Understanding Time Current Curves

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A time current curve (TCC) plots the interrupting time of an overcurrent device based on a given current level. These curves are provided by the manufacturers of electrical overcurrent interrupting devices such as fuses and circuit breakers. These curves are part of the product acceptance testing required by Underwriters Laboratories (UL) and other rating agencies.

The shape of the curves is dictated by both the physical construction of the device as well as the settings selected in the case of adjustable circuit breakers. The time current curves of a device are important for engineers to understand because they show graphically the response of the device to various levels of overcurrent.

The curves allow the power system engineer to graphically represent the selective coordination of overcurrent devices in an electrical system. Modern power system design software packages such as EasyPower, SKM Power Tools, and Etap contain graphical libraries of curves to allow the power system engineer the ability to plot, analyze and print the curves with minimal effort compared to the previous methods used when coordinating a power system.

TCC Item Identification

The TCC curves shown (Figure 1) plot the interrupting response time of a current interrupting device versus time. Current is shown on the horizontal axis using a logarithmic scale and is plotted as amps X 10X. Time is shown on the vertical axis using a logarithmic scale and is plotted in seconds X 10X. The light blue curve is a switchgear feeder circuit breaker curve.

The violet curve is the switchgear main circuit breaker curve. The red curve is the transformer primary fuse curve. The orange curve is the transformer damage curve. The green curves are the cable damage curves. Each one of these items will be explained. The system represented by this curve is well coordinated and adequately protected from damage. It also has minimal Arc Flash hazard category ratings due to low instantaneous circuit breaker trip values.

The One Line Diagram and TCC curve show a typical hypothetical industrial power system (Figure 2). There is a utility delivery point with power supplied at a medium voltage level (In this case 4160 volts), which feeds the primary side of a 2.5MVA power transformer through a medium voltage fused switch containing an E class fuse. The 480 volt secondary side of the transformer feeds a piece of low voltage power switchgear utilizing draw out low voltage power circuit breakers for the main and feeder circuit breakers. The TCC plot also displays the transformer and cable damage curves. These curves are based on accepted industry consensus standards published by ANSI (for the transformer) and ICEA (for the cables).

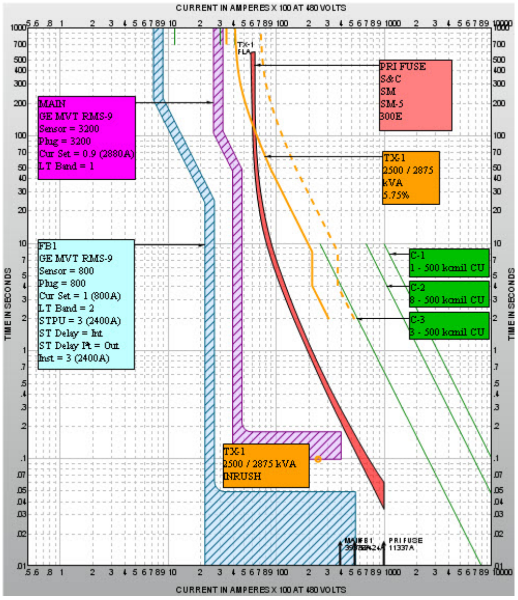

Figure 1: Typical Time Current Curve Plot

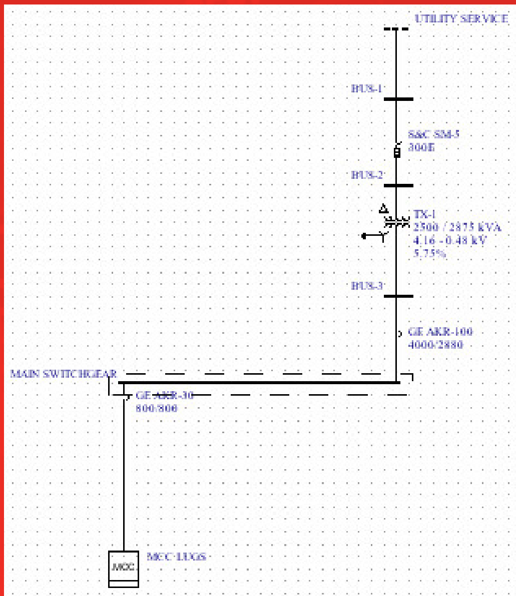

Figure 2: The One Line Diagram shown in figure 2 is represented in the TCC Curve in figure 3

