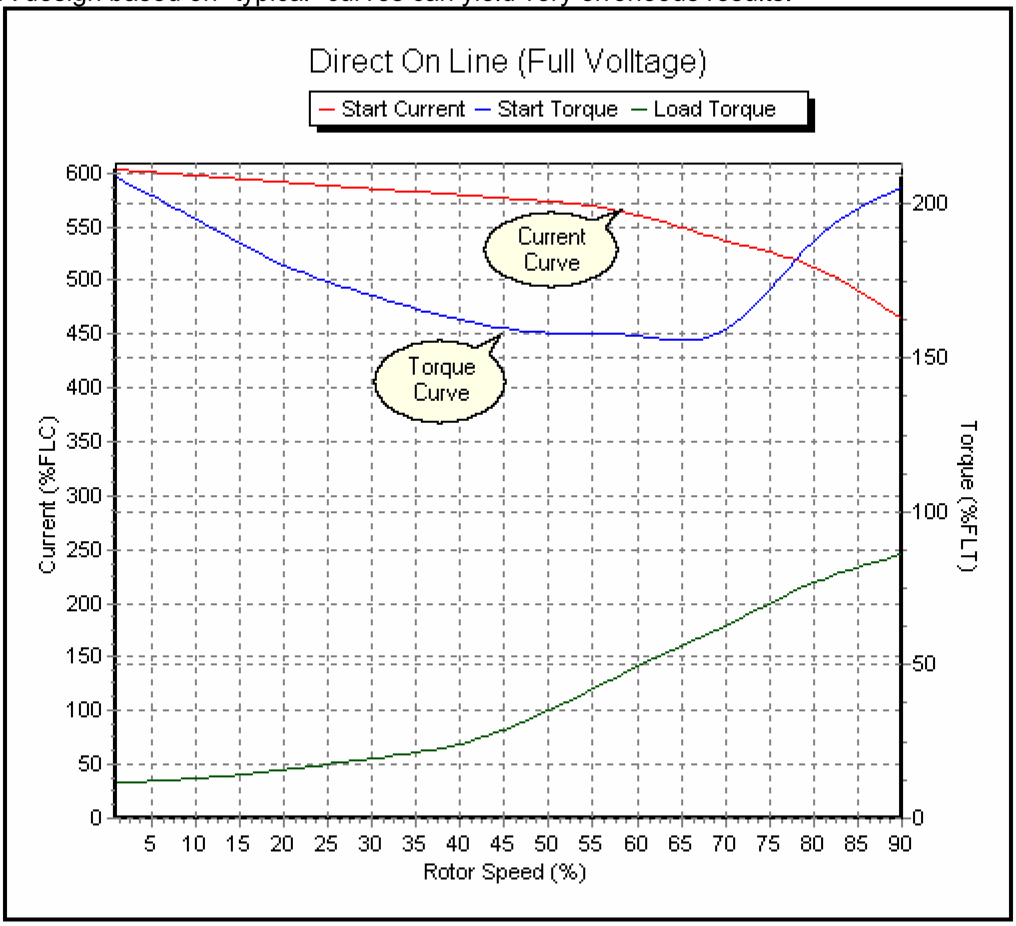
The induction motor has two major components: The Rotor and The Stator. In most motors, the Stator is in the outer part of the motor and comprises a stack of steel laminations and two or more windings. The inner part of the stator is hollow, and the windings are distributed around the inner surface of the stator imbedded in a number of slots. The windings are organized to form two or

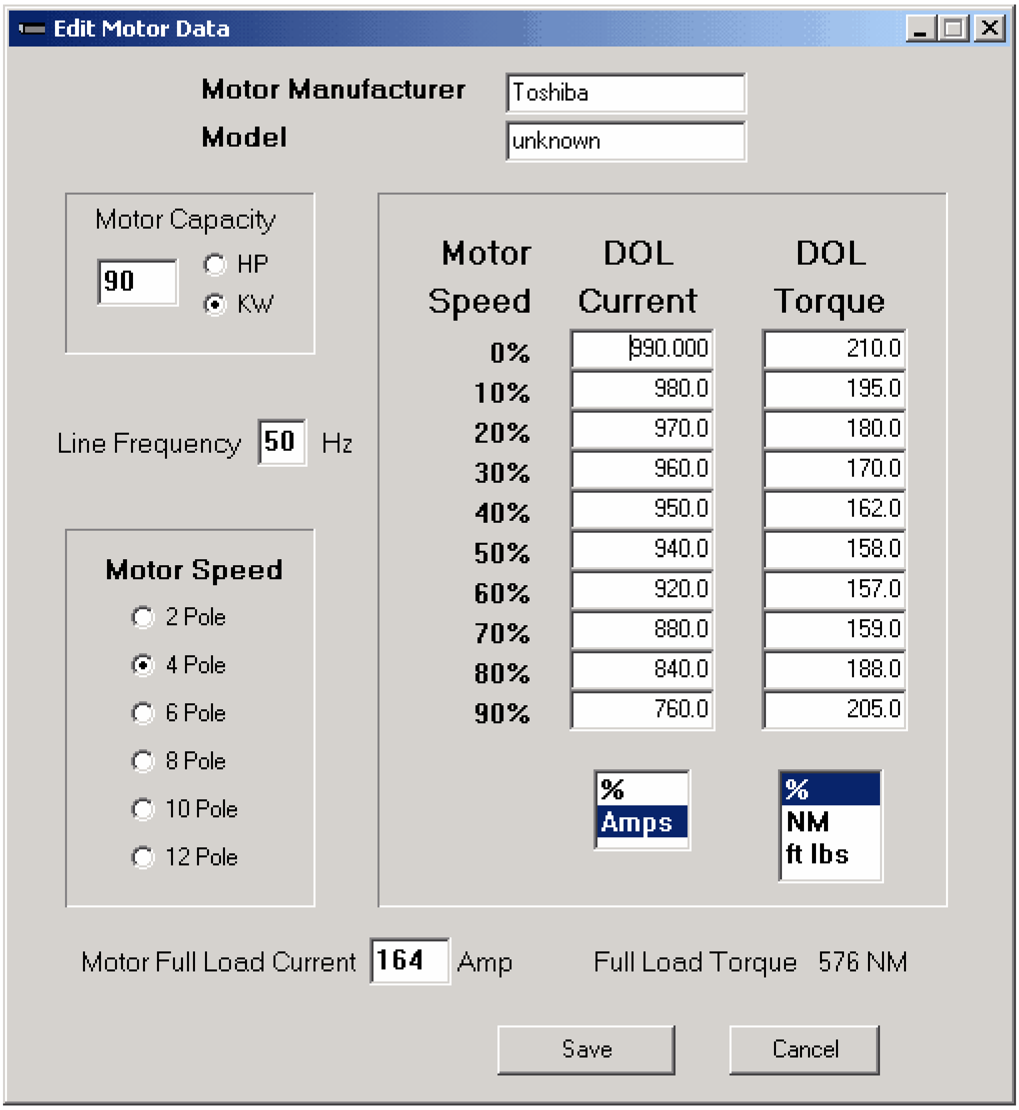
more electromagnetic poles.
The Rotor is a solid cylindrical stack of laminations with a series of conducting bars imbedded near the surface. The ends of these bares are shorted together by shorting rings.

When the supply is connected to the stator windings, a magnetic field is created which is rotating at the supply frequency. The field in a two pole machine will do one complete revolution per cycle of the supply. A Four pole machine requires two cycles for a complete revolution and a Six pole machine requires three cycles for a complete revolution.

The rotating magnetic field developed by the stator, causes a current to flow in the short circuited rotor winding in the same manner as the secondary current is caused to flow in a transformer. - infact the motor emulates a transformer with a short circuited secondary.
The rotor current in turn develops a rotating magnetic field which interacts with the stator field to develop a rotating torque field in the direction of the stator field rotation. The strength of the torque field is dependent on the interaction of the two magnetic fields, and is therefore dependent on the magnitude of the fields and their relative phase angle.
The full voltage start current and start torque curves vary tremendously between different motor designs due to the variations in rotor designs.

In designing a motor starting system, it is important to base the design on the actual motor being used. A design based on "typical" curves can yield very erroneous results.

