Overcurrent Protection and Short-Circuit Coordination for Power Systems

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INTRODUCTION

Equipment protection and short-circuit coordination are common tasks that electrical specifiers undertake when designing facility power systems with generators.

Sufficient protection schemes must be designed to protect the generator from operating in the damage region, while coordination with downstream equipment ensures that faults are localized and equipment damage is minimized.

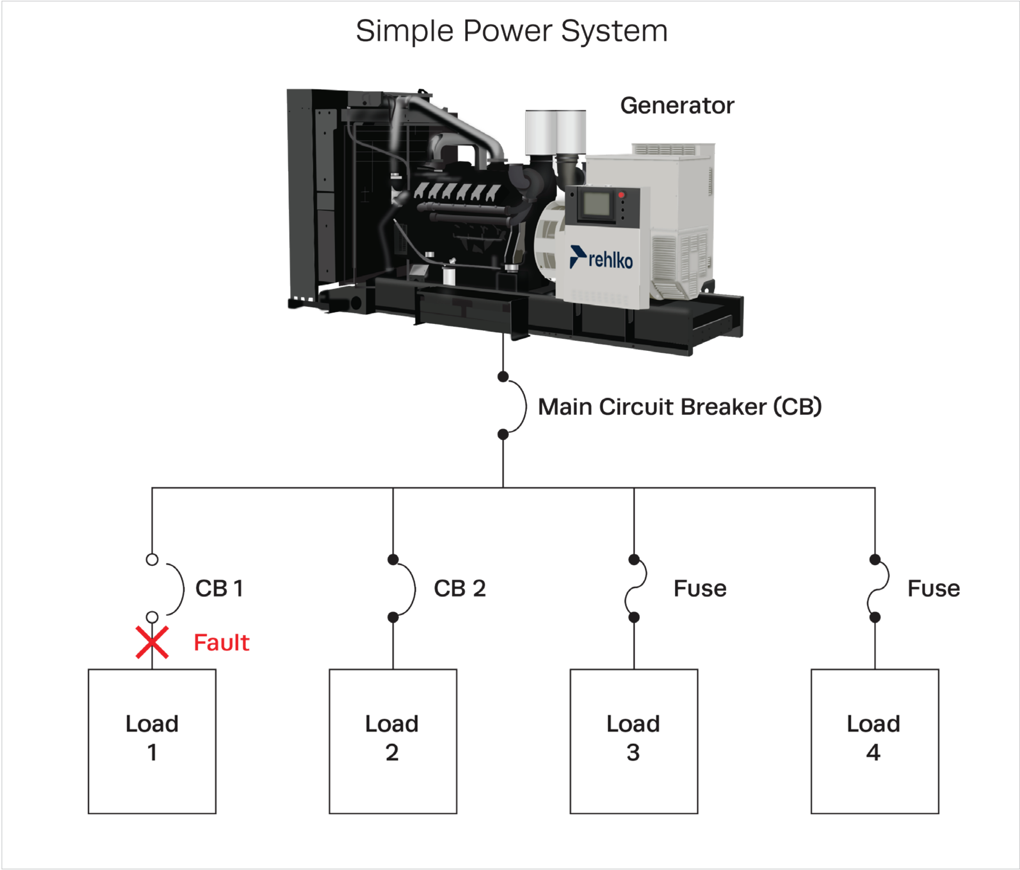
To accomplish this, the engineer must carefully consider different protection curves and regions in the generator's time current curve.

This paper aims to clarify terminologies used in this task and provide additional perspective on this topic.

OVERCURRENT PROTECTION DEVICE

Figure 1 shows a simple power system. An overcurrent protective device, such as the main circuit breaker (CB), protects the generator from overload. It is coordinated with a downstream circuit breaker, CB1, to localize and minimize equipment damage.