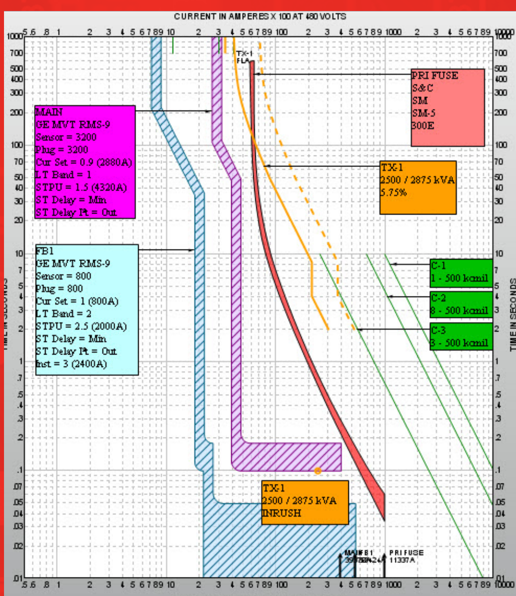

Figure 3: Selectively coordinated electrical power system. Major elements of the time current curve are labeled.

Interpreting the damage curves is fairly straightforward. Operating conditions (overcurrent protection) must be kept to the left of the damage curve to guarantee no permanent damage is done to the transformer or cable in question (Figure 3). Operating conditions which allow operation to the right of the damage curve subject the device in question to currents that cause permanent irreversible damage, a shortened lifespan and possible catastrophic failure. Therefore the overcurrent and circuit breaker coordination schemes must take this into account during the initial design phase.

There are two transformer damage curves (shown in orange), one is dashed and the other is solid. The solid damage curve is the unbalanced damage curve which takes into account a derating factor for transformer winding type and fault type. The dashed damage curve is the 100% rating curve with no derating consideration. The transformer inrush current is also plotted as a single point on the TCC diagram. Again, as part of the initial design, the transformer inrush current must be to the left of the transformer primary fuse curve otherwise the fuse will open when the transformer is energized. These differences in the unbalanced and 100% damage curves can be mitigated with additional protective relaying to allow the 100% curve to be used for power system design without the risk of transformer damage.

There are three cable damage curves (shown in green). There is one curve for each cable represented on the one line diagram. As part of the initial design, the overcurrent interrupting device must limit the fault current to the left of the damage curve to prevent permanent damage. The damage curves for the cables are dependent on size, insulation type and raceway configuration.

The light blue curve represents the circuit breaker settings for the feeder circuit breaker. The lower portion of the curve (below .05 seconds or 3 cycles on the time axis) is the instantaneous trip function. The purpose of the instantaneous trip is to trip the circuit breaker quickly with no intentional delay (no more than a few cycles) on high magnitude fault currents. This quick trip protects electrical distribution equipment from damage and keeps arc flash hazard categories low. Clearly these type faults must be interrupted quickly and do not allow the system to wait and see if the fault will self clear. The minimum instantaneous setting determines the minimum trip setting for the circuit breaker.

In the case shown above, the instantaneous setting is 2400 amps and the maximum value displayed is available fault current at the circuit breaker. Small changes in the instantaneous setting can result in significant changes in the Arc Flash Hazard category, so this is a setting which must be carefully selected according to sound engineering principles.

The next section of the curve moving up the time axis is determined by the short time settings. Short time settings cover the time range from 0.05 to 0.50 seconds (3 to 30 cycles). The purpose of short time settings is to allow a time-based delay to elapse before tripping the circuit breaker for moderate current faults. This allows moderate faults time to clear themselves without tripping the circuit breaker. Examples of these types of overcurrents would be the inrush on a large motor starting or a transformer inrush when it is first energized. The short time pickup setting shifts the curve on the current axis. Increasing the short time pickup settings shifts the curve to the right and conversely lower settings shift the curve to the left. The short time delay setting moves the "knee" of the curve vertically on the time axis. Increasing the short time delay setting moves the "knee" vertically up the time axis. Similarly, decreasing the settings moved the "knee" lower on the vertical axis. The described curve shifts are depicted on the TCC plots below. (Figures 4 - 7)

