ECET 4520

Industrial Distribution Systems, Illumination, and the NEC

Distribution System Protection

Overcurrent Protection

One of the most important aspects of distribution system design is system protection.

Overcurrent protection for conductors and equipment is provided to de-energize (open) a circuit if the circuit current reaches a value that will cause the operational temperature in the circuit conductors or in the terminating equipment to exceed the temperature rating.

Overcurrent

<u>Overcurrent</u> – any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from an overload, short circuit, or ground fault.

Although any current above rated current may be considered an overcurrent, overcurrents are typically separated into two distinct classes:

- **Fault (Short Circuit) Currents**
- **Overload Currents**

System Faults – Short Circuits

<u>Short-Circuit</u> – a short-circuit occurs when one or more of a circuit's energized conductors are either directly connected to each other or to a neutral (grounded) conductor.

A short-circuit can result in exceptionally large currents that, if not mitigated quickly, can damage or destroy system components, cause a fire, and/or lead to injury or death.

System Faults – Short Circuits

The short-circuit current available at any point in a distribution system is key factor that must be considered when selecting the system's protective devices.

As per the NEC:

"Equipment intended to interrupt current at fault levels shall have an <u>interrupting rating</u>… sufficient for the current that is available at the line terminals of the equipment." **(Article 110.9)**

"The overcurrent protective devices… shall be selected and coordinated to permit the circuit protective devices used to clear a fault to do so without extensive damage to the electrical equipment of the circuit." **(Article 110.10)**

System Faults – Ground Faults

<u>Ground Fault</u> – a ground fault occurs in a distribution system when an electrically conductive path is created from a circuit conductor back to the electrical supply source through the system's <u>normally non-current-carrying</u> conductors or equipment, external conductive materials or pathways, or the earth itself.

Ground-Fault Circuit Interrupter

Although ground faults can also result in exceptionally large currents, a high-impedance ground fault can produce relatively small currents that may still present a risk of fire or injury due to electrocution but may not be detectable by a system's primary protective devices.

A <u>Ground-Fault Circuit Interrupter</u> (GFCI) is a device intended for the protection of personnel that functions to de-energize a circuit within an established period of time when a current to ground exceeds the values of 4-6mA.

Note – GFCIs are not covered in this presentation.

Overcurrent vs. Overload

<u>Overcurrent</u> – any current in excess of the rated or maximum allowable continuous current of a circuit.

<u>Overload</u> – operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating.

Note – the term <u>overcurrent</u> is sometimes used to refer only to currents whose magnitudes are in excess of those associated with an overload, up to and including those that result from an ideal short-circuit fault.

Overloads

Overload – an overload occurs when more than the rated (maximum allowable continuous) current flows along the normally conductive path of a circuit.

An overload is not the result of a system fault since a fault, by nature, bypasses the normal conductive path in a circuit.

Instead, an overload is typically the result of either improper circuit loading or improper/abnormal operation of a load.

Overload Examples

Examples of Overloads due to Improper Circuit Loading:

- Too many loads are simultaneously plugged into the receptacles of a 20A, general-purpose branch circuit resulting in a current draw that is greater-than 20A.
- Over time, as the lightbulbs in a dimly-lit parking deck burn-out, the fixtures are retrofitted for brighter bulbs. The higher wattage rating of the new bulbs eventually cause the current draw to exceed the rating of the circuit.
- The 240/120V 1Φ service of a small commercial facility is upgraded to a 208Y/120V 3Φ service without replacing the facility's 230V 1Φ AC compressor motors. When supplied at 200V instead of 230V, the motors draw larger currents, in-turn overloading their circuits.