Figure 1



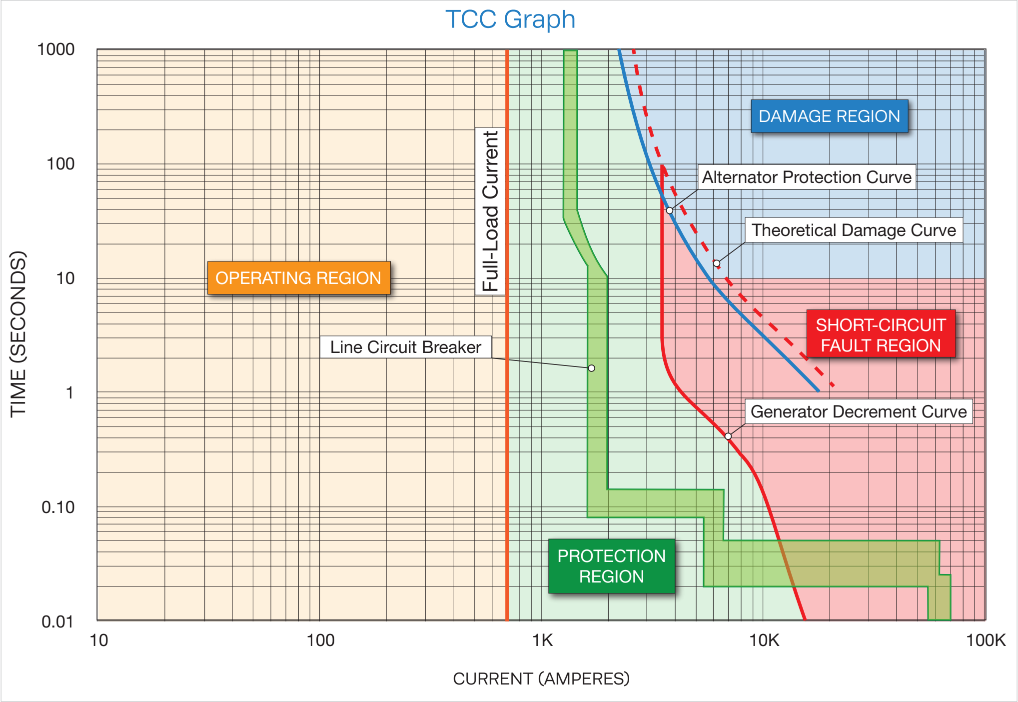
TIME–CURRENT CURVE

NFPA 70 National Electric Code Section 445.12 requires generators to be protected from overload by inherent design, circuit breakers, fuses, protective relays, or other identified overcurrent protective means.

To properly protect and coordinate the operation of the generator, the engineer must be aware of the generator's time-current curve (TCC) graph to establish where the generator is intended to operate and where the generator is prevented from operation.

Figure 2 shows an example of a generator TCC graph. The scale is logarithmic for both the X and Y axis.

Figure 2



OVERCURRENT PROTECTION DEFINITIONS

FULL-LOAD CURRENT

The full-load current is the rated capacity of the generator. This can vary based on application or settings. This line is the upper limit of current during continuous operation.

OPERATING REGION

The operating region is where the generators are intended to operate. The operating region is to the left, or equal to and below the nameplate current rating of the alternator. Generators can operate in this region without limitation.

INSTANTANEOUS REGION

Generators are typically allowed to operate above their nameplate rating for a short period of time. This is in the instantaneous region, bordered by the alternator decrement curve, allowing the generator to continue operating for a short time giving downstream breakers a chance to clear a fault. This is essential to short-circuit coordination to prevent downstream faults from shutting down the generator and all other circuits.

DECREMENT CURVE

The decrement curve provides information on short-circuit capability for the generator's alternator. The curve starts at the theoretical infinite bus calculation (FLA / X″d) for fault current where FLA stands for full-load amps and X″d stands for subtransient reactance of the alternator. The curve then decays over time.

DAMAGE CURVE

The damage curve borders the damage region. It is cost prohibitive for alternator manufacturers to establish damage curves because it would require testing several alternators of each model to failure. Therefore, it is typically a theoretical line based on empirical data collected during alternator development testing and established over many years.