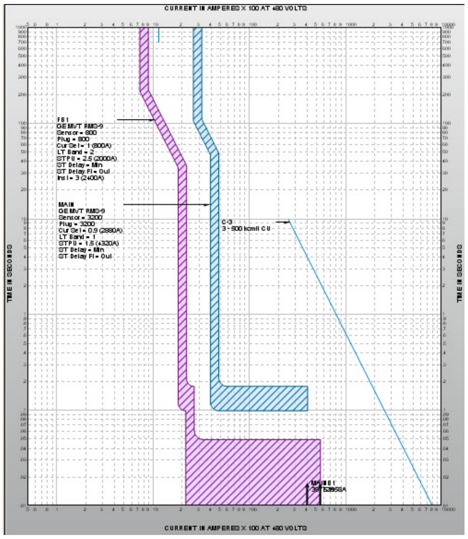

Figure 4: Short Time Base Case
STPU=2.5 ST DLY=Min

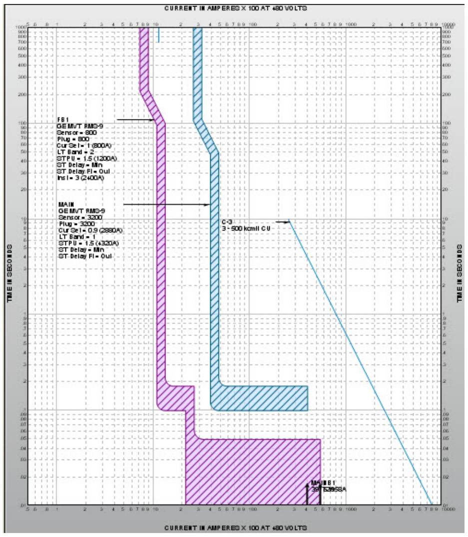

Figure 5: Decreased Short Time Pickup
Notice curve shift to left STPU=1.5

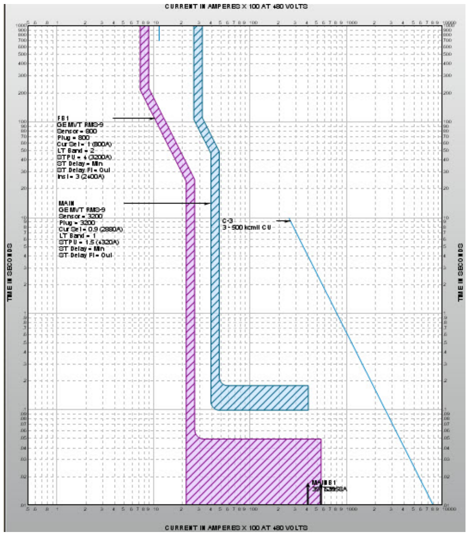

Figure 6: Increased Short Time Pickup
Notice curve shift to Right STPU=4

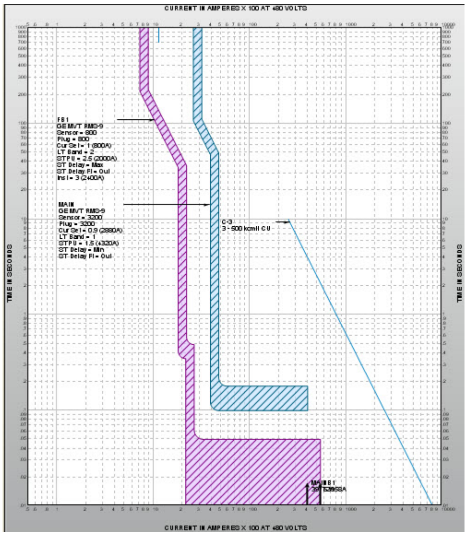

Figure 7: Increased Short Time Delay
Notice curve shift vertically ST DLY=Max

The next section of the curve moving up the time axis is the long time section. Long time settings cover the time range from 0.5 to 1000 seconds. The purpose of long time settings is to allow a time-based delay to elapse before tripping the circuit breaker for low level current faults. This allows low level faults time to clear themselves and allows electrical equipment to operate in a temporarily overloaded condition provided it will not produce permanent damage to the equipment. Examples of these types of overcurrents would be the overloading of a power transformer or large motor for a few minutes. The long time pickup setting sets the ultimate trip value of the circuit breaker. Generally circuit breakers