Overload Examples

Example of an Overload due to <u>Improper Load Operation</u>:

- **Thirty people squeeze into an elevator that has a posted "maximum occupancy" of twenty. The excessive weight causes the elevator's motor to run slower, in-turn drawing a larger-than-rated current that could be potentially damaging if the improper operation is allowed to continue for extended periods of time.**

Example of an Overload due to <u>Abnormal Load Operation</u>:

- **Due to a mechanical failure, the shaft of a 3Φ Induction Motor is not able to rotate. If energized and supplied with rated voltage, the motor may draw from 4-10x it's rated current, resulting in quick, excessive heating in both the motor itself and in the conductors of the circuit supplying the motor.**

Ampacity vs. Current Rating

<u>Conductor Ampacity</u> – the maximum current, in amperes, that a conductor can carry continuously under the conditions of use without exceeding its temperature rating.

In comparison to ampacity, the <u>Current Rating</u> of a circuit is the maximum current that a circuit can supply to its load(s), as determined by the rating or setting of the overcurrent device that is protecting the circuit.

Ampacity vs. Current Rating

Note that:

- **The <u>ampacity</u> of a circuit's conductors provides a <u>maximum limit</u> to the current rating of a circuit.**
- **Although conductor ampacity provides an upper limit for a circuit's current rating, it is the rating of the circuit's <u>overcurrent protective device</u> that defines the actual current rating of the circuit.**
- **Despite its rating, a circuit may not be able to supply rated current <u>continuously</u> to its loads.**

Overcurrent Protection Devices

The proper design of a distribution system may include the use many different devices that provide protection during the occurrence of a system fault or overload.

These devices primarily include:

- **Fuses**
- **Circuit Breakers**
- **Ground-Fault Circuit Interrupters**

Fuses

A <u>fuse</u> is a protective device that can be placed in series with a circuit conductor in order to limit the conductor current to a safe level.

A fuse can only interrupt current flow one time, after which the fuse (or the fusible link) must be replaced.

Fuse Operation

A fuse consists of a <u>fusible link</u> (metal strip or wire) that is encapsulated in a non-conductive housing. The link is designed such that it will melt when the current flowing through the fuse exceeds a prescribed value.

During normal operation, the link simply acts as a part of the conductive circuit. But, when an overcurrent occurs, the link melts and open-circuits the conductive path in order to prevent any further damage to the distribution system.

Fuse Ratings

Fuses are characterized by several different criteria, including:

- the current rating of the fuse
- the interrupting rating of the fuse
- the voltage rating of the fuse
- the time-delay or rate at which the fuse will operate when exposed to an overcurrent

Current Rating of a Fuse

The Current Rating of a fuse provides the maximum current magnitude that may continuously flow through the fuse without the fuse "blowing". situation.

For example: A 30A fuse will theoretically "blow" if subjected to a current over 30 amps.

Note that the above statement may or may not hold true depending on the specific type of fuse, the actual magnitude of the current (above 30A), and the duration of the current flow exceeding 30A.

Interrupting Rating of a Fuse

A fuse's <u>Interrupting Rating</u> (IR) defines the maximum current magnitude that the fuse can safely interrupt.

Fuses must be chosen such that their IR not less than the available short-circuit current at their location.

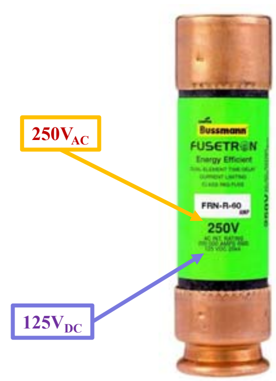
Note that fuses may have different IR values for AC and DC systems.

Voltage Rating of a Fuse

A fuse's <u>Voltage Rating</u> defines the maximum operational voltage of the system in which the fuse can be applied.

For example: A fuse with a 600V$_{AC}$ rating is suitable for use in AC systems having an operational voltage that is less than 600 volts.

Note that fuses may have different voltage ratings for AC and DC systems.



Fuse Type

Along with their current and voltage ratings, fuses are classified by the rate at which they operate:

- Fast Acting
- Time Delay
- Current Limiting
- Dual Element

For example: A fuse protecting a motor circuit must operate with a time delay due to the motor's large starting current while still offering fast protection in the case of a short circuit.

