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APPLICATION NOTE:

HOW TO CHOOSE A CIRCUIT BREAKER

Considerations with respect to input characteristics

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EXECUTIVE SUMMARY

Circuit breakers can be considered the first line of defense for protecting a system from prolonged damage due to a short circuit or other destructive event. This paper will discuss about the important considerations when selecting a circuit breaker. These considerations include type, application, form factor, derating factors, regulatory standards, short circuit current rating and a step by step selection procedure and example.

INTRODUCTION

Circuit breakers are electrical switches designed to protect a circuit from excess current caused by an overload or short circuit condition. When selecting a circuit breaker, one must consider the circuit to be protected. Is a branch circuit breaker or supplemental protector needed? The type of circuit breaker used depends on the trip time and application. What are your size and space constraints ie. what form factor is acceptable? Is the trip rating and short circuit current rating adequate for your application?

TYPES OF CIRCUIT BREAKER PROTECTION

There are two categories of "circuit breakers", branch (protecting multiple circuits) and supplemental (protecting a single circuit). A branch circuit breaker is UL489 rated while a supplemental protector is UL1077 rated. A few major differences between the two are that a branch circuit breaker can be used as a supplemental function however a supplemental cannot be used a branch protector per UL ratings. UL489 is tested to more rigorous tests and require larger terminal spacing which usually denotes a slightly larger size.

The main difference between the two is that a circuit breaker must be capable of being operated without damage to itself when properly applied within its ratings, and the standard for supplementary protectors allows them to be damaged when applied within their ratings.

CIRCUIT BREAKER TECHNOLOGIES

There are many types of circuit breaker technologies from thermal, magnetic, thermal-magnetic, magnetic-hydraulic, and solid-state. Single-phase or multi-phase circuit breakers with various voltage and current ratings are available. Depending on the type, the trip characteristic and time to trip will vary. It is important to choose the circuit breaker depending on the application.

The wrong circuit breaker can trip too early during startup or inrush events which are not necessarily faults in the system. They can also take too long to trip which would mean disaster for the circuit or products they are intended to protect.

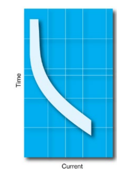
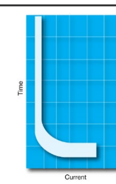
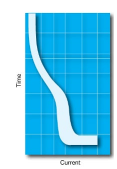
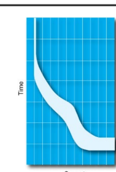
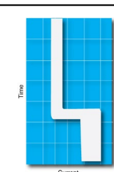
CB Type	Principle of Operation	Advantages	Disadvantages	Characteristic
Thermal	Thermal Actuator & mechanical latch.	Discriminates between temporary current surges and prolonged overloads.	Temperature sensitive with respect to ambient temperature.	
Magnetic	Solenoid releases latch to open contacts when current exceeds rated level	Not temperature sensitive with respect to ambient temperature.	Vulnerable to current surges.	
Thermal-Magnetic	Solenoid in series with a bimetal thermal actuator.	Provides 2-step time/current characteristic. Thermal mechanism responds to prolonged low value overloads while magnetic responds quickly to a high overcurrent value.	Overall response time is slower compared to other types.	
Magnetic-Hydraulic	Solenoid with a hydraulic time delay. A viscous fluid restricts the solenoid motion speed.	Less prone to tripping during momentary overload conditions.	Preferably requires mounting in a horizontal position to reduce gravity influencing the movement of the solenoid.	
Solid-State	A microprocessor samples the current, if the threshold is reached, it opens the connection.	Very fast disconnection time ranging from 10-100mS.	Rated for DC voltage and current only. Also do not have very high current ratings.	

Figure 1– Circuit Breaker Types

Figure 1 shows the different circuit breaker types, their principle of operation, characteristics, advantages, and disadvantages of each type. Each type can specify different "Trip Curves" which will depend on the application. For example, D curves usually tend to react slower and are used for highly inductive loads such as motors.