are set at their maximum long time setting and cannot exceed the rating of the circuit breaker. They can be set at reduced values, which shifts the curve to the left on the current axis. There is also “knee” in the long time portion of the curve. The long time “knee” can be shifted up the time axis by increasing the long time delay setting. Conversely, the “knee” can be shifted lower by decreasing the long term delay setting. The described curve shifts are depicted on the TCC plots below. (Figures 8 - 11)

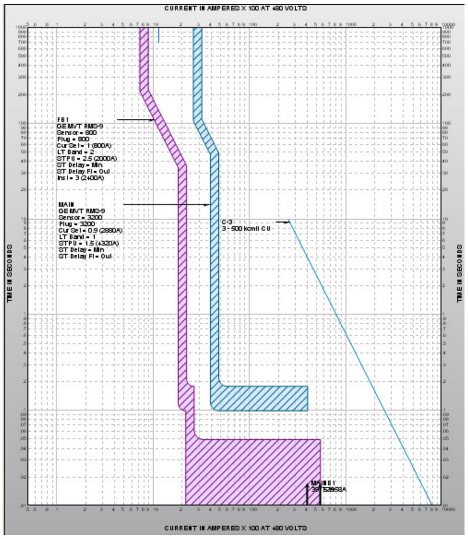

Figure 8: Long Time Base Case Trip = 800 A

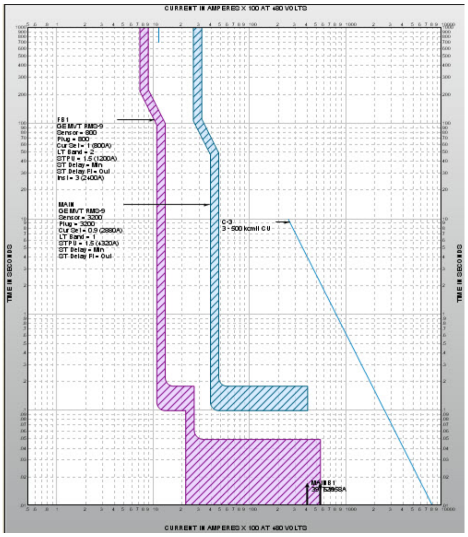

Figure 9: Long Time Delay Increased

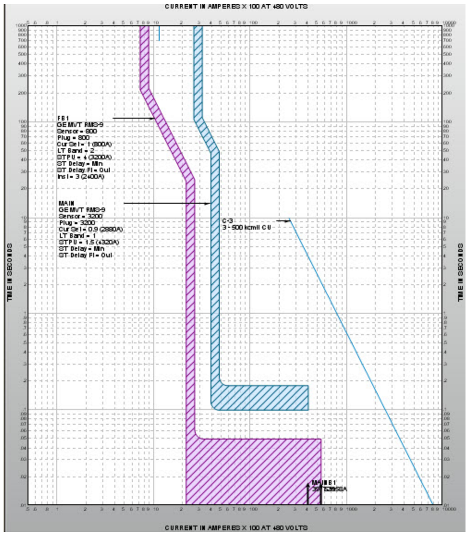

Figure 10: Long Time Delay Decreased

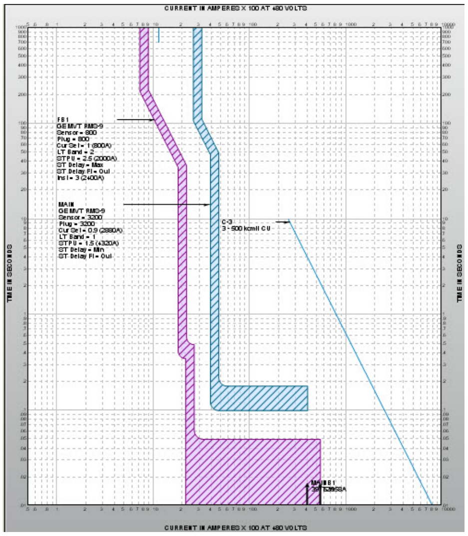

Figure 11: Long Time Pickup Decreased Trip = 400 A

Another factor to notice in the curves is that they have a width to them. This is due to tolerance of the trip elements in the circuit breaker. The curves below (Figures 12 and 13), will show the differences in this deadband for the same circuit breaker using an electronic versus non-electronic trip mechanism.