Fuse Classes

Furthermore, fuses are separated into many standardized classes based upon:

- the type of circuit/load for which they are intended (AC, DC, lighting, motor, etc.)
- their ratings
- their performance (current limiting ability, etc.)
- their physical construction

Fuse Classes

Selected Fuse Classifications:

UL Class	Type	Interrupting Rating (kA)	AC Voltage Ratings (V)	Available Ampere Ratings (A)	Suitable Uses / Protection
H	Fast-Acting	10	250 600	1 – 600	General-purpose branch & lighting circuits (not inductive/motor loads)
L	Time-Delay	200, 300	600	601 – 6000	Feeders and service entrance equipment
CC	Time-Delay	200	600	1/10 – 30	Motors, control transformers, etc.

Selective Coordination

The proper design an electric distribution system requires the selective coordination of the system's overcurrent protection devices.

Selective Coordination is "The act of isolating a faulted circuit from the remainder of the electrical system, thereby eliminating unnecessary power outages. The faulted circuit is isolated from the selective operation of only that overcurrent protective device closest to the overcurrent condition."

- Bulletin EDP-2, "Selective Coordination of Overcurrent Protective Devices" – Cooper Bussmann

Selective Coordination

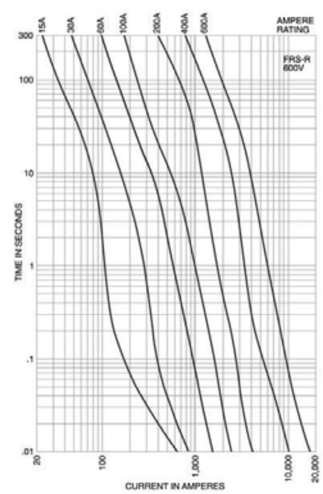
The proper design an electric distribution system requires the selective coordination of the system's overcurrent protection devices.

Selective coordination requires knowledge of the exact operational characteristics of the fuse.

These characteristics are provided by the fuse manufacturer by means of a time-current curve.

Fuse Time-Current Curves

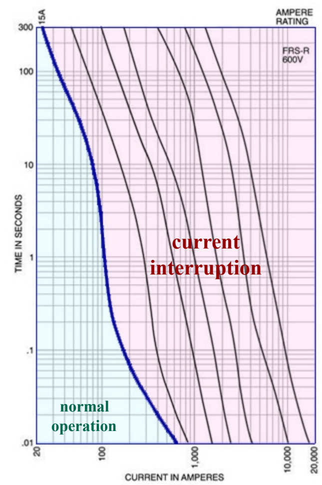
A Time-Current Curve, also referred to as an I^2t curve, defines the rate at which a fuse will operate as a function of the current magnitude flowing through the fuse.



Fuse Time-Current Curves

Operation in the area to the left of any curve defines normal operation (both continuous and transient current flow), while operation in the area to the right of any curve result in current interruption.
(i.e. – a blown fuse)

Note – the regions for normal operation and for current interruption are highlighted for the 15A fuse.

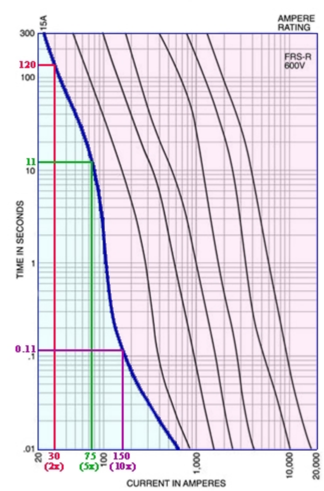


Fuse Time-Current Curves

For example:

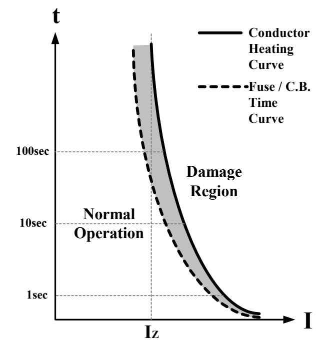
The 15A fuse whose time-curve is shown to the right will:

