Time Current Coordination & Calculator Implementation

Jefferson Bronfeld
John Cadick
Cadick Corporation

Abstract

Time current coordination is a method of coordinating the operation of power system protection and control devices. The goals of such a coordination are to protect power system equipment from short circuits, faults and overloads; to minimize system wide impacts of these fault conditions by limiting the affected area; and to accomplish all this while staying out of the way of normal power system operation.

The authors present the graphical method of time current coordination, utilizing the operating and damage curves of typical power system equipment.

The authors follow with a discussion of available computer tools used by power engineers in the accomplishment of time current coordination, with emphasis on the unique role the hand held calculator may have, as differentiated from desk top computer applications.

Introduction

It is said that whereas ships are safe in the harbor, it is not what they were made for.

In the same way, power system protection, must accomplish two seemingly contradictory goals, keep things safe and keep things running. De-energized equipment is safe, but that is not what it was made for.

Electrical equipment can only withstand so much current. While this is fairly obvious, certain pesky questions come up when actually applying equipment in real situations. Let's postulate a device with a continuos rating of say 100 amps. This means that the device is designed to carry (or handle or be exposed to) a maximum of 100 amps, round the clock, incessantly, without end. Does this mean that it will fail if the current momentarily rises to 101 amps? Certainly there is a value at which the device or equipment will fail immediately, and per its rating that value is above 100 amps, but how far above?

Let's be realistic. Such a device could probably withstand a very small overload for a while, and even a significant overload very briefly. This is important because during times of heavy production, when you are making product to beat the band, you would like to be able to operate equipment at full capacity, right up close to that full load capability. Certainly you don't want to trip equipment off line for tiny and momentary excursions above that magic rating number.

On the other hand, you don't want to operate equipment in an unsafe manor, such that it is likely to fail, or even prematurely age.

Protective devices have to accomplish both agendas. They have to allow equipment to operate safely at its rated capacity, and to protect equipment from operating damage due to overload or fault current. Keep it running and keep it safe.

Equipment Failure

Many types of electrical equipment, when exposed to too much current, heat up and eventually melt or burn as a failure mechanism. The equipment's ability to dissipate energy is exceeded, and the excess energy takes the form of heat. Energy going in exceeds energy going out by a certain threshold, and the equipment fails.

Power is the time rate of energy. If it takes so much energy to accomplish something, that thing is accomplished quickly with the application of high power. At a lower power the accomplishment takes longer. Just like velocity is the time rate of distance traveled. If a destination is a certain distance away, to get there in a short period of time you need a high velocity. At lower velocity it takes longer to reach your destination.

If you want to know how far you have gone when you have traveled 60 miles per hour for 2 hours, you just multiply 60 by 2 and get 120 miles. Distance e1quals rate times time. In the same way, we multiply electrical power by its duration to achieve the amount of energy it represents. Energy equals rate times time.

Electrical power is the product of the voltage applied and the current that results.

$$P = E \times I$$

Substituting from Ohms Law

$$E = I \times R$$

we derive the expression for power:

$$P = I^2 \times R$$

So, if power is the current squared time the resistance, we can find the energy absorbed by multiplying this quantity by the time duration. If something is going to be damaged, to melt or burn up, upon absorbing too much energy, the amount of energy which causes damage is proportional to the current magnitude squared multiplied by the time duration of that current, as follows:

$$E_d \propto I^2 \times T$$

Without too much simplification, the damage energy of an electrical component can be portrayed as a parametric curve of the two quantities I and T. This curve is the damage characteristic, and is plotted on a graph of time and current axis. Figure One shows a typical plot. Notice that time is plotted vertically, while the horizontal axis is for current.