ALTERNATOR PROTECTION CURVE

NEC 445.12 also allows protection by inherent design or other identified overcurrent protective means to protect the generator's alternator. The Rehlko® alternator guard is a controller-based overcurrent protective means which is factory set, providing an alternator protection curve to prevent the alternator from entering the damage region.

The alternator protection curve is designed to be just left of the theoretical damage curve as shown in *Figure 2.*

EQUIPMENT PROTECTION AND COORDINATION

EQUIPMENT PROTECTION

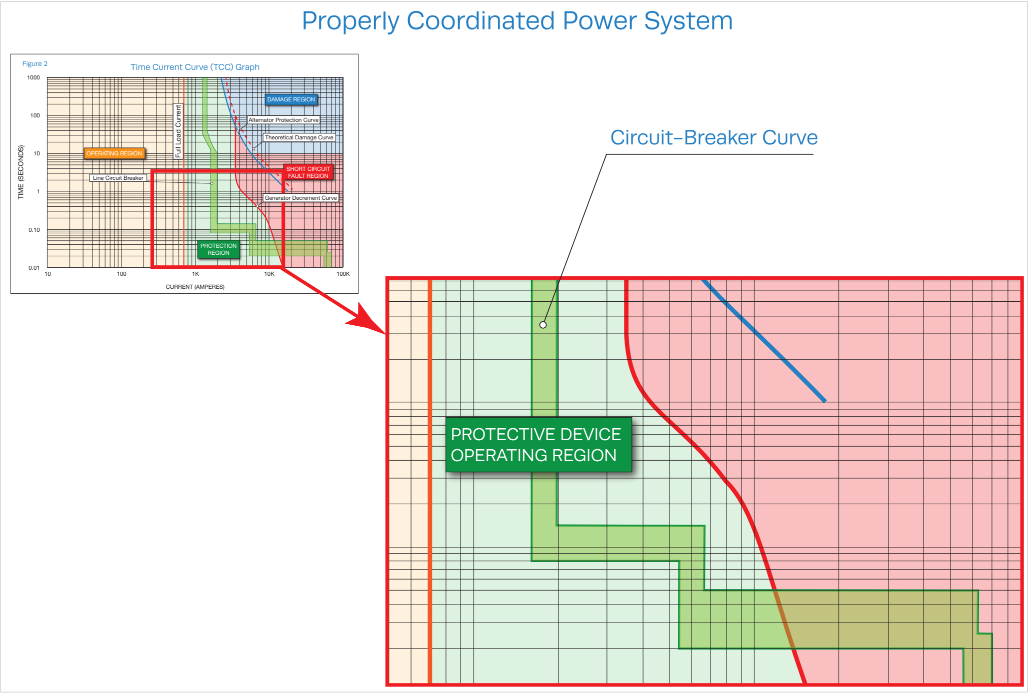
The protective device region is where engineers set the time-current curve (TCC) of the protective device. There are various protective devices that can be implemented to allow the generator to operate in the operating region while accomplishing the required overcurrent protection and coordination. Typical devices include circuit breakers, fuses, protective relays, fuses, and alternator protection curve. Circuit breakers should have a trip curve with a long and short trip portion. This long and short trip is then set in the protective device region for overcurrent protection.

SHORT-CIRCUIT COORDINATION

NEC Section 700 has multiple sections that require short-circuit coordination. The intent of this section is to localize an overcurrent condition to the affected circuit. Without short-circuit coordination, there may be equipment loads in the building that lose power unnecessarily. This could be hazardous for life safety (e.g., healthcare) or mission-critical applications such as water treatment facilities or data centers.

Engineers must therefore carefully select and set all the overcurrent devices and coordinate them so that the overcurrent protection device closest to the fault will trip, opening the local circuit, before other devices upstream are tripped. Upstream loads will remain energized and unaffected. As mentioned above, circuit breakers with adjustable trip settings are ideal devices for coordination of the TCC graph. *Figure 3* shows a diagram that helps to visualize a properly coordinated power system.