FORM FACTOR

The different types of circuit protection come in a variety of shapes, sizes, mounting options and reset mechanisms (switch, lever, button, etc).

Mounting Options	Description	Example Diagram
Panel Mount	Mounted on a flat surface or panel.	
Panel Mount Snap-in	Same as panel mount however does not require additional screws or bolts to hold in place.	
DIN-Rail	A molded case that contains a clip in the back to allow for mounting on a metallic rail that is bolted down to a surface.	
Through-Hole	Reset mechanism is fed through a hole of the mounting surface and casing is held in case by the threaded casing of the reset mechanism.	

Figure 2– Circuit Breaker Form Factors

DERATING FACTOR

When choosing a circuit breaker, it is important to understand several derating factors that will affect the rated performance, lifetime, and reliability. The specifications on a datasheet for a circuit breaker are usually with respect to a specified ambient temperature and operating voltage and frequency.

Usually an ambient compensation table is provided with a rating correction factor for a specified ambient temperature. This correction factor should be multiplied by the original ratings to determine the compensated rating.

REGULATORY STANDARDS

Figure 3 highlights several standards that are related to circuit breakers and supplementary protectors.

Standard	Covers
UL489	Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures
UL1077	Supplementary Protectors for Use in Electrical Equipment
UL 60950-1	Information Technology Equipment: General Requirements
NFPA 70	National Electrical Code (USA)
CSA22.2	National Electrical Code (Canada)
BS7671	National Electrical Code (UK)
IEC 60364	Electrical Installations for Buildings (EU)
IEC 60947-2	Circuit breakers for industrial applications
IEC 60898-1	AC low-voltage circuit breakers
IEC 60934	Circuit breakers for household applications including appliances

Figure 3– Regulatory Standards related to Circuit Breakers

Consult your local jurisdiction regarding any regulatory standards to adhere to for your installation.

SHORT CIRCUIT CURRENT RATING

When selecting a circuit breaker, the short circuit current rating (SCCR) must be considered as it is the maximum short circuit current a device can safely withstand for a specified time or until a fuse or circuit breaker opens and clears the circuit.

Short-circuit current rating is not the same as interrupting rating and the two must not be confused.

Before choosing a circuit, breaker and looking at the short circuit current rating, it must be determined for a specific device and per a specific standard if applicable.

A circuit breaker should be chosen to match or exceed the rating of the device.

If an application requires a very high short circuit current rating and there are no circuit breakers or supplementary protectors available for the application, fuses are required to increase the short circuit current rating.

Please see our fuse selection application note for additional information.

CONSIDERATIONS WHEN SELECTING A CIRCUIT BREAKER

1. Do I need a Branch Circuit Breaker (UL489 rated) or Supplemental Protector (UL1077 rated)? Is the system I am trying to protect already protected by a branch circuit breaker upstream?
2. What is the voltage of the system I am trying to protect? Is it AC or DC? If AC, what frequency is it?
3. What is the ambient temperature or temperature of the environment that the system is in?

4. What is the nominal load current? Trip current? Short Circuit Current Rating required?
5. What is the input characteristic of the system? How long does the inrush current last and what is the peak?
6. What are the number of poles needed? Is the input single-phase? Three-phase?
7. Depending on the number of input poles, do I need all three poles to disconnect at the same time?
8. What is the required trip characteristic? What type of system am I trying to protect? Is it a highly capacitive or inductive system (has huge inrush current)?
9. What are my size constraints? Where can I mount the circuit breaker?
10. What type of connection methods can I use? Screw terminals, solder pins, quick disconnects etc.
11. Do I need any other special features? Automatic reset, auxiliary functions, etc.
12. Which other safety approvals are required?
13. Which trip curve do I need?

EXAMPLES

The following examples will demonstrate the selection process for a circuit breaker for two of Astrodyne TDI's flagship products the LiquaBlade™ and Mercury Flex.