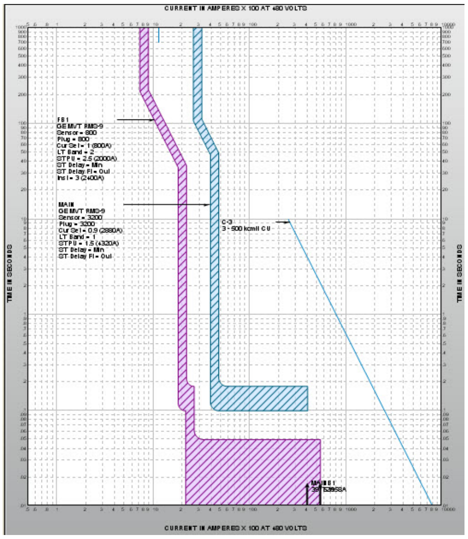

Figure 12: Feeder Circuit Breaker with Electronic trip unit Microversa Trip RMS-9 GE AKR series LVPCB

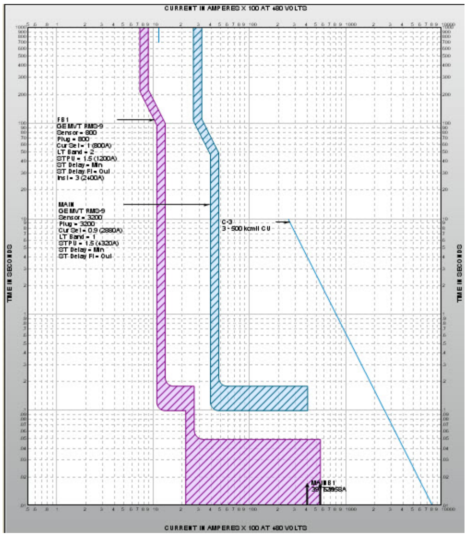

Figure 13: Feeder Circuit Breaker with Non-Electronic Trip EC-2 GE AKR series LVPCB

Notice the difference in the tolerance in the trip curve of the feeder circuit breaker. The circuit breaker unit itself is the same for both curves, so the tripping delays are constant. Settings for both trip units were set as similar as possible to each other so performance could be easily compared. Notice there is more tolerance +/- in the non-electronic trip unit due to analog component tolerances and electro-mechanical devices inside the trip unit. The transition points on the electronic trip curve between instantaneous, short time and long time are much more distinct and accurate because of the digital microprocessor-based trip. In the non-electronic trip, the transition points have time-based decay curves associated with them due to the physics of the electro-mechanical trip elements. It is simply impossible to improve the performance of the non-electronic trip because of the physical limits of the components. As can be seen in the above TCC curves, electronic trip units provide the engineer greater ability to accurately and selectively coordinate the electrical power system. Because of the obsolesce and lack of repair parts for older non-electronic trip units, the replacement of these units with electronic trip units can improve system coordination and reduce arc flash values in a properly designed electrical power system.

Now that the basics of the TCC curves have been explained, a review of coordination is in order. Our sample curves to coordinate will consist of an MCC with main 800 A fuses, a 1200 A feeder circuit breaker and the switchgear 3200 A main circuit breaker (Figures 14 - 15). In the uncoordinated system there is overlap of the circuit breaker trip curves, and in some instances the main circuit breaker will trip before the feeder circuit breaker. The main fuse in the MCC is also uncoordinated. While the fuse is not required, it is included in this example because it is typical of an industrial installation. The purpose of the fuse is to provide current limiting to increase the short circuit withstand rating of the MCC bus. For example purposes, it is assumed the MCC fuse is required and the cable feeder sizes cannot be changed. These assumptions make the example case realistic as there are often constraints such as this found in real world coordination problems in industrial facilities. "Coordinated" means that selectivity between the feeder and the main circuit breaker is maintained. Per National Electric Code, "coordinated" is defined as "localization of an overcurrent condition to restrict outages to the circuit or equipment affected, accomplished by the choice of overcurrent protective devices and their ratings or settings."