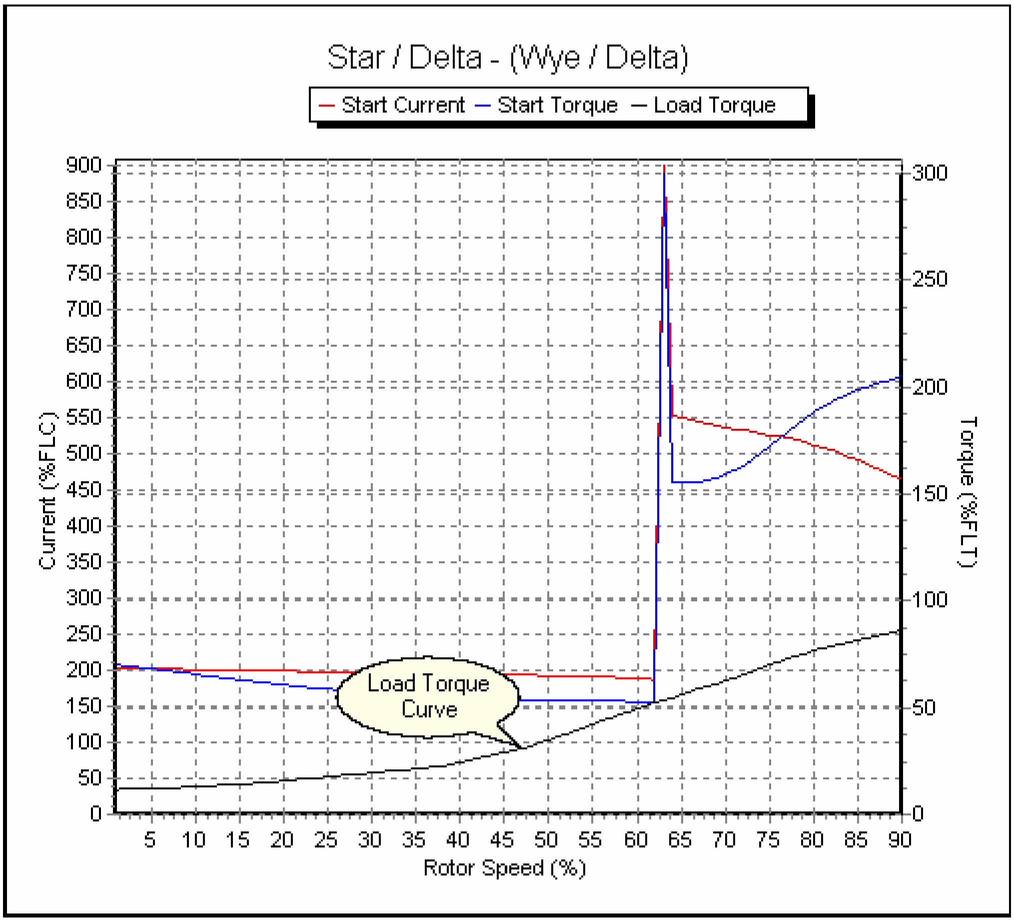




8.3 Load Characteristics

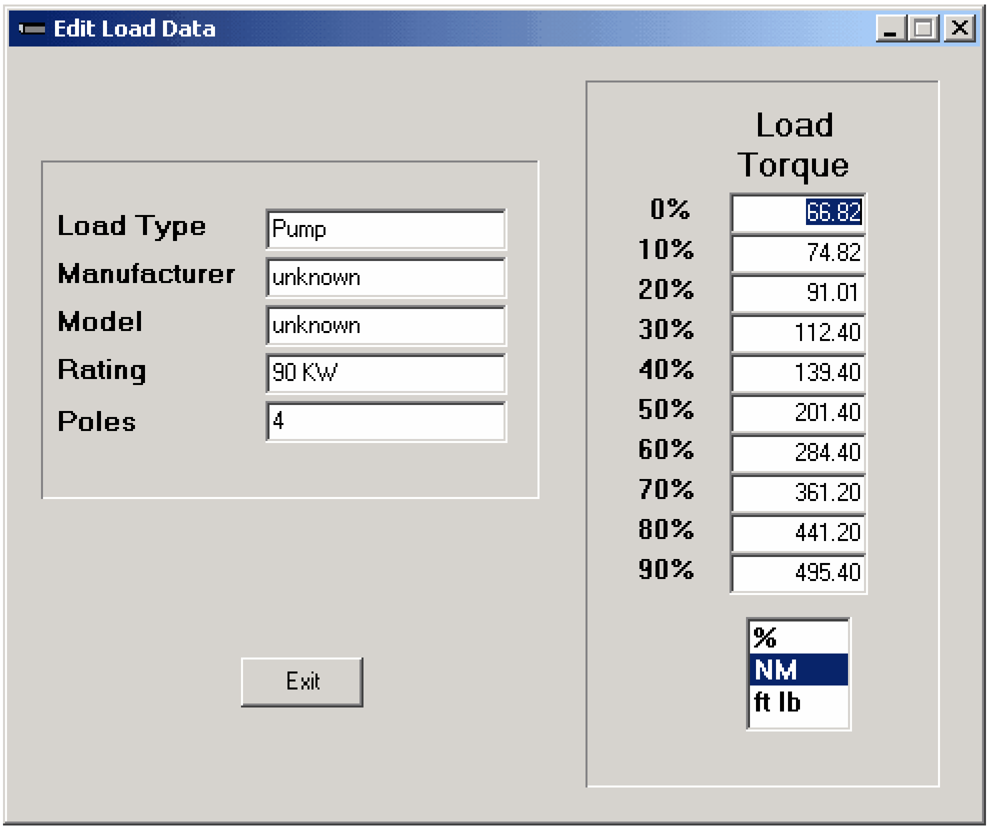
The induction motor is used to convert electrical energy into mechanical energy. The driven load presents a mechanical load to the shaft of the motor. As the motor is started, it accelerates the driven load from zero speed to the rated full load speed of the motor. As the load accelerates, the torque presented to the motor shaft will vary depending on the design of the machine.

Generally, the load torque is expected to be higher at full speed than at lower speeds. Some applications such as loaded conveyors may require a high breakaway torque to get the load to begin to move from zero speed.



In order to correctly design a motor starting system, it is important to know the load torque curve. The load (machine) design determines the required starting torque. The motor design then determines how much current is required to develop that torque. If the torque developed by the motor is insufficient, the motor can not accelerate the load to full speed.

The load torque can be expressed in Newton Meters, Pound Foot, or as a percentage of the motor full load torque.
For a specific machine, it is best to always work in absolute units such as Newton meters or Pound Foot. This way, if the motor size is changed, the starting characteristics and curves will be changed automatically. When relative units (%) are used, all the values need to be altered to reflect the change in motor Full Load Torque.



Generic or indicative curves can be saved in relative units (%) to enable approximations to be made where absolute details for a specific load are not available.

8.4 Minimum Start Current

The minimum start current is a function of the trhee major components in the system, the driven load, the motor and the starter.

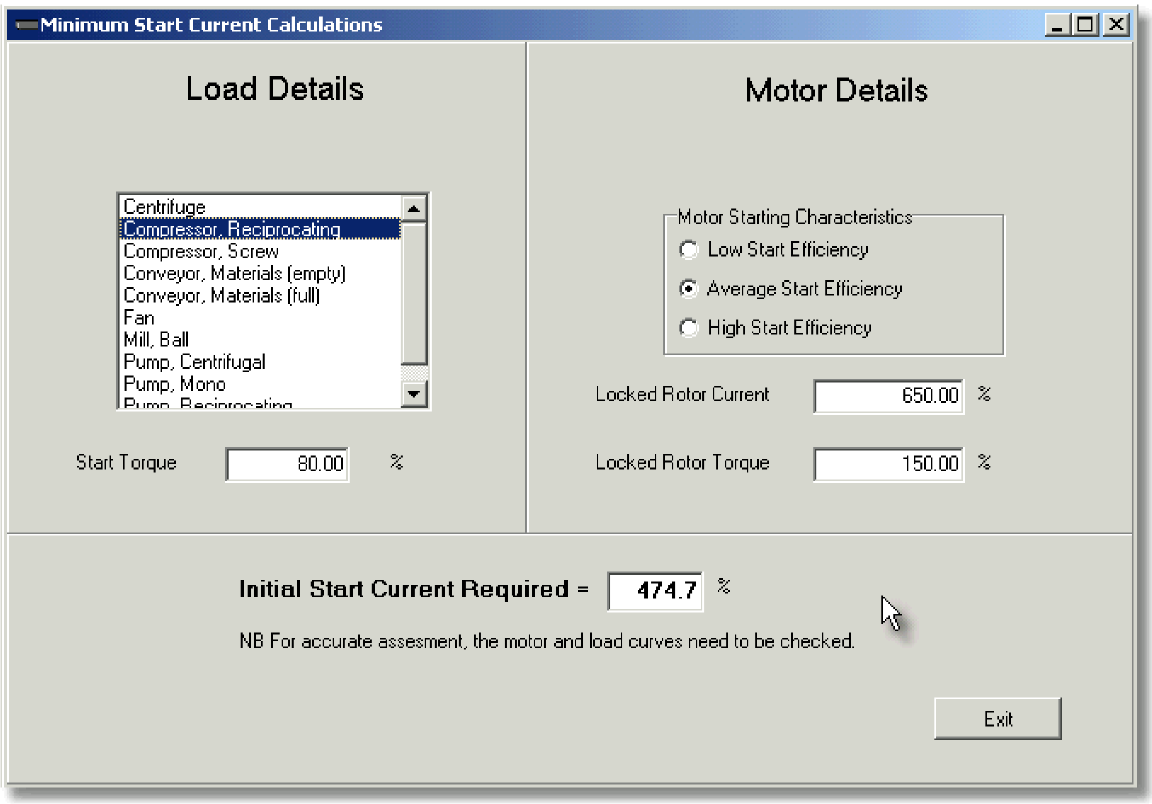
The **Driven Load** requires a miimum amount of torque to start and accelerate it to full working speed. This is a function of the driven load and can not be changed by the motor or the starter. Changes to the driven load can alter the minimum starting torque. For example closing the valve on a centrugal pump, pressure equalising a screw compresor, lifting the valves on a reciprocating compresor.

The **Motor** converts amps into newton meters, or current into torque. Some motors are better than others in this function. In effect, the starting efficiency of motors varies tremendously from motor to motor. This is a function of the rotor design in the motor and is independant for the starter and the load provided that standard componentary is used. Starters that introduce high even harmonic contents or negative sequence currents will reduce the output torque from the motor for a given input current.
The motor has two characteristics that indicate it's ability to convert amps into newton meters. These are the Locked Rotor Current (LRC) and the Locked Rotor Torque (LRT). The ideal motor has a low LRC and a high LRT. Motor comparisons can be made by taking the LRT/LRC with both expressed as a percentage. A higher value equates to a better starting result.

The **Starter** controls the voltage applied to the motor and this in turn controls the start current and torque applied to the load. If the load requires a high torque, the starter can not cause the motor to develop that torque without providing the required current.

The load dictates the torque, the motor then dictates the current and the starter controls the voltage to deliver that current.

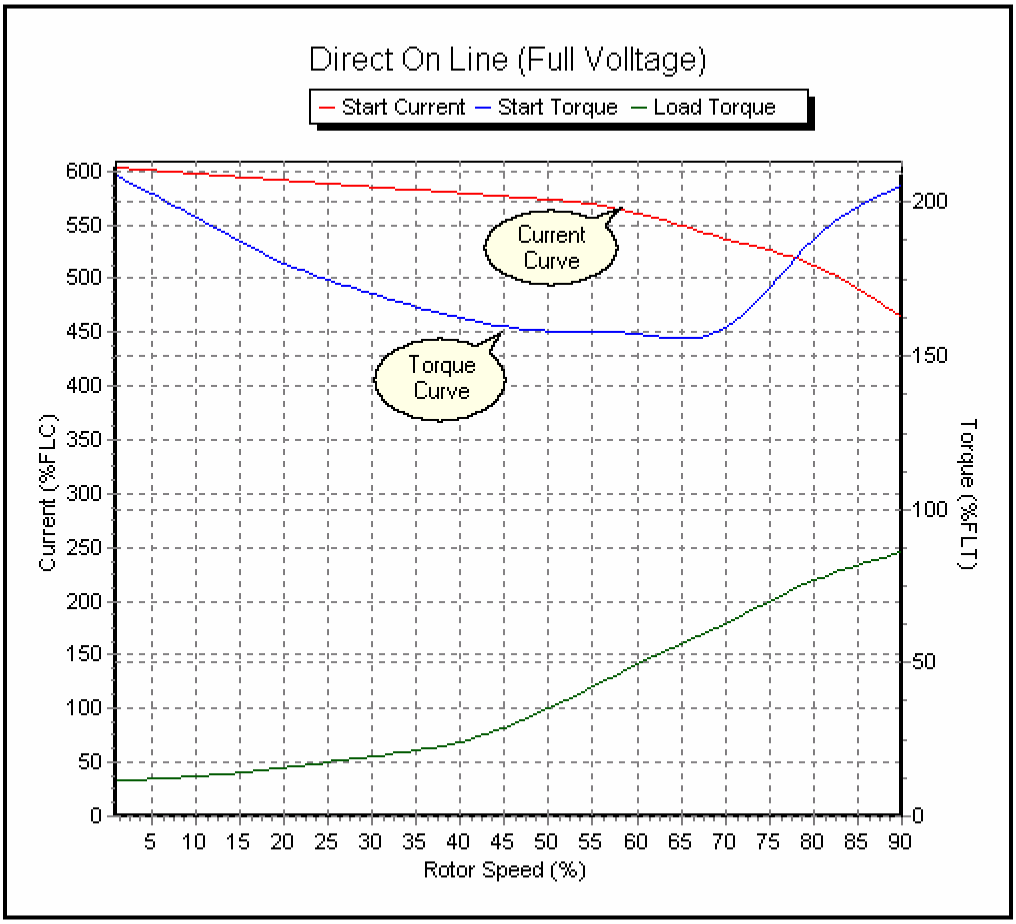
The Electrical Calculations software provides a means to estimate the minimum start current required based on load characteristics and motor characteristics.



Select your load, or enter an estimate of the value for the maximum load torque during start. Enter your motor details, either by starting efficiency or Locked Rotor characteristics. This will give you an indicative start current requirement.