- blow in 120 seconds for a 30A steady-state circuit current
- blow in 11 seconds for a 75A steady-state circuit current
- blow in 0.11 seconds for a 150A steady-state circuit current



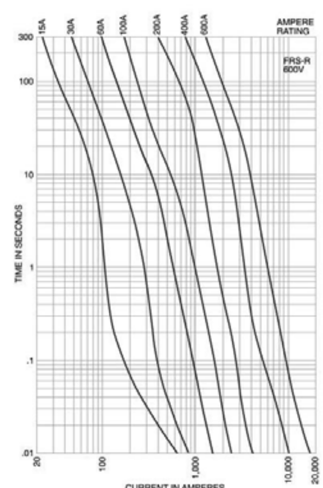
Fuse Time-Current Curves

To prevent conductor damage, fuses should be chosen such that their time-curve allows them to interrupt the circuit current before unsafe heating occurs in the conductors.



Fuse Time-Current Curves

In terms of selective coordination, fuses are selected by overlaying their time-current curves to guarantee that the fuse closest to a fault will operate faster than fuses that are further up-stream (closer to the service entrance).



Circuit Breakers

Similar to a fuse, a circuit breaker is a device that is also placed a circuit to protect the circuit against overcurrents.

But, unlike a fuse, a circuit breaker can be reset after operation, thus allowing it to operate many times without replacement.

Circuit Breakers

Circuit breakers are also given ratings based upon:

- the normal current that they are expected to carry
- their current interrupting ability
- their operational system voltage

Circuit Breakers

Unlike fuses that can protect only a single circuit conductor, circuit breakers come in a variety of configurations (single-pole, multi-pole, etc.), allowing the to simultaneously protect one or more circuit conductors.

Additionally, a circuit breaker's operation can be based upon several different fundamental principles, allowing for very complex operational characteristics.

Some circuit breakers even allow for adjustment of the operational settings.

Circuit Breaker Operation

Magnetic circuit breakers rely on the magnetic pull force created by a solenoid to release a latch, allowing a spring to open a set of electric contacts, thereby interrupting the current flowing in a circuit.

Thermal circuit breakers rely on the heating and bending of a bimetal strip to due to release a latch and allow a spring to open a set of electric contacts.

Note that circuit breakers can be constructed such that they incorporate both techniques; using the magnetic mechanism to provide a quick response to large (short-circuit) currents, and using the thermal mechanism to provide a time-delayed response to lesser currents (overloads).

Circuit Breakers

The construction of circuit breakers is also greatly affected by their operational voltage level and their current interrupting capability.

The various issues involved when designing circuit breakers that are capable of operating at high voltages and/or interrupting large currents are beyond the scope of this presentation.

Circuit Breaker Configuration

Circuit breakers are produced in a variety of different configurations:

- Single-pole circuit breakers operate based upon the current flowing in a single conductor & protect only that conductor
- Multi-pole circuit breakers protect multiple conductors simultaneously, operating if any one of the protected conductor currents exceed their rated values

Circuit Breaker Time Curves

The detailed operation of a circuit breaker is characterized by an inverse time-current curve.

Circuit breaker time-curves are used in the same manner as those provided for fuses, allowing for circuit breakers to be incorporated into the selective coordination scheme for the distribution system.

Circuit Breaker Time Curves

Furthermore, some circuit breakers are designed such that a limited adjustment may be made to their operational time-current curve, increasing the flexibility of their use within a distribution system.

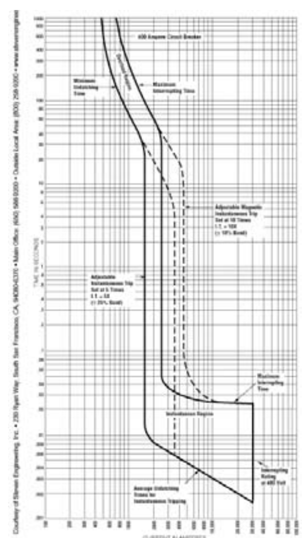


Figure 4. Typical Circuit Breaker Time-Current Characteristic Curve