LIQUABLADE™ CIRCUIT BREAKER SELECTION EXAMPLE

The LiquaBlade™ is a robust 16.5kW liquid-cooled power supply available in variable 60V/120V/180V output configurations.

1. Do I need a Branch Circuit Breaker (UL489 rated) or Supplemental Protector (UL1077 rated)? Is the system I am trying to protect already protected by a branch circuit breaker upstream?

Assume both cases, no branch circuit breaker installed, will need a UL489 rated breaker and other case that supplementary protector (UL1077 rated) is acceptable. One advantage of UL1077 rated products are that there are typically more types available and their trip curves are faster overall.

2. What is the voltage of the system I am trying to protect? Is it AC or DC? If AC, what frequency is it?

   AC Input Voltage Range: 480VACL-L/60Hz maximum.

3. What is the ambient temperature or temperature of the environment that the system is in?

   Assume 25 degrees C.

4. What is the nominal load current? Trip current?

   Nominal current at full load ~28A per phase at 342V input.

5. What is the input characteristic of the system? How long does the inrush current last and what is the peak?

   Peak inrush current reaches maximum of 44A and lasts about two AC cycles or less than 48mS.

6. What are the number of poles needed? Is the input single-phase? Three-phase?

   The system is 3-Phase, so a 3-Pole breaker is needed.

7. Depending on the number of input poles, do I need all three poles to disconnect at the same time?

Yes, I want all three poles to disconnect if any one pole is tripped.

8. What is the required trip characteristic? What type of system am I trying to protect? Is it a highly capacitive or inductive system (has huge inrush current)?

   I am trying to protect a power supply which has PFC or a high power factor. The inrush current reaches a peak of 44A.

9. What are my size constraints? Where can I mount the circuit breaker?

   Do not have any constraints, will adapt to fit the correct & available breaker.

10. What type of connection methods can I use? Screw terminals, solder pins, quick disconnects etc.

    Do not have any constraints, will adapt to fit the correct & available breaker.

11. Do I need any other special features? Automatic reset, auxiliary functions, etc.

    Mainly need all three poles to trip at the same time if any one pole is tripped. Anything else is an added benefit.

12. Which other safety approvals are required?

    Closest adherence to UL508 guidelines unless my installation requires specific UL certification. I may need to consult my local expert.

13. Which trip curve do I need?

Since I know the power supply has a large inrush for a short amount of time, I can go with a "B curve" or fastest reacting curve available.

To calculate current for a 3-Phase system: Power/Minimum Voltage/Sqrt(3)/Power Factor

16,500W / 342VAC (lowest voltage supported at input) / Sqrt(3) / 0.99 = 28.16A

Using the UL508 guidelines, 28.16A*115% = 32.38A. A 35A breaker is chosen as it is the closest standard denomination.

Using an electronic components distributor website, searched for Circuit Breaker products, filtered out 277VAC/480VAC or higher rated products, filtered UL489 approved products/filtered UL1077 approved products, filtered 3 Pole products, filtered 35A products. We found mostly thermal-magnetic type circuit breakers and magnetic-hydraulic type supplementary protectors.

If searching for a branch circuit breaker, the following part was found:

E-T-A 4230-T130-K0BU-35A

Notice that with Curve B, for the inrush current with the times rated current at 44A/35A=1.25, the trip time will take over 100 seconds which is plenty of time to handle the inrush current.