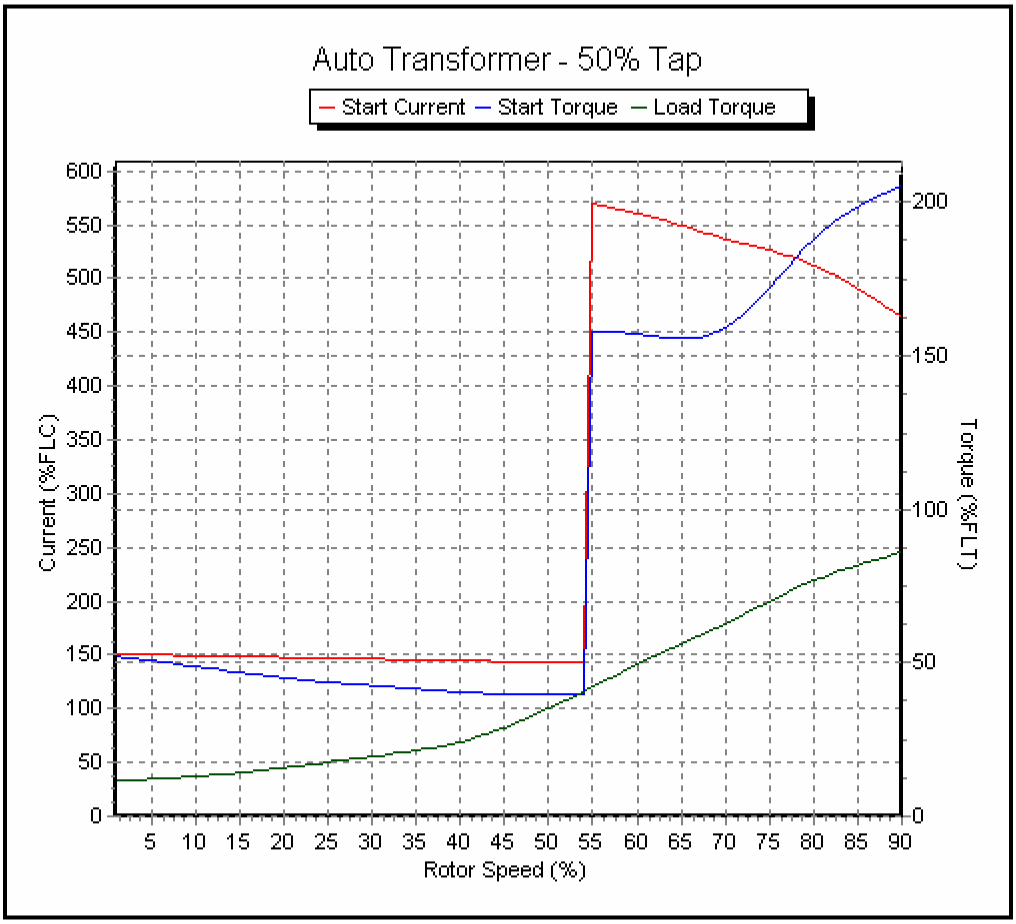
8.5 Direct On Line Starter

The Direct On Line (DOL) or Across the Line starter is the simplest form of starter for induction motors.

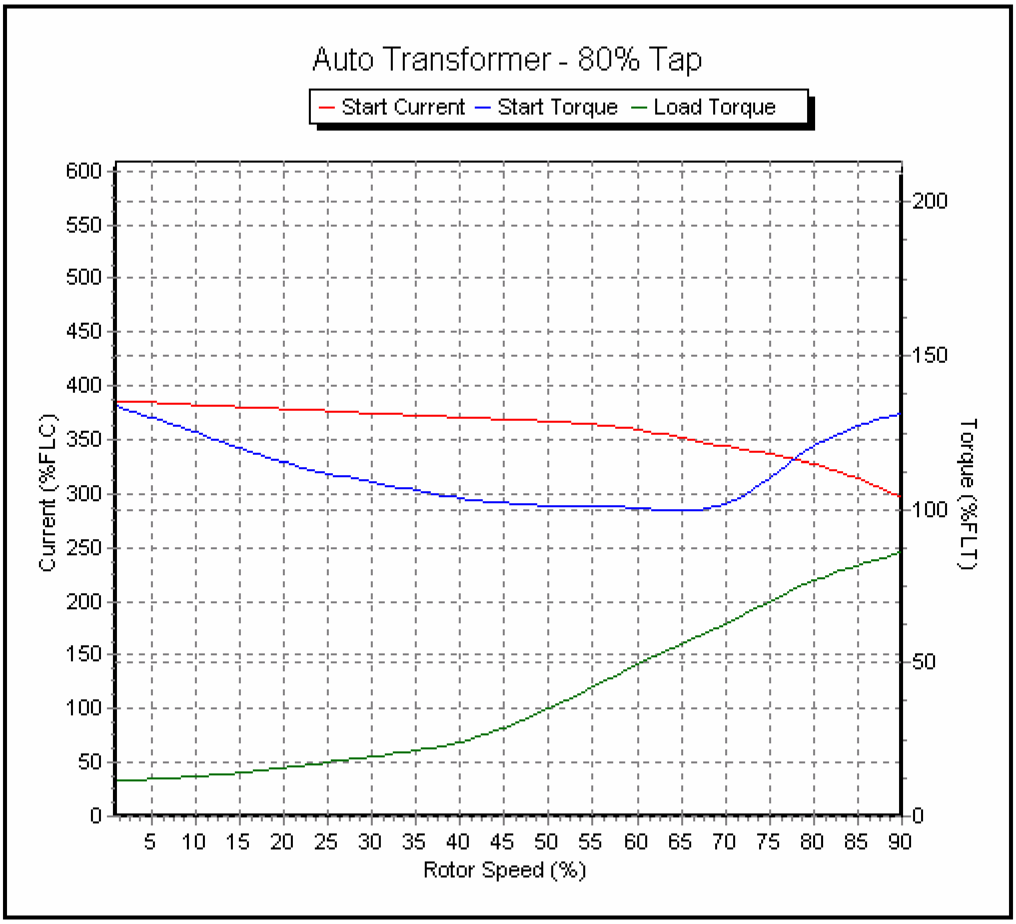


8.6 Autotransformer starter

The autotransformer starter is an electromechanical means of reduced voltage starting an induction motor. Usually, there are three sets of output taps allowing connection on the 50% start voltage, 66% start voltage and 80% start voltage. The starter operates by connecting the motor to the reduced voltage tap for a period of time and then switching to full voltage. If there is sufficient torque to accelerate the motor to full speed at the reduced starting voltage, and the start timer is set long enough, there will be a useful reduction in starting current and starting torque. If the torque available at the reduced voltage is insufficient to accelerate the driven load to full speed, the starter will change to full voltage at less than full speed, resulting in a high start current and little or no advantage over DOL starting.

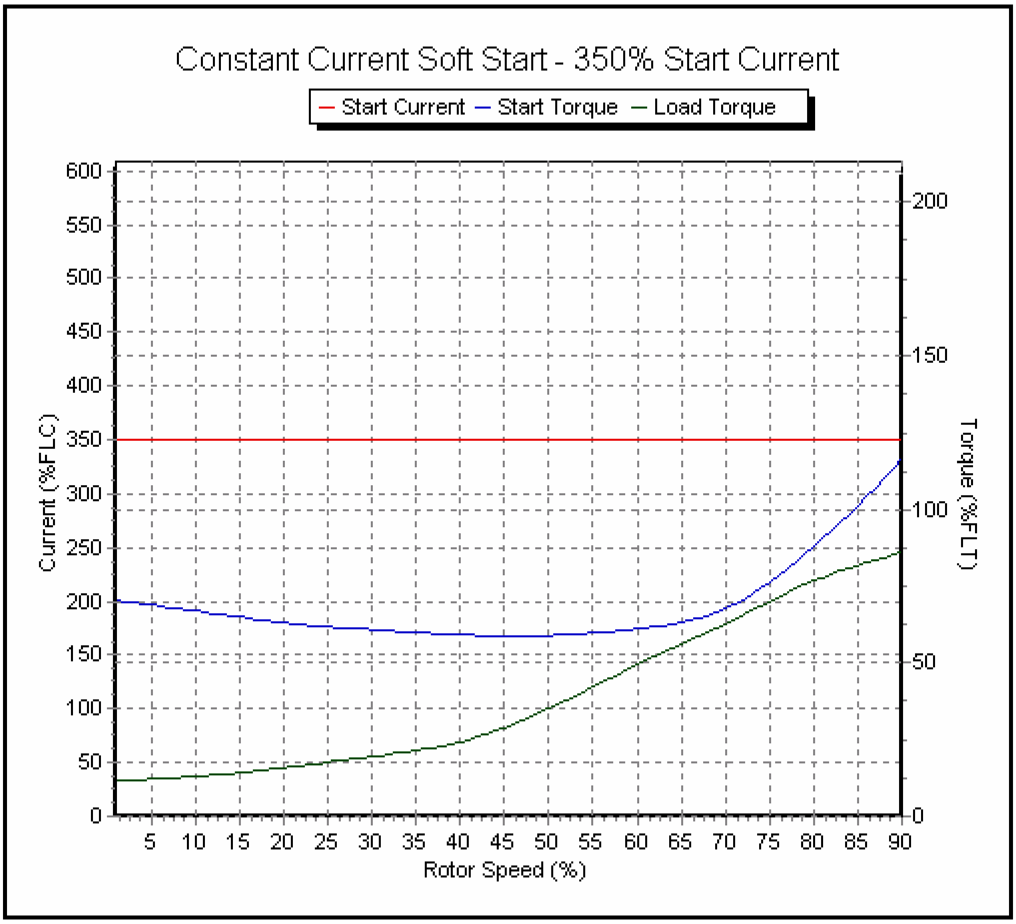


Where insufficient torque is available to accelerate the load to full speed, the starter can be set to a higher tap, increasing the start torque developed.



8.7 Constant Current Soft Starter

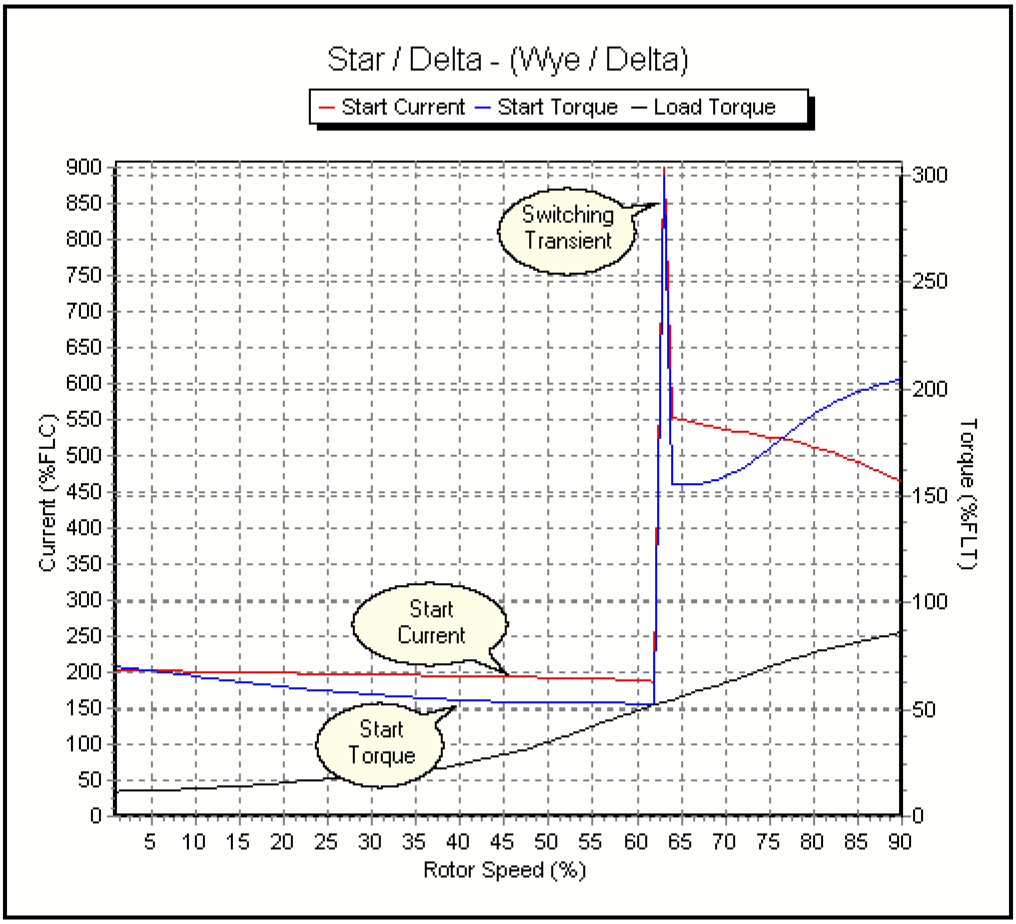
The Constant Current Soft Starter is a Solid State Starter employing SCRs to control the voltage applied to the motor. The start current is monitored and the voltage applied to the motor is controlled in a fashion to maintain the prescribed start current until the motor reaches full speed.