Figure 3

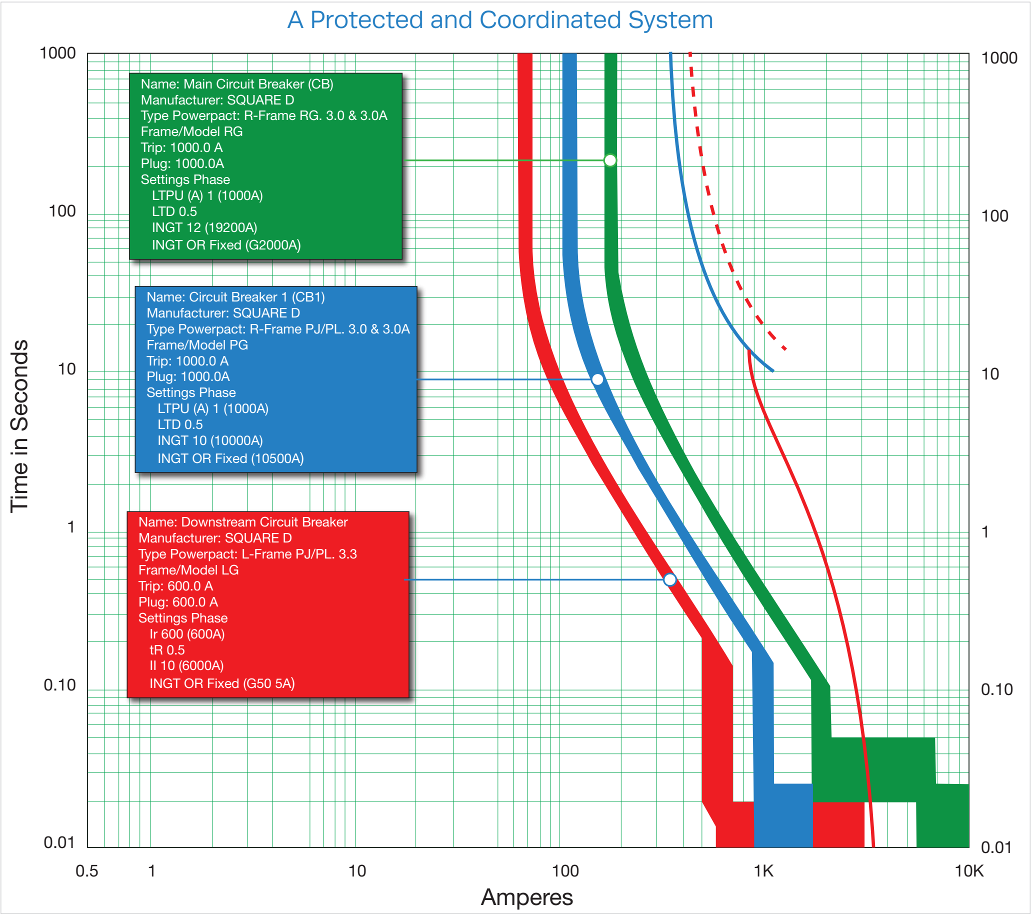


PROTECTED AND COORDINATED SYSTEM

The TCC in *Figure 4* shows a protected and coordinated system. The generator is protected from operating in the damage region by the alternator protection design. It is subsequently protected by the generator's main circuit breaker using the long-trip setting.

The system is also coordinated with other overcurrent devices. The generator's circuit breaker's short circuit and instantaneous settings can be selected and adjusted to allow downstream breakers to trip open. This allows unaffected circuits to continue functioning. The generator's main circuit breaker is the last to trip if the fault persists.

Figure 4



REHLKO ADVANTAGES

COORDINATION SOFTWARE

There are several software applications for power system analysis and coordination that make it easier to design overcurrent and short-circuit current protection schemes. The software contains product libraries of manufacturer's protective device curves and alternator decrement curves to assist engineers in establishing the operating and nonoperating regions for complex power distribution systems. Rehlko® generator model alternators decrement curves, circuit breakers, and alternator guard protection curves can be found in SKM coordination study software.