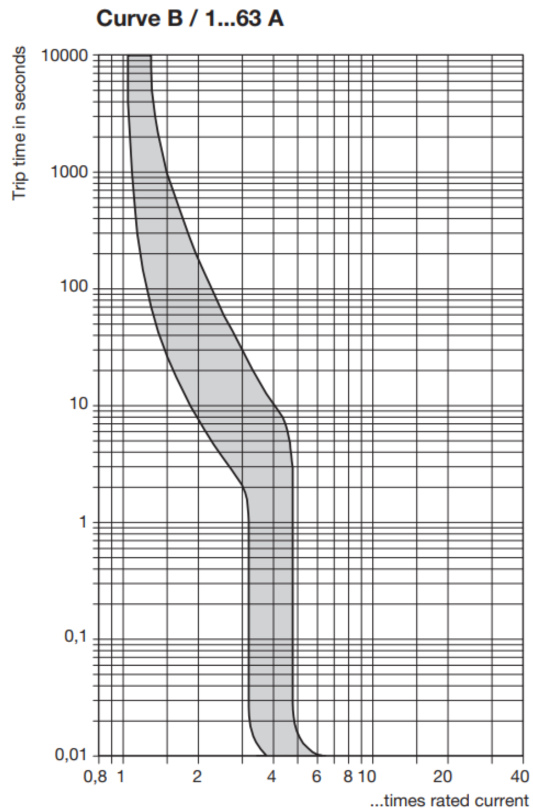


Figure 5– Circuit Breaker Trip Curve Example LQB

While searching for a supplementary circuit breaker, we could not find any 3-Pole models. It may be the case that not all types are offered.

MERCURY FLEX CIRCUIT BREAKER SELECTION EXAMPLE

The Mercury Flex is a flexible shelf system in which a single shelf can house up to four 3.8kW air-cooled power supplies which are available in variable 28V/56V/125V/180V/250V/450V output configurations.

1. Do I need a Branch Circuit Breaker (UL489 rated) or Supplemental Protector (UL1077 rated)? Is the system I am trying to protect already protected by a branch circuit breaker upstream?

   Assume both cases, no branch circuit breaker installed, will need a UL489 rated breaker and other case that supplementary protector (UL1077 rated) is acceptable. One advantage of UL1077 rated products are that there are more different types available and their trip curves are usually faster overall.

2. What is the voltage of the system I am trying to protect? Is it AC or DC? If AC, what frequency is it?

   AC Input Voltage Range: 265VAC/60Hz maximum.

3. What is the ambient temperature or temperature of the environment that the system is in?

   Assume 25 degrees C.

4. What is the nominal load current? Trip current?

   Nominal current at full load ~22A at 90V input.

5. What is the input characteristic of the system? How long does the inrush current last and what is the peak?

   Peak inrush current reaches maximum of 45A and lasts for less than 48mS.

6. What are the number of poles needed? Is the input single-phase? Three-phase?

Each rectifier is a single-phase input however we need to consider the shelf configuration. The shelves are available in two of the following configurations shown below. If using a shelf on the left, will need 1 Pole circuit breakers that are all the same value. If using a shelf on the right, will need 2 circuit breakers of the same value and 1 circuit breaker with increased value that can handle two rectifiers.