8.8 Star/Delta Starter

The Star/Delta starter is probably the most commonly used reduced voltage starter, but in a large number of applications, the performance achieved is less than ideal, and in some cases, the damage and interference is much worse than that caused by a Direct On Line starter.

The Star/Delta starter requires a six terminal motor that is delta connected at the supply voltage. The Star Delta starter employs three contactors to initially start the motor in a star connection, then after a period of time, to reconnect the motor to the supply in a delta connection. While in the star connection, the voltage across each winding is reduced by a factor of the square root of 3. This results in a start current reduction to one third of the DOL start current and a start torque reduction to one third of the DOL start torque. If there is insufficient torque available while connected in star, the motor can only accelerate to partial speed. When the timer operates, the motor is disconnected from the supply and then reconnected in Delta resulting in full voltage start currents and torque.



The transition from star connection to Delta connection requires that the current flow through the motor is interrupted. This is termed "Open Transition Switching" and with an induction motor operating at partial speed (or Full load speed), there is a large current and torque transient produced at the point of reconnection. This transient is far worse than any produced by the DOL starter and causes sever damage to equipment and the supply.

If there is insufficient torque produced by the motor in star, there is no way to accelerate the load to full speed without switching to delta and causing severe current and torque transients.

8.9 Selecting a Starter

1) Identify the driven load and if possible, obtain the starting requirements of this load. If this load has not been used in earlier calculations, you will need to enter the speed / torque data into the table, otherwise the data can be recalled.

2) Identify a potential motor and if possible, obtain the starting characteristics of the motor. Of particular interest are the speed / torque curve and the speed current curve for that particular motor. If this motor has not been used in earlier calculations, you will need to enter the speed / torque and speed / current data into the table, otherwise the data can be recalled from disk.

3) Open the "Motor Starting" section of the program and fill in all the data on the motor and load. Where the full data is not available, enter in the locked rotor characteristics only. Make sure that the correct units are selected. When the units are changed, you are given the option of changing the values or leaving the values as entered. For specific load and motor data, it is preferable to save them as absolute units to avoid confusion. Much of the data available is quoted in percentage

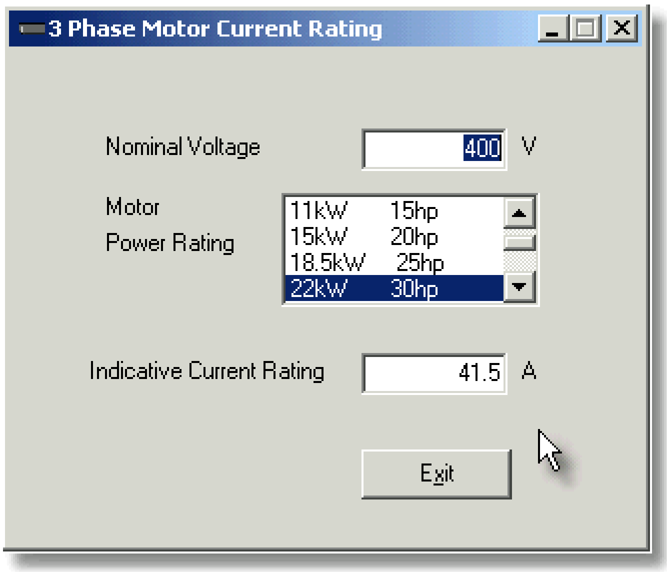
only. This refers back to the motor rating. If the data has been previously entered and saved, use the "File" "Open Motor" and/or "Open Load" menu options to select and open the relevant data file. When the data is correctly displayed in the table, the starter options are shown in a results panel at the bottom of the page. This panel includes the minimum starter setting, i.e. auto transformer on the 80% tap, of soft starter at 380% current.

4) Save the data for future usage using the "File" "Save ...." menu options. Use a file name that is very descriptive to make it easy to identify this information next time. Save the data in absolute units, (NM or lbft) unless you wish to save the data as a generic curve that can be applied indicatively across a range of KW sizes. NB using generic curves, particularly for motors can be very erroneous due to the massive variation between motor designs.

5) The starting current and starting torque curves for a range of starter and starting conditions can be displayed using the "Graph" menu option.

8.10 Motor Current Rating

Electrical Calculations provides a table to estimate the current rating of motors with different sizes and voltages. This information is indicative only. Motors with a high powerfactor and high efficiency will be less than the figure in the table, but motors with very low efficiency and/or olw power factor may have rated current higher thn the table value. Submersible pumps are always high.



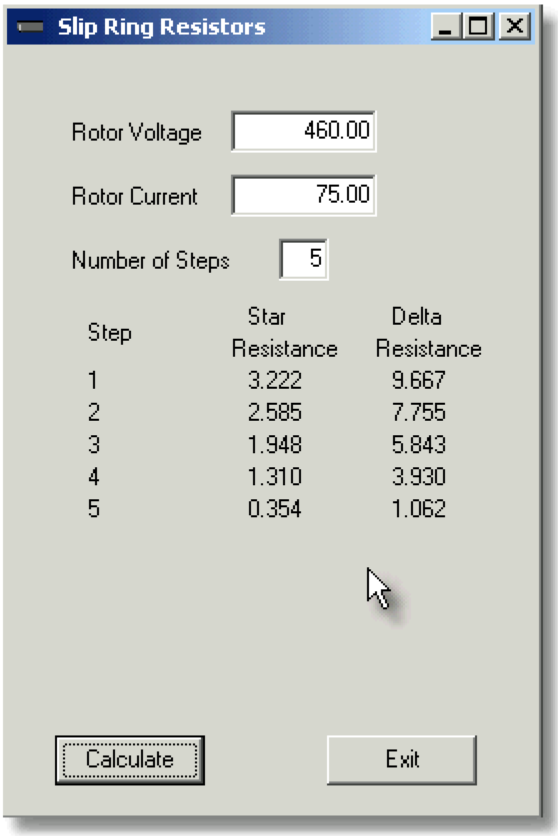
8.11 Slip Ring Resistors

Slip ring motors, or wound rotor motors, need to have resistors in their rotor circuit to enable them to develop high slip torque. If the rotor is shorted out, the motor will have a very highLocked Rotor Current and a low Locked Rotor Torque.
If you then apply a reduced voltage starter to the stator, the shaft torque will be much lower than for a standard cage type motor.
The resistors in the rotor circuit modify the start torque curve of the motor. As the resistance is increased, the slip at which the maximum torque occurs is increased. At zero ohms, the maximum torque is at very close to full speed. By selecting a number of stages with the torque occuring across the slip range from zero to 100%, you can design a start system where the motor can produce maximum torque for minimum current fromzero speed to rated speed. In order to prevent a very high current surge when shorting the last resistor stage, it is important to position the final

stage close to full speed. If you position the final stage maximum torque at half speed, there will be a big jump in torque when the last contactor is closed.

When selecting resistors for a slip ring motor, you must select a resistor that has the correct resistance and also is capable of absorbing enough energy.
When starting a machine, the full speed kinetic energy of that machine is dissipated in the secondary resistors. This is usually a significant amount of energy.

To determine the values of the rotor resistances, you need to know the rotor voltage and rotor current of the motor, and the number of steps required.

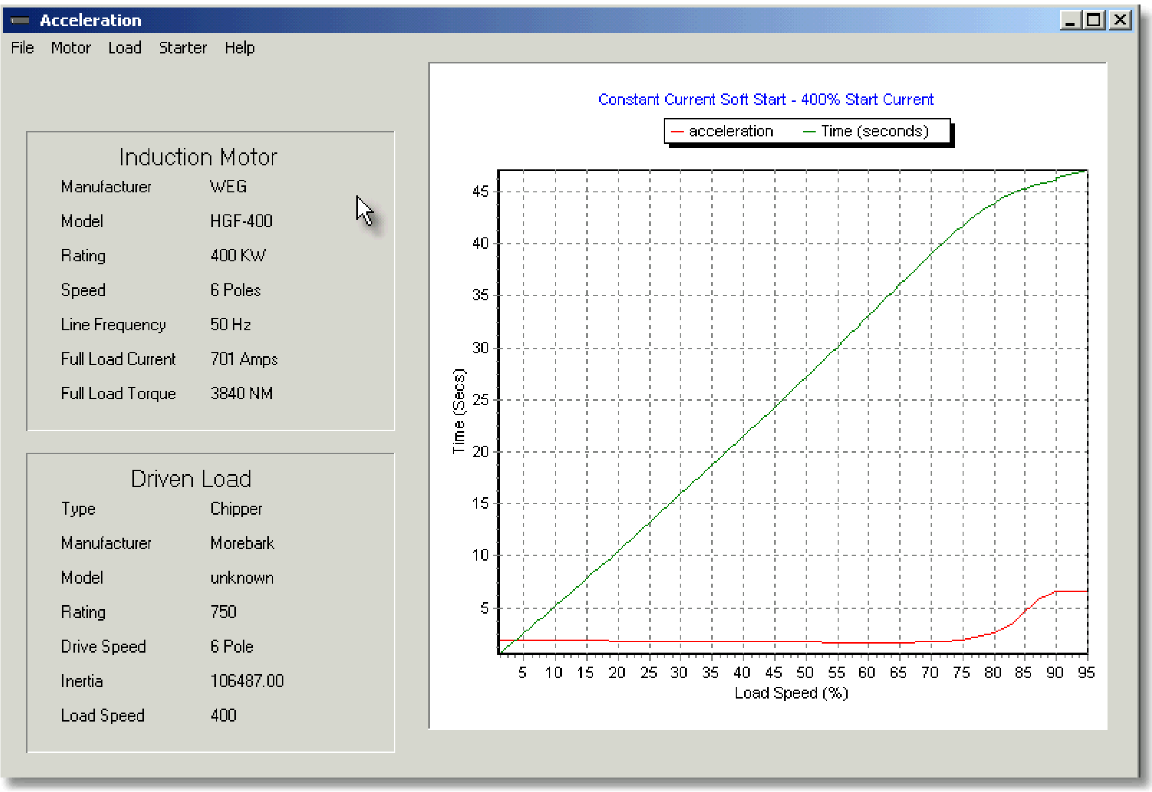


The resistors can be connected in a star configuration, or in a delta configuration. If you are going to apply a soft starter to the stator of the slip ring motor, you select 1 stage only and use that value. This will result in a lower torque and higher start current than would be achieved using a proper multistage slip ring starter.

8.12 Acceleration

The rate of acceleration of the motor and driven load is a function of the effective load inertia and the acceleration torque. The acceleration torque at any speed, is the difference between the load torque at that speed and the torque produced by the motor.
Electrical Calculations will plot out the speed time curve for a motor and load provded that you have entered in the load torque cure and inertia, and the motor characteristics. You can select different starters and see the effects of these starters on the acceleration time.
If the load torque is close to the torque developed by the motor, the rate of acceleration will be reduced considerably and the start current should be increased to ensure that there is always a

good margin between the two torque curves.