REHLKO APM603 CONTROLLER

Figure 5 depicts the APM603 controller. It has additional features that assist in the overcurrent protection efforts, including current-limiting settings for alternator and fault protection. With an integral voltage regulator, the APM603 can precisely control alternator excitation. The on-board configuration files have overload and short-circuit protection built in. This is a function of designed setpoints for maximum protection of the generator.

The system is also coordinated with other overcurrent devices. The generator's circuit breaker's short circuit and instantaneous settings can be selected and adjusted to allow downstream breakers to trip open. This allows unaffected circuits to continue functioning. The generator's main circuit breaker is the last to trip if the fault persists.

ARC ENERGY REDUCTION MAINTENANCE

The maintenance mode function is a flexible event subsystem that allows for creating an instantaneous current overload without changing the software. The customer will set these limits based on their load profile permitting a warning present whenever the instantaneous trip or maintenance mode was enabled, which would prevent it from being in "system ready" mode.

The APM603 includes the addition of energy reduction maintenance switching (ERMS) capability, so the controller can be classified as an overcurrent protective device according to NEC 240.87 Arc Energy Reduction.

Figure 5

SUMMARY

The two essential tasks for power systems are (1) to protect and prevent the generator from operating in the damage region and (2) to coordinate with downstream circuit breakers and allow the closest device to remove the faulted circuit before opening the generator circuit breaker.

This is accomplished by looking at the generator's time-current curve which will indicate the short-circuit region and the damage region. The regions are bordered by curves. Typically damage curves would border the damage region, but the controller's alternator protection curve can also be used to avoid the damage region. The short-circuit region is bordered by the generator's decrement curve.

Knowing these regions, curves, and lines will allow the coordination study engineer to identify the protective device settings and design a power system that maximizes the capacity of the system and minimizes the potential of equipment damage and personal injury. It must also be pointed out that time-current curves must not be looked at as absolutes. Lines and curves that border the operating regions only represent nominal values. Real operational values can vary. Manufacturing tolerances, installation methods, and operating environment may have an impact.

Analyzing the time-current curves of the generator set, the controller, and the overcurrent protective devices is essential in ensuring that the generator functions as intended throughout its designed life expectancy. Power systems coordination software allows engineers to perform these tasks more efficiently and be able to present a properly designed power generator system.

The Rehlko® APM603 controller has integral alternator thermal protection to limit the delivered current from exceeding the damage curve. The controller features adjustable settings to and an energy reduction mode setting to meet NEC requirements for arc energy reduction. The controller protection curve model is available in power systems software library or upon request from Rehlko.

ABOUT THE AUTHOR

Al deLeon is a Senior Project Engineer at Rehlko Energy. He holds a bachelor of science degree in electrical engineering from Marquette University. Al joined Rehlko in 2022 with extensive experience in facility design as a consulting engineer for more than a decade. He has been part of engineering teams designing large industrial, commercial, and educational buildings with generator systems. He has also designed wind, hydroelectric, and solar power plants.

ABOUT POWER SYSTEMS

Power Systems, Rehlko's largest division, delivers worldwide energy solutions designed to ensure resilience for mission-critical applications of all sizes. Building on more than a century of expertise and dedication, the company offers complete power systems, including industrial backup generators (HVO, diesel, gaseous), enclosures, hydrogen fuel cells systems, automatic transfer switches, switchgear, monitoring controls, genuine parts and end-to-end services. As a global company with service partners in every country, Power Systems provides reliable, cutting-edge technology to keep industries and businesses running. www.powersystems.rehlko.com

ABOUT REHLKO

A global leader in energy resilience, Rehlko delivers innovative energy solutions critical to sustain and improve life across home energy, industrial energy systems, and powertrain technologies, by delivering control, resilience and innovation. Leveraging the strength of its portfolio of businesses – Power Systems, Home Energy, Uninterruptible Power, Clarke Energy, Heila Technologies, Curtis Instruments, and Engines, and more than a century of industry leadership, Rehlko builds resilience where and when the grid cannot, and goes beyond functional, individual recovery to create better lives and communities, and a more durable and reliable energy future.

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