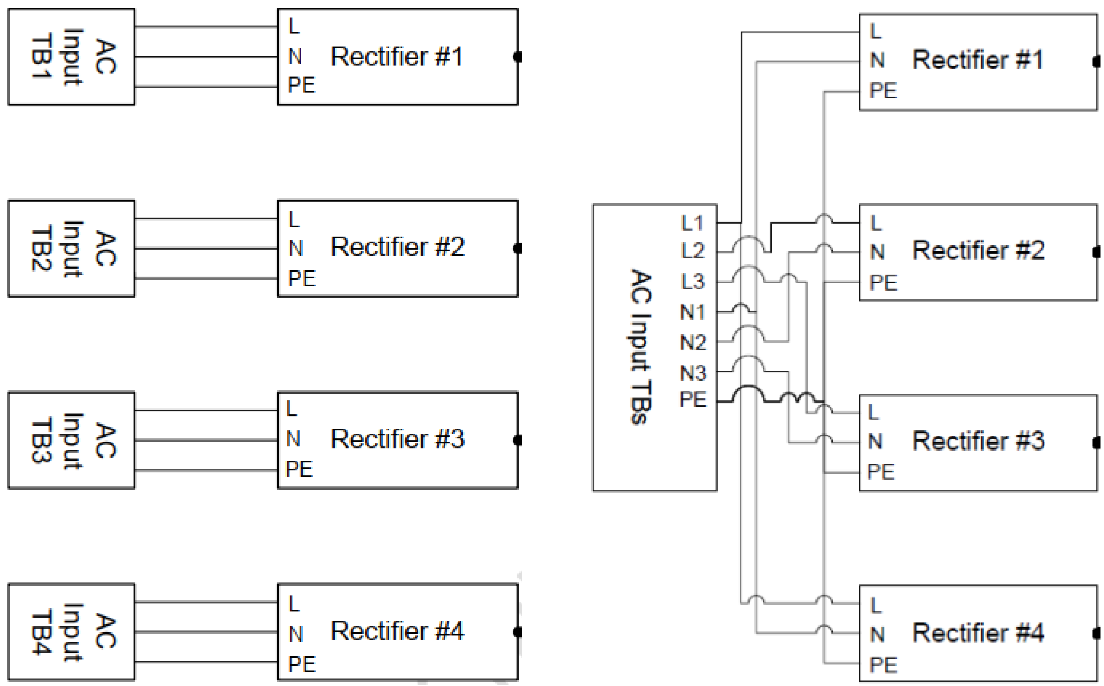


Figure 6– MF Shelf with individual terminal block inputs (left)

MF Shelf with single terminal block input (right)

7. Depending on the number of input poles, do I need all three poles to disconnect at the same time?

No, each breaker can trip independently.

8. 8What is the required trip characteristic? What type of system am I trying to protect? Is it a highly capacitive or inductive system (has huge inrush current)?

   I am trying to protect a power supply which has PFC or a high power factor. The inrush current reaches a peak of 45A at maximum.

9. What are my size constraints? Where can I mount the circuit breaker?

   Do not have any constraints, will adapt to fit the correct & available breaker.

10. What type of connection methods can I use? Screw terminals, solder pins, quick disconnects etc.

    Don't have any constraints, will adapt to fit the correct & available breaker.

11. Do I need any other special features? Automatic reset, auxiliary functions, etc.

    No special features needed.

12. Which other safety approvals are required?

    Closest adherence to UL508 guidelines unless my installation requires specific UL certification. I may need to consult my local expert.

13. Which trip curve do I need?

    Since I know the power supply has a large inrush for a short amount of time, I can go with a "B curve" or near fastest reacting curve available.

To calculate current for a single phase 220V system: Power/Minimum Voltage/Power Factor

3,800W / 176VAC (lowest voltage supported at input) / 0.99 = 21.8A

Below 176VAC at the input, power is limited to 1900W.

To calculate current for a 120V single phase system: Power/Minimum Voltage/Power Factor

1900W / 90VAC (lowest voltage supported at input) / 0.99 = 21.3A

Using the UL508 guidelines, 21.8A*115% = 25.07A in a 220V system. In a 120V system, 21.3A*115% = 24.5A.

A 25A breaker is chosen as it is the closest standard denomination.

If connecting two units to a single AC line, the load current is cumulative, so we decided to go with a 50A circuit breaker.

Using an electronic components distributor website, searched for Circuit Breaker products, filtered out 277VAC/480VAC or higher rated products, filtered UL489 approved products/filtered UL1077 approved products, filtered 1 Pole products, filtered 25A and 50A products. We found mostly thermal-magnetic type circuit breakers and magnetic-hydraulic type supplementary protectors.

For one module connected to a line, 25A both UL489/UL1077 Rated:

E-T-A 4230-T110-K0BU-25A (SCCR=5kA)

For two modules connected to a line, 50A both UL 489/UL1077 Rated:

E-T-A 4230-T110-K0BU-50A (SCCR=5kA)

Notice that with Curve B, for the inrush current with the times rated current at 45A/25A=1.8, the trip time will take over 10 seconds which is plenty of time to handle the inrush current.