Part IX

9 Power Factor Correction

9.1 Introduction

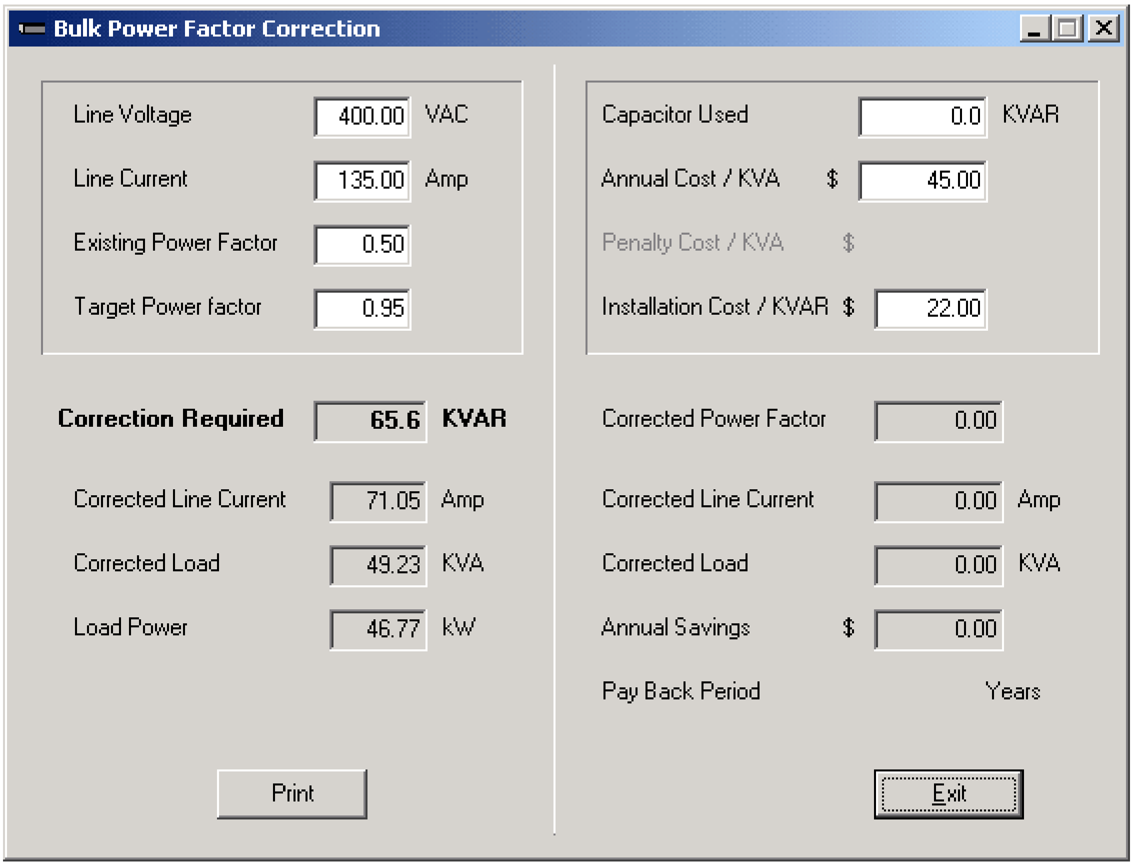
Power factor is the ratio between KW and KVA and is a measure of the usefulness of the current applied to the load. A poor power factor can result due to a significant reactive component to the current, or due to a high level of harmonics in the current flowing. A lagging power factor is common and is due to an inductive load such as induction motors, chokes, lighting ballasts and transformers. A lagging power factor can be corrected by the addition of power factor correction capacitors. Poor power factor due to a high level of harmonic currents as caused by variable speed drives, rectifiers and discharge lighting can not be corrected except by the use of expensive filter circuits.

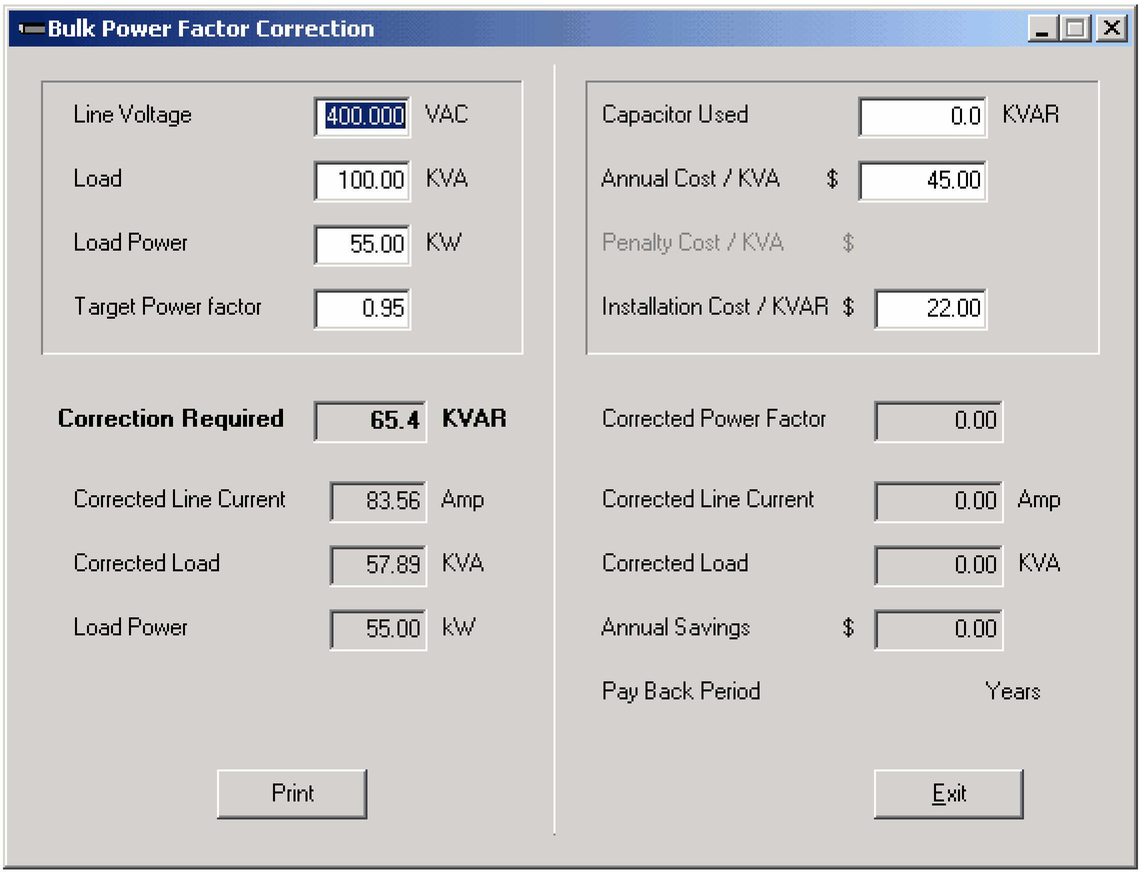
Power Factor correction is applied to circuits which include induction motors as a means of reducing the inductive component of the current and thereby reduce the losses in the supply. There should be no effect on the operation of the motor itself.
Power factor correction is achieved by the addition of capacitors in parallel with the connected motor circuits and can be applied at the starter, or applied at the switchboard or distribution panel.
Capacitors connected at each starter and controlled by each starter is known as "Static Power Factor Correction" while capacitors connected at a distribution board and controlled independently from the individual starters is known as "Bulk Correction".

9.2 Bulk Power Factor Correction

The Power factor of the total current supplied to the distribution board is monitored by a controller which then switches capacitor banks In a fashion to maintain a power factor better than a preset limit. (Typically 0.95) Ideally, the power factor should be as close to unity as possible. There is no problem with bulk correction operating at unity or even over corrected.

The power factor correction required can be calculated from either a known power factor, load and required power factor, or from known KVA and KW of the load.


Bulk Power Factor Correction
Line Voltage 400.00 VAC
Line Current 135.00 Amp
Existing Power Factor 0.50
Target Power factor 0.95
Capacitor Used 0.0 KVAR
Annual Cost / KVA $ 45.00
Penalty Cost / KVA $
Installation Cost / KVAR $ 22.00
Correction Required 65.6 KVAR
Corrected Line Current 71.05 Amp
Corrected Load 49.23 KVA
Load Power 46.77 kW
Corrected Power Factor 0.00
Corrected Line Current 0.00 Amp
Corrected Load 0.00 KVA
Annual Savings $ 0.00
Pay Back Period Years
Print
Exit



9.3 Static Power Factor Correction

As a large proportion of the inductive or lagging current on the supply is due to the magnetizing current of induction motors, it is easy to correct each individual motor by connecting the correction capacitors to the motor starters. With static correction, it is important that the capacitive current is less than the inductive magnetizing current of the induction motor. In many installations employing static power factor correction, the correction capacitors are connected directly in parallel with the motor windings. When the motor is Off Line, the capacitors are also Off Line. When the motor is connected to the supply, the capacitors are also connected providing correction at all times that the motor is connected to the supply. This removes the requirement for any expensive power factor monitoring and control equipment. In this situation, the capacitors remain connected to the motor terminals as the motor slows down. An induction motor, while connected to the supply, is driven by a rotating magnetic field in the stator which induces current into the rotor. When the motor is disconnected from the supply, there is for a period of time, a magnetic field associated with the rotor. As the motor decelerates, it generates voltage out its terminals at a frequency which is related to it's speed. The capacitors connected across the motor terminals, form a resonant circuit with the motor inductance. If the motor is critically corrected, (corrected to a power factor of 1.0) the inductive reactance equals the capacitive reactance at the line frequency and therefore the resonant frequency is equal to the line frequency. If the motor is over corrected, the resonant frequency will be below the line frequency. If the frequency of the voltage generated by the decelerating motor passes through the resonant frequency of the corrected motor, there will be high currents and voltages around the motor/capacitor circuit. This can result in sever damage to the capacitors and motor. It is imperative that motors are never over corrected or critically corrected when static correction is employed.