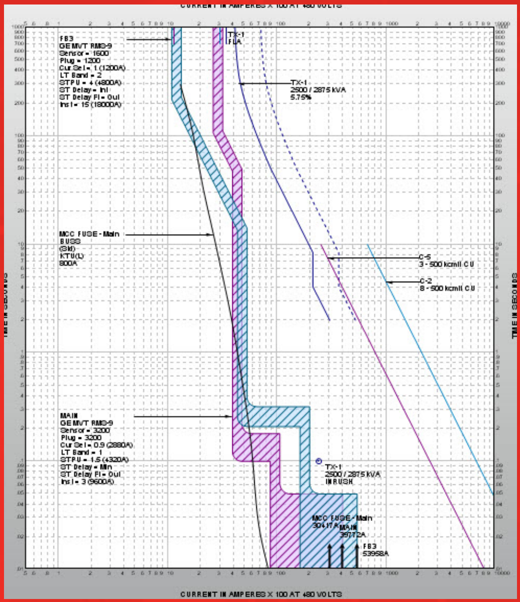

Figure 14: Uncoordinated System overlap between feeder and main circuit breaker trip curves

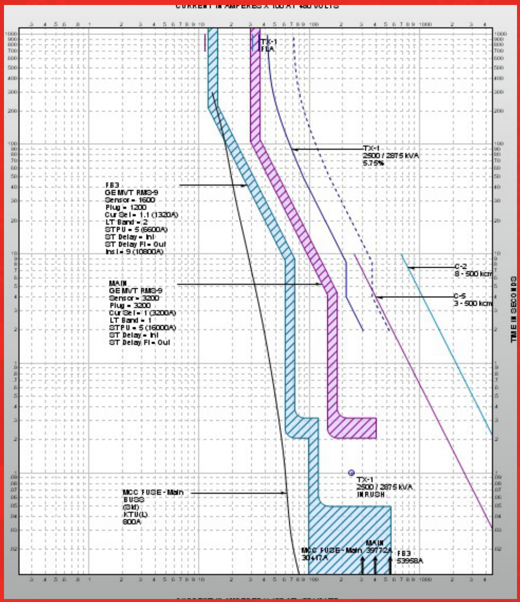

Figure 15: Coordinated System selectivity between feeder and main circuit breaker trip curves

In the coordinated example, the main and feeder circuit breakers are selectively coordinated, and the main circuit breaker provides adequate protection for the power transformer. Coordination between the MCC main fuse and the feeder circuit breaker was also improved. Coordination improvements to these circuit breakers included the following changes:

- Main Circuit Breaker Long Time Pickup (LTPU) from 2880 to 3200
- Main Circuit Breaker Short Time Pickup (STPU) from 1.5 to 5
- Main Circuit Breaker Short Time Delay (ST DLY) from Min. to Int.
- Main Circuit Breaker Instantaneous Pickup from 3 to disabled
- FB3 Circuit Breaker Long Time Pickup (LTPU) from 1 to 0.95
- FB3 Circuit Breaker STPU from 4 to 5
- FB3 Circuit Breaker Instantaneous Pickup from 15 to 9

There is overlap of the MCC main fuse and the feeder circuit breaker time current curves for long term low level overloads. This overlap could be eliminated if a larger long time pickup setting was used in the feeder circuit breaker. Increasing this setting would then require the upsizing of the feeder cable to maintain conformance with the National Electric Code (NEC). Coordination involves tradeoffs and selections that require engineering experience and judgment to find the most optimal settings. In many real world cases, it is impossible to coordinate all possible cases. As such, engineering judgment is required to coordinate the most likely scenarios and create the most reliable system.

Additionally, arc flash hazard category reductions generally result in diminished selective coordination. Conversely, improved coordination may result in increased arc flash hazard categories in some cases. In the above example, arc flash hazard category ratings for both the uncoordinated and the coordinated cases were unchanged even with improved coordination. It is possible to achieve these optimized results through the use of engineered selections. It is for these reasons that the selection of overcurrent device ratings and settings be left to power system engineers experienced in industrial power systems.

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