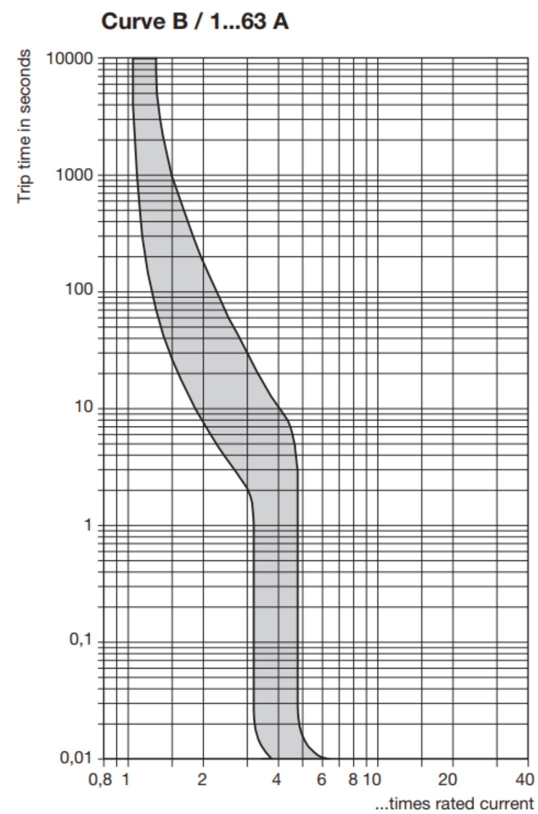


Figure 7– Circuit Breaker Trip Curve Example MF

CONCLUSION

There are many circuit breaker and supplementary circuit protector models available. Take time to consider all aspects of the installation and environment. Consult a licensed electrician or professional who is knowledgeable of your local jurisdiction in case a second opinion is needed.

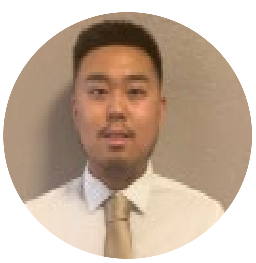
Astrodyne TDI offers many single-phase and three-phase input product that are flexible and robust enough to handle your input power and output power and reliability requirements. Besides the importance of protecting your product and system it is even more important to protect your life and the lives of others!

With Astrodyne TDI's legacy of reliable power supplies and systems, you will have one less thing to worry about. Now you have power.

ABOUT THE AUTHORS

Loay Elbasyouni
Principal Engineer
West Coast Tech Center
Email: loay.elbasyouni@astrodynetdi.com

Mr. Elbasyouni has wide experience from lean manufacturing to engineering development. Loay earned his bachelor's and master's Degrees in Electrical Engineering from the University of Louisville. Loay is an active member in IEEE, Power Electronics and Control Society. He brings a significant background in Power Electronics working the last 17 years as an Electrical Engineer in several different industries including Aerospace, Automotive, Industrial, and Renewable Energies. Loay joins us from Safran Aerospace, where he was Electronic and controls engineering manager. prior to that Loay was Sr. Staff Engineer at AeroVironment. He has also worked for different size company large companies such as GE, Dana Corp and Safran and startup companies such as Coda Automotive, Azure Dynamics. During his work at AeroVironment Loay had opportunities to work on advanced power conversion and propulsion technologies used for the development of NASA-JPL projects such as the Mars Helicopter. Loay received the achievement award as part of Mars Helicopter team for exceptional achievement in demonstrating feasibility of helicopter flight in the extremely thin atmosphere at Mars.



Kevin Do
Electrical Engineer
West Coast Tech Center
Email: kevin.do@astrodynetdi.com

Kevin Do is an application engineer at the West Coast Technology Center of Astrodyne TDI. He received his Bachelor's in Electrical Engineering from the University of California, Riverside. He joins us from Safran Aerospace where he designed and developed aircraft components and systems conforming to RTCA-DO160, RTCA-DO178 and RTCA-DO254 standards.

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