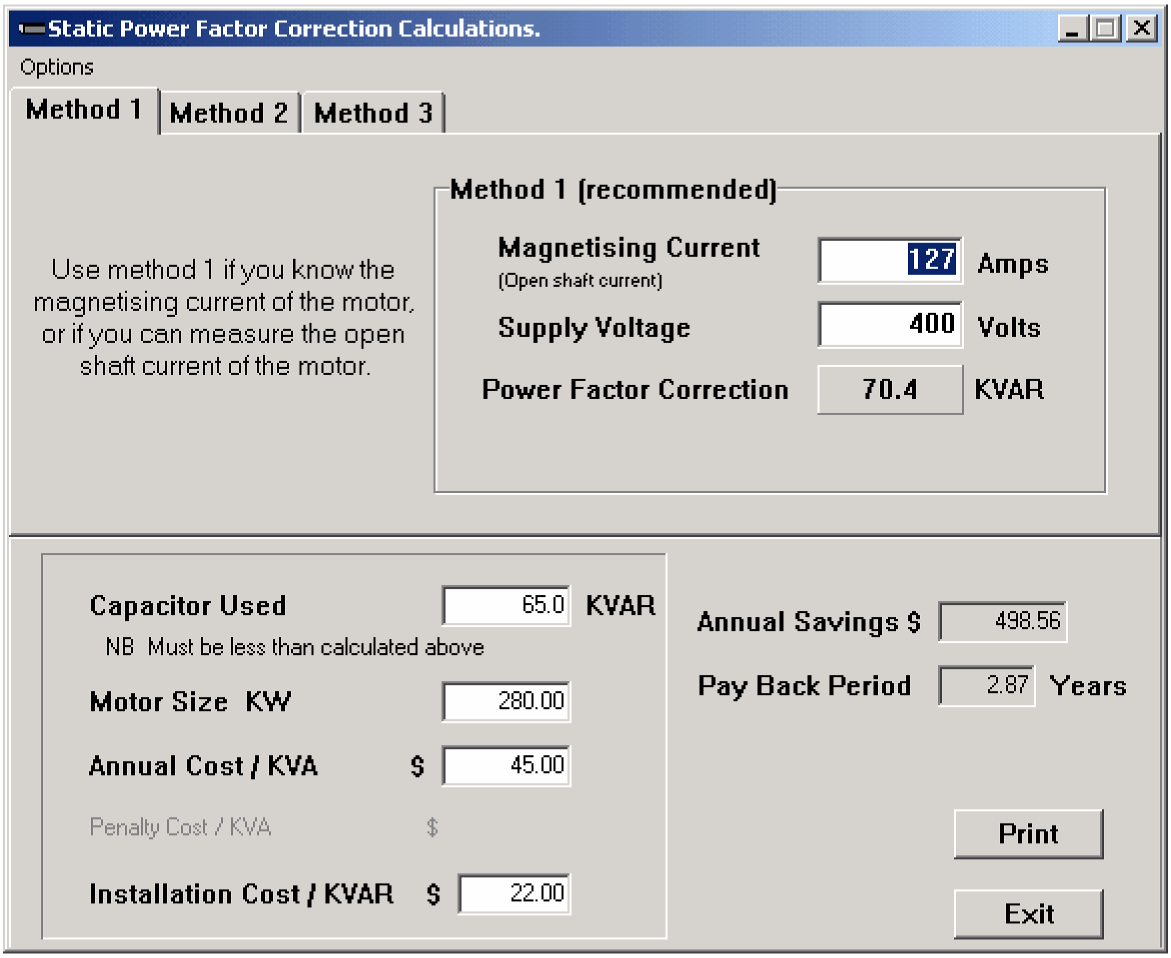
Static power factor correction should provide capacitive current equal to 80% of the magnetizing

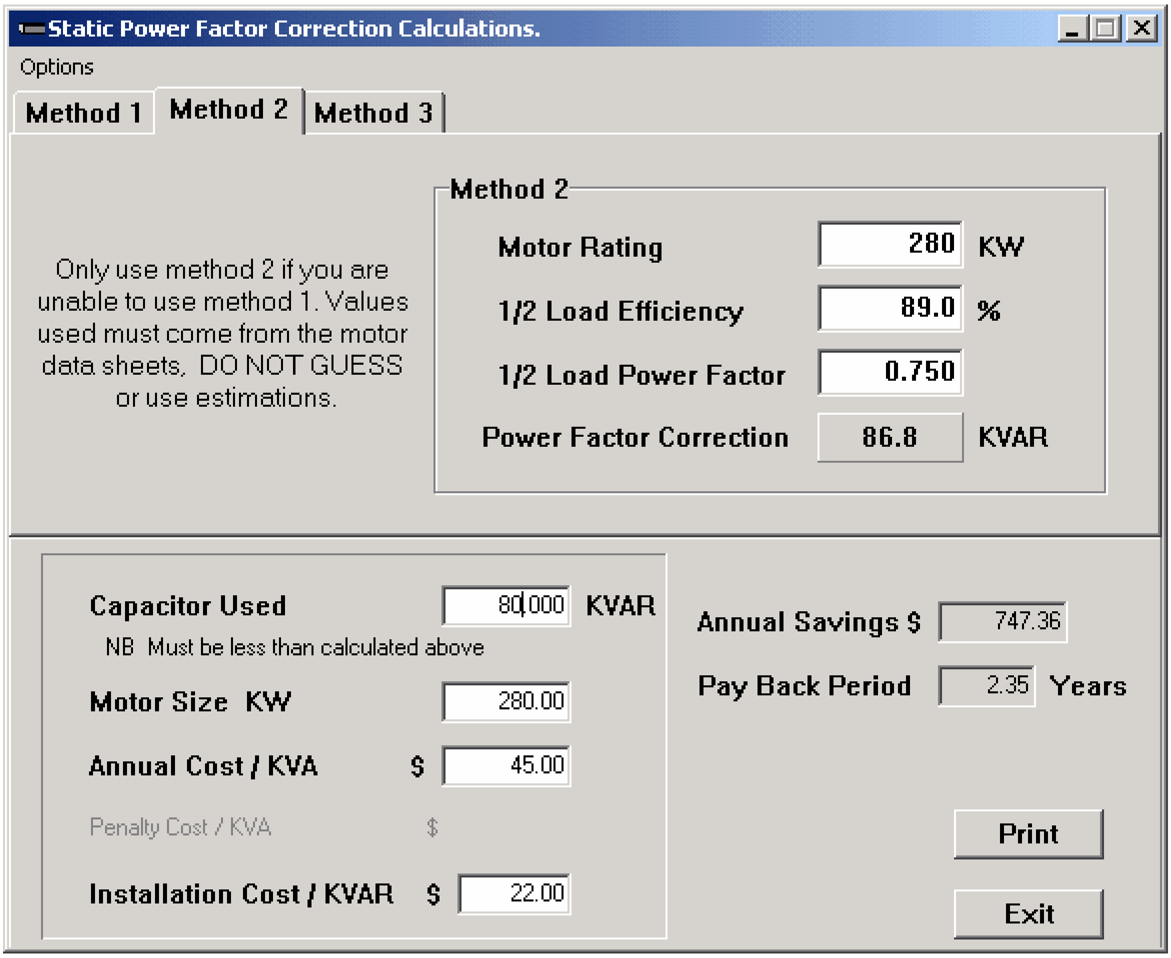
current, which is essentially the open shaft current of the motor.
The magnetizing current for induction motors can vary considerably. Typically, magnetizing currents for large two pole machines can be as low as 20% of the rated current of the motor while smaller low speed motors can have a magnetizing current as high as 60% of the rated full load current of the motor. It is not practical to use a "Standard table" for the correction of induction motors giving optimum correction on all motors. Tables result in under correction on most motors but can result in over correction in some cases. Where the open shaft current can not be measured, and the magnetizing current is not quoted, an approximate level for the maximum correction that can be applied can be calculated from the half load characteristics of the motor. It is dangerous to base correction on the full load characteristics of the motor as in some cases, motors can exhibit a high leakage reactance and correction to 0.95 at full load will result in overcorrection under no load, or disconnected conditions.

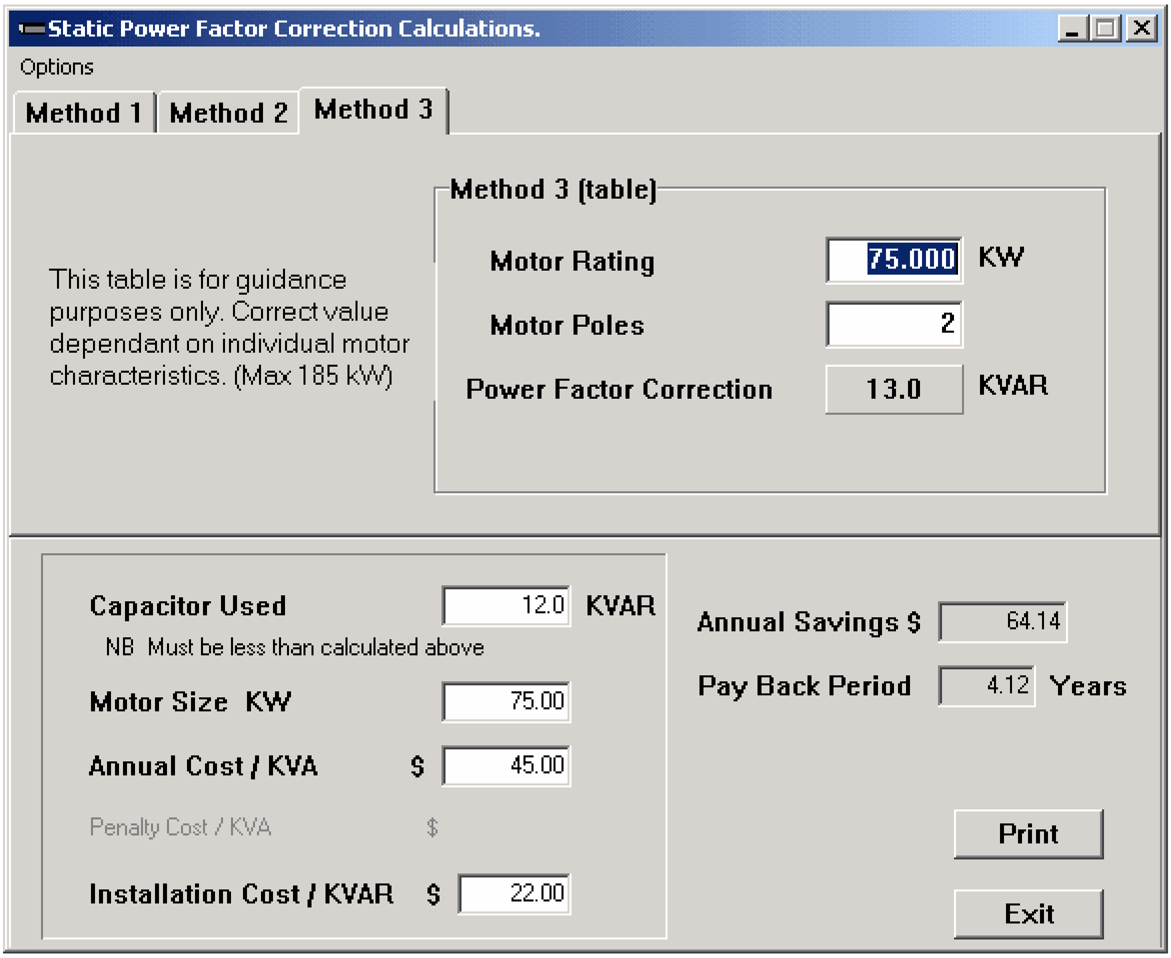
Static correction is commonly applied by using one contactor to control both the motor and the capacitors. It is better practice to use two contactors, one for the motor and one for the capacitors. Where one contactor is employed, it should be up sized for the capacitive load. The use of a second contactor eliminates the problems of resonance between the motor and the capacitors.

Inverter. Static Power factor correction must not be used when the motor is controlled by a variable speed drive or inverter.

Solid State Soft Starter. Static Power Factor correction capacitors must not be connected to the output of a solid state soft starter. When a solid state soft starter is used, the capacitors must be controlled by a separate contactor, and switched in when the soft starter output voltage has reached line voltage. Many soft starters provide a "top of ramp" or "bypass contactor control" which can be used to control the power factor correction capacitors.


Static Power Factor Correction Calculations.
Options
Method 1
Method 2
Method 3
Use method 1 if you know the magnetising current of the motor, or if you can measure the open shaft current of the motor.
Method 1 (recommended)
Magnetising Current
(Open shaft current)
127
Amps
Supply Voltage
400
Volts
Power Factor Correction
70.4
KVAR
Capacitor Used
65.0
KVAR
NB Must be less than calculated above
Motor Size KW
280.00
Annual Cost / KVA $
45.00
Penalty Cost / KVA $
Installation Cost / KVAR $
22.00
Annual Savings $
498.56
Pay Back Period
2.87
Years
Print
Exit


Static Power Factor Correction Calculations.
Options
Method 1
Method 2
Method 3
Only use method 2 if you are unable to use method 1. Values used must come from the motor data sheets, DO NOT GUESS or use estimations.
Method 2
Motor Rating
280
KW
1/2 Load Efficiency
89.0
%
1/2 Load Power Factor
0.750
Power Factor Correction
86.8
KVAR
Capacitor Used
80.000
KVAR
NB Must be less than calculated above
Motor Size KW
280.00
Annual Cost / KVA
$
45.00
Penalty Cost / KVA
$
Installation Cost / KVAR
$
22.00
Annual Savings $
747.36
Pay Back Period
2.35
Years
Print
Exit


Static Power Factor Correction Calculations.
Options
Method 1
Method 2
Method 3
Method 3 (table)
This table is for guidance purposes only. Correct value dependant on individual motor characteristics. (Max 185 kW)
Motor Rating
75.000
KW
Motor Poles
2
Power Factor Correction
13.0
KVAR
Capacitor Used
12.0
KVAR
NB Must be less than calculated above
Motor Size KW
75.00
Annual Cost / KVA
$
45.00
Penalty Cost / KVA
$
Installation Cost / KVAR
$
22.00
Annual Savings $
64.14
Pay Back Period
4.12
Years
Print
Exit

Part X

10 Supply

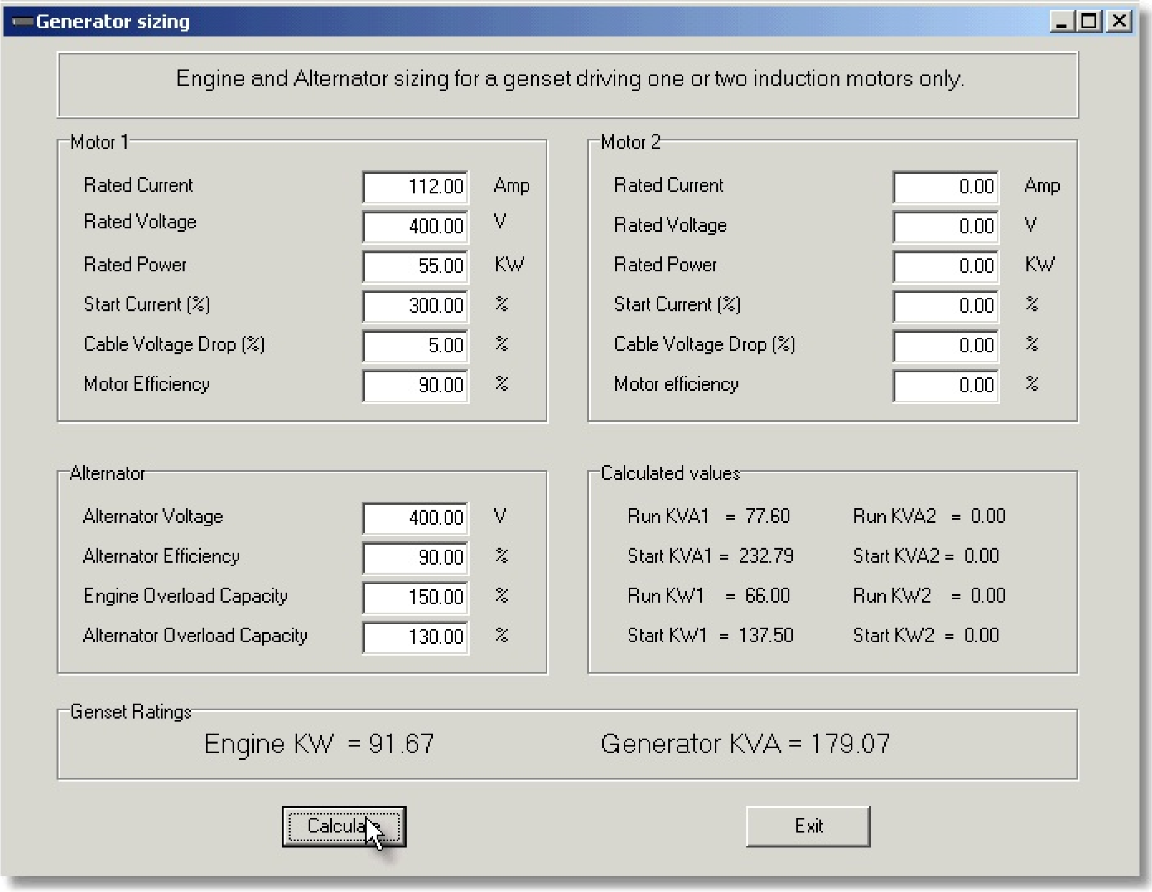
10.1 Genset Ratings

There are two major components to a genset, the Engine and the Alternator.
The Engine supplies power, rated in KW or HP and the Alternator provides voltage and current and is usually rated in KVA, volts and Power Factor. For the best performance, it is important to select the correct engine and alternator and couple them together rather than assume a standard set. This can result in the most commercial and best performing result.

The engine must supply all the power required by the installation, this includes work power and loss power. If the engine is not large enough to supply all the power demanded, it will slow and the frequency will drop.
In sizing the engine for an installation, it is necessary to determine the maximum KW demand and the continuous KW demand and ensure that the engine is suitably rated.
The engine has a continuous output rating and has a short term maximum power rating. The short term rating can be used to provide the energy for starting motors, but often the overload capacity is not sufficient to provide the full start requirement without over sizing the engine.
During start, the motor will draw up to its rated KW (particularly as it approaches full speed) plus a high copper loss in the stator. If the copper loss is 5% at full load, and the motor is started with a DOL (Full voltage) starter, it will draw Locked Rotor Current during start. This could be in the order of 700% of the rated current of the motor, so the copper loss will be 7 x 7 x 5 % of the rated power of the motor, or just under 250% of the motor rating!! The same applies to the cable losses. If the cable loss is 5%, then under full voltage starting, the power demanded from the engine could be another 250%. Additionally, the copper loss of the alternator could add another 250% power demand on the engine. Now we have a power demand of around 850% of the motor rating.
Reduced voltage starting will reduce the start current and thereby the power demand on the engine. With very low inertia loads, the inertia of the engine and alternator may be sufficient to supply the power to start the load, but there will still be a significant frequency droop.
The engine is fitted with a governor which is a means of speed regulation. The governor will adjust the throttle on the engine to keep the speed and output frequency constant. Severe overloads will often result in a droop in speed during start, and a surge in speed as the load comes off. It is best to have a relatively slow load application to allow the governor to track the load.
If the engine is a diesel engine, it is preferable to try to size the engine so that the continuous operating power is reasonable high. Continuous operation at light load will increase the required maintenance on the engine plus increase the fuel consumption.

The Alternator supplies the current to the load. The Alternator has a finite internal impedance and the voltage is regulated by an AVR (Automatic Voltage Regulator) which controls the excitation applied to the alternator. There is a finite maximum excitation that can be applied and this limits the maximum current that the alternator can supply. When the alternator is fully excited, the excitation is saturated, additional load will cause the voltage to drop quickly. The alternator tends towards current limiting.
The AVR monitors the output voltage either by single phase, half wave, peak reading or by three phase full wave averaging detection systems. The single phase method is usually connected across two phases but is only measuring on the peak of one half cycle per cycle. The three phase averaging method has six times the effective sample rate and is able to respond much quicker to any variations and provide a more stable output in response to step and transient loads.
Were a single phase AVR is used, it is best to avoid getting too close to saturation of the excitation system, as there can be hunting of the AVR as it tries to regulate the output voltage as the load drops off. Apply a larger "safety margin" in alternator sizing when using a single phase AVR.
Alternators have a rated short term overload capacity and this can supply the start current to motors. Some alternators can be fitted with excitation boost kits to further increase the short term overload capacity. Typically, the short term overload capacity of an alternator is in the region of 130% to 200%. It is important to determine the maximum that can be achieved reliably. If this information is not available, use 120%.

The Electrical Calculations software provides for engine and alternator sizing for installations using one or two induction motors only. There is no allowance for residual load. The assumption is that motor 1 will always start first. If there is only one motor, leave all the parameters for motor 2 as zero. Installations with more than two motors, or with significant other residual load, will not be as dependant on overload ratings for the engine and alternator sizing.



Motor

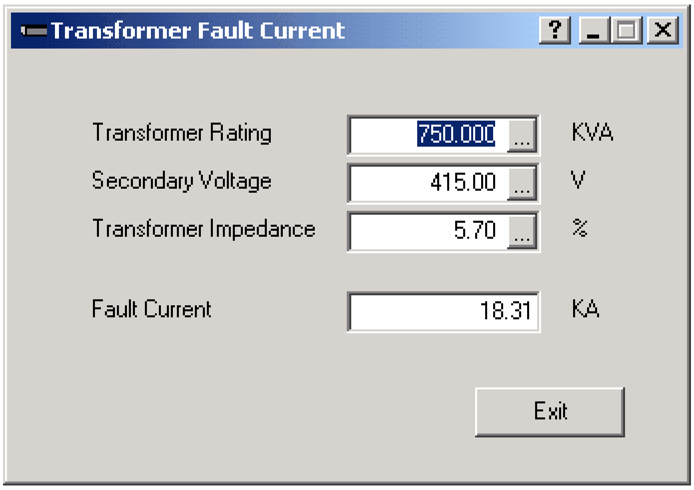
Rated Current = Rated full load current of the motor
Rated Voltage = Rated voltage of the motor
Rated Power = Rated shaft power of the motor.
Start Current = Current required to start the machine. This current is a function of the motor, the driven load and the starting method used. For Full voltage starting (DOL) the start current is equal to the locked rotor current of the motor, irrespective of the load being started.
Cable Voltage Drop. = Total voltage drop between the Alternator and the motor. For genset applications, this should be less than 5% in order to minimise the power dissipated during start. This will have a major bearing on the Engine rating.
Motor Efficiency = Rated full load efficiency of the motor.

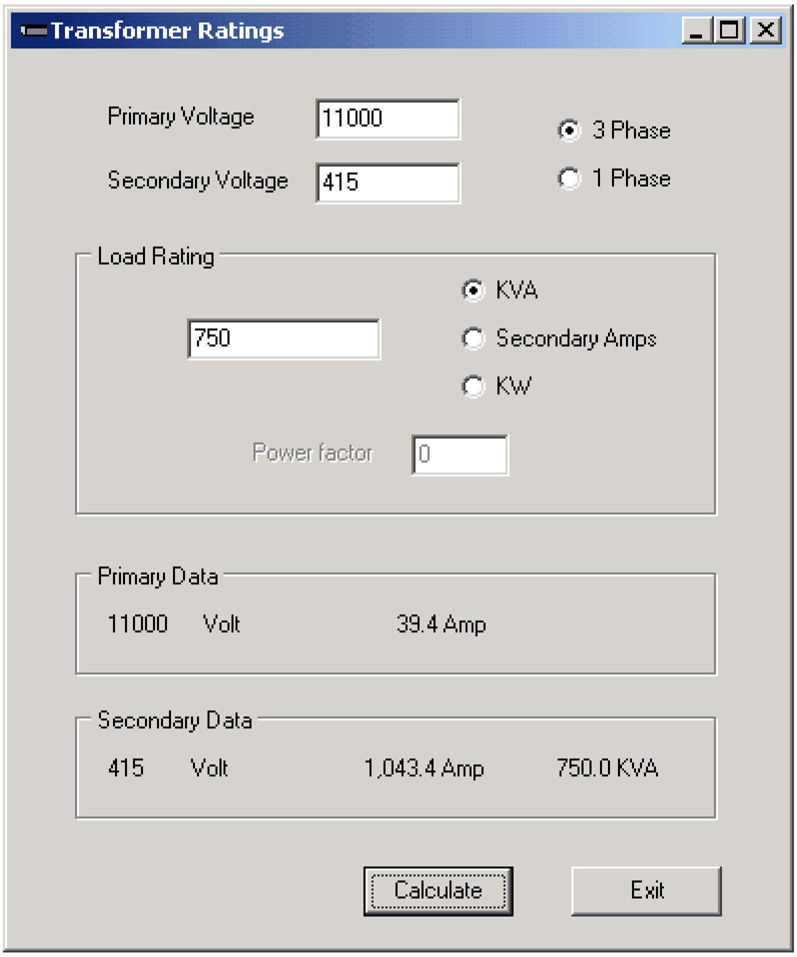
Alternator

Alternator Voltage = Output voltage of the alternator
Alternator Efficiency = rated full load efficiency of the alternator (excluding the excitation energy)
Engine Overload Capacity = Rated short term load capacity of the Engine. Typically 130% to 200% of the continuous rating.
Alternator Overload Capacity = Rated short term load capacity of the alternator. Typically 130% to 200% of the continuous rating.

10.2 Transformer Ratings

Transformers are normally rated in the output capacity in KVA and the input and output voltages. From these it is possible to calculate the input and output currents.





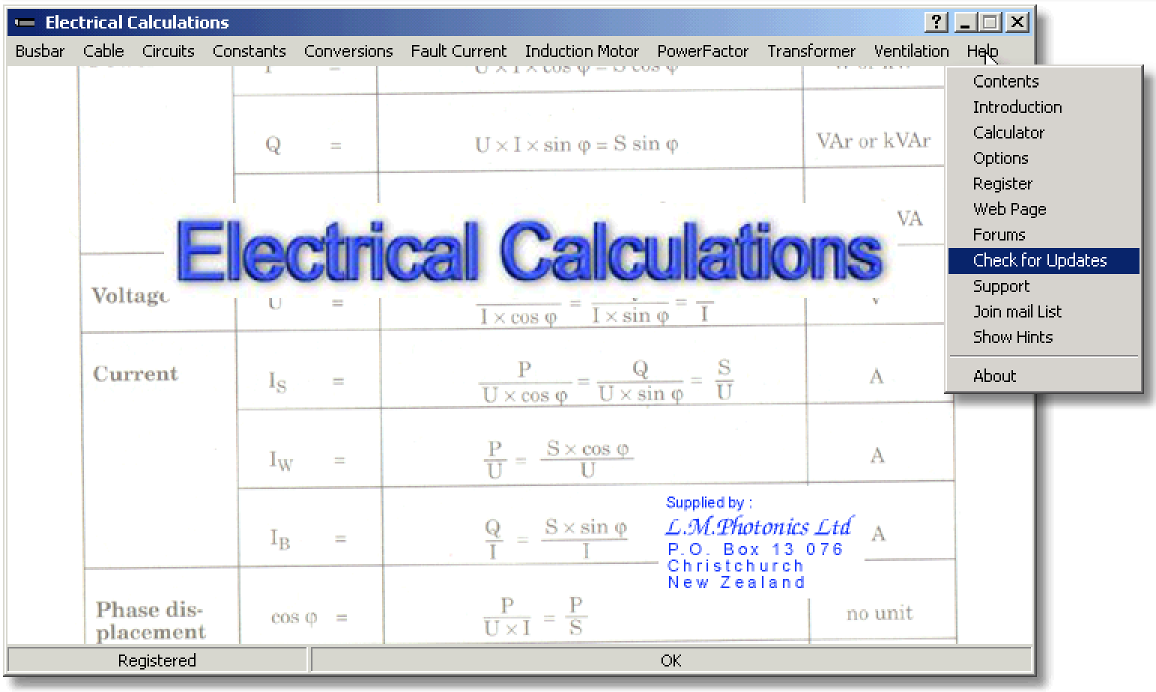
Part XI

11 On Line Updates

11.1 On Line Updates

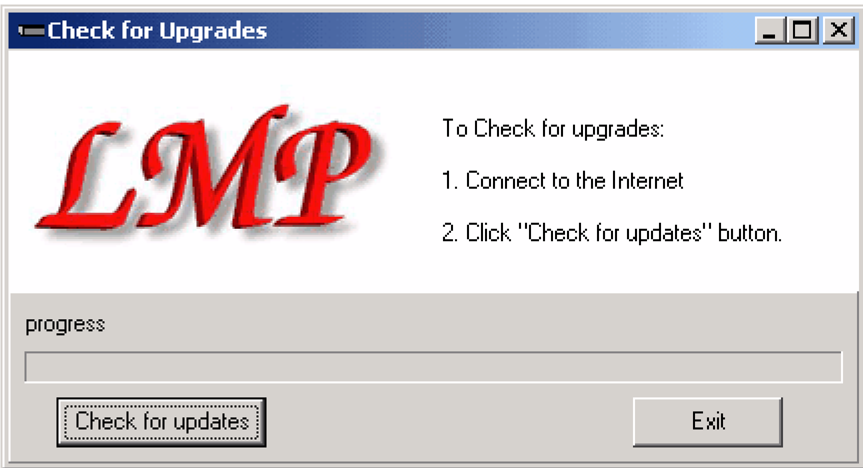
This software can be updated via the internet. Check regularly to ensure that you have an up to date copy.
 - You must have access to the internet for this to function!!

Click on the Check for Updates option under the help menu.



You must then connect to the internet and click OK in the dialog box as instructed.

An update window will open and show your current file version and the latest available. If you wish to update, click the download button, otherwise click on the exit button.



The program will download the update, install and automatically restart the program to complete the update.

Part XII

12 Registration

12.1 Registration

It is important to register this software in order to use it. Unregistered software will expire after twenty days of usage. There is no limit to the number of times this software can be used during this period, but once it has expired, the only way to unlock it, is by registration. If the software is used one day per week, then it will operate for twenty weeks. The trial period is for twenty days usage, (not consecutive days) and is to allow you to determine the usefulness of this package.

The cost of registration is $NZ35 (or $US22).

To register, click on the 'help' 'register' menu option and fill in the details.
There are three ways to register. Registration via methods 1 and 2 will be charged $NZ35 and methods 3 and 4 will be in $US22.

1. Register via secure email. Fill in your name and address etc., and your credit card details then click the **email** button on the registration form. Your Credit card and personal information is totally encrypted using 128 bit encryption and is very secure.

or

2. Print the registration form and fax or post with payment to :

   L.M.Photonics Ltd
   P.O. Box 13 076
   Christchurch
   New Zealand

   Fax ++64 3 332 5220 *[New Zealand 03) 332 5220]*

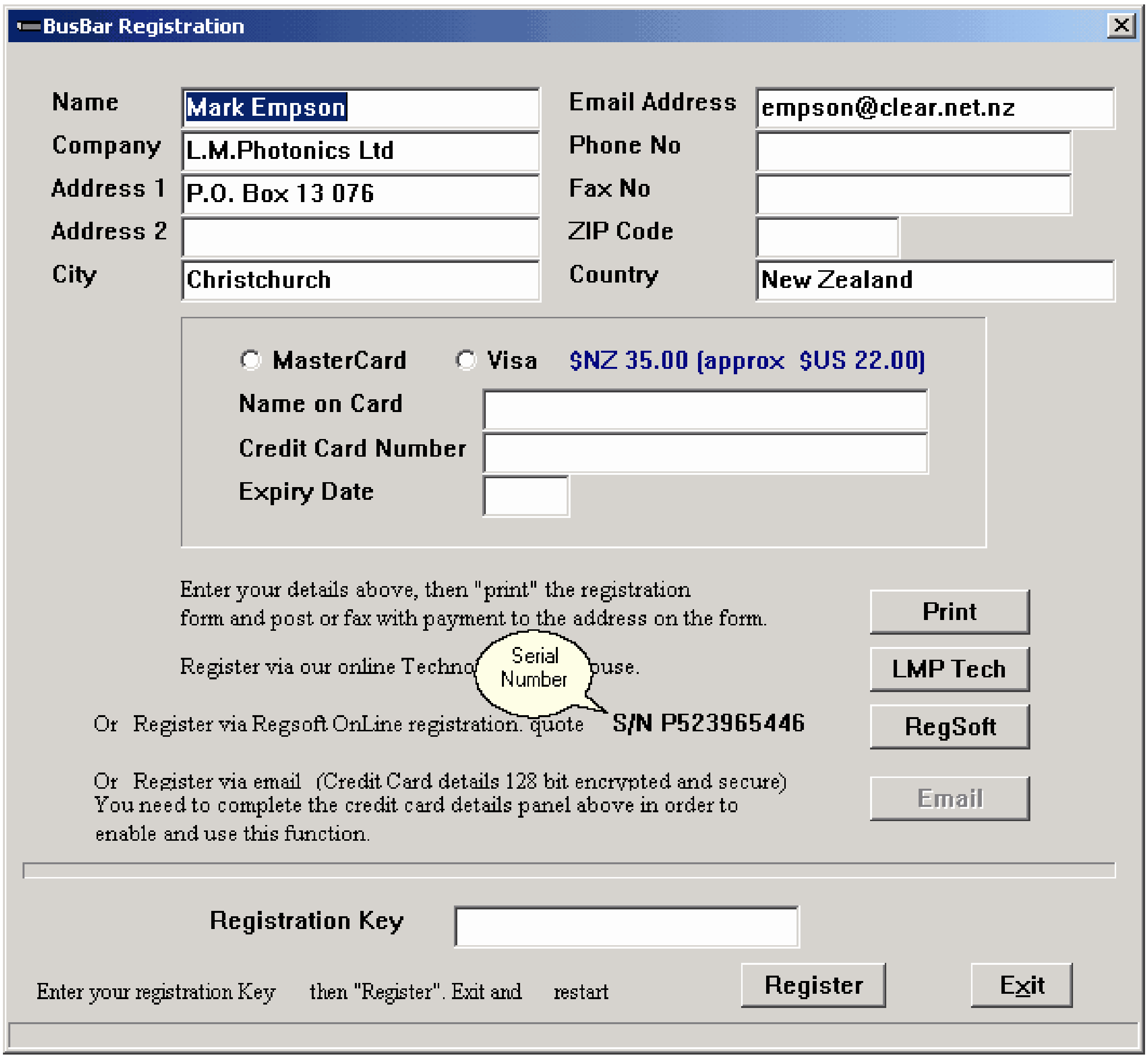
   Payment can be made by Credit Card or bank cheque.

or

3. Register via L.M.Photonics Technology Warehouse. - click on the LMP Tech button, or at :
   http://www.lmphotonics.com/store/product_info.php?products_id=28

or

4. Register online via Regsoft by clicking on the **Regsoft** button on the registration form, or register at :
   http://www.regsoft.net/purchase.php3?productid=31458
   You will need to quote the S/N shown on the registration form.



The Registration key is for the computer from which the registration request form was printed and is unique to that machine. Each installation must be separately registered.
Replacement Registration keys are available for upgraded or replaced machines, Just email reg@lmphotonics.com for details.
Registration entitles you to one years free upgrades, and you will be advised of further developments.
The information you submit on your registration form is considered confidential and will not be disclosed or sold to any other party.

Please direct any enquires to : reg@lmphotonics.com

Part XIII

13 Disclaimer

13.1 Disclaimer

This software provides indicative ratings only and in no way is a substitute for type testing of busbar and cable systems. There are many parameters which can influence the actual temperature rise of busbars and cables, and where practical these are accounted for, however issues such as the enclosure, ventilation etc will determine the actual temperature rise achieved. Where a busbar rating under determined conditions has been measured, this can be used as a reference and from this a correction factor can be derived. It is then useful to use this software to determine the effects of different bar profiles with the correction factor applied.

Power factor calculations are limited to the information provided. Poor or incorrect information will result in incorrect correction. Where ever possible, the calculations should be based on the magnetizing current of the motor (method 1) as this is the most accurate calculation. Always use quoted or measured values, never guess!!

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