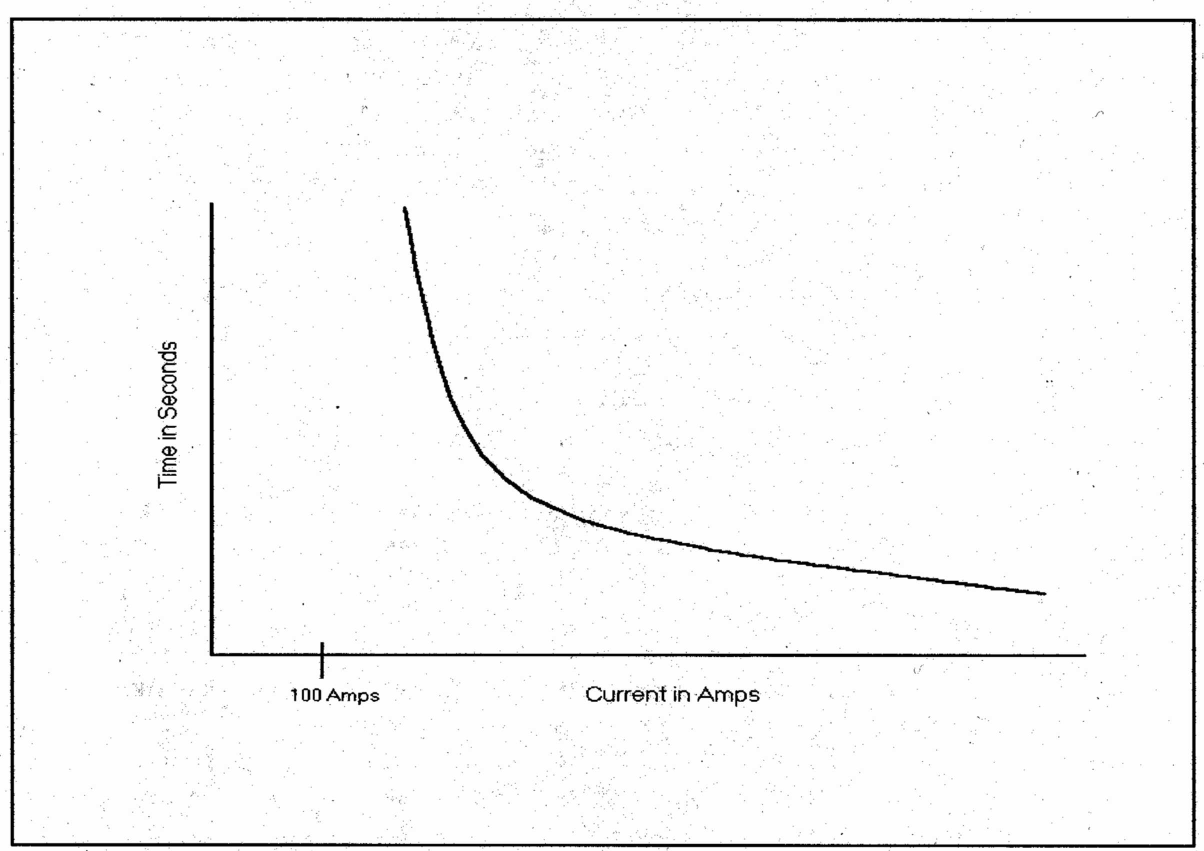


Figure One

Every point on this graph corresponds to a certain amount of current for a certain duration. The parametric curve shown represents all the points where the product $I^2 \times T$ is a particular constant value, i.e. a fixed amount of energy - the damage energy. Every point on the curve represents the amount of energy required to damage the component whose damage characteristic we are graphing. Another way of saying this is that every point on the curve represents an amount of current and the duration of that current, required to cause damage.

The particular curve shown is the damage characteristic of the 100 amp device discussed in the introduction. The curve in fact indicates the current withstand capability of the device. Points above and to the right of the curve denote current magnitudes large enough and lasting long enough to damage the device. Operating points below and to the left are safely accommodated by the equipment. As expected, the device can withstand currents in excess of its 100 amp rating for only short periods of time. Lower current magnitudes can be withstood longer. Notice that a current magnitude below 100 amps can be withstood indefinitely, as we would expect of a device with a continuous rating of 100 amps.

Equipment Protection

One of the earliest and simplest protective devices is the fuse. There is a story that Edison was giving a demonstration of his newfangled electric lights. Someone audience member in the employ of the gas light company had secretly short circuited Edison's display in order to sabotage the entire presentation. Luckily Edison had already invented the fuse, and was employing them in his apparatus. Far from a disaster, the act of sabotage provided Edison an opportunity to demonstrate protective devices.

A fuse, at its most basic, is a piece of metal that is designed and calibrated to self-destruct (and fail in such a way as to open the circuit), when the through current exceeds a certain value for a certain time. The fuse operates on the same mechanism as a device's thermal damage: the fuse is absorbing energy, and if too much energy is absorbed it melts open. A fuse curve will have the same type of inverse, "constant energy" parametric shape as the devices thermal damage curve.

As stated in the introduction, power system protection has to keep the equipment safe, and keep it running. This is accomplished by the method of time-current coordination. The basis of time current coordination is to pick the protective device, in this case a fuse, whose operating characteristic coordinates with the damage characteristic of the equipment.

A correctly sized fuse will have a operating characteristic that when graphed on the same time-current graph as the equipment's damage curve, lies at all points below and to the left it. The fuse is designed to destruct at somewhat less energy than the equipment protected. Very high current, or overcurrent lasting too long, will melt the fuse before the equipment is exposed to damaging currents. The fuse melts; interrupting service to the protected equipment before it is damaged.

Figure Two is a real world example, showing two time current characteristics plotted on the same time-current graph. Note that the graph is log - log. The curve to the left is the operating characteristic of a 125 amp fuse. In this case it is protecting a cable that is rated to carry 187 amps continuously. Note that the fuse characteristic is everywhere to the left and below the cable characteristic, indicating that for a given fault current the fuse will melt and de-energize the cable before the cable experiences enough current long enough to incur any damage.

Other more sophisticated protective devices, overcurrent relays and the like, are designed, by and large, to operate along time-current operating characteristics that emulate the fuse melting characteristic. Originally these devices used an amazing assemblage of springs and gears and induction disks, to replicate the fuse melting characteristic. Modern incarnations of these relays replicate the operating curves digitally. The operating characteristics can be easily manipulated to suit the particular conditions of their application.

Minimizing System Wide Impact

In order to ensure that only the faulted part of the system is de-energized, protective devices are coordinated with each other. The protective device characteristics are staggered in time so that the fuse or relay closest to the fault operates first. Figure Three shows` that if the main fuse responded to a fault on feeder one before the feeder one fuse, feeders two and three would be unnecessarily de-energized. The curves of Figure Four show how the main fuse is selected so that for all current levels it will respond slower than the feeder one fuse. Note also that if for some reason the feeder one fuse were to fail to operate, the main fuse would operate and protect the cable, thus backing up the feeder fuse. In this case de-energizing the other feeders would be unavoidable.

Hand Held Calculator Applications

The procedures used to coordinate relays have changed over the years. Originally time current characteristics were drawn by hand, the engineer plotting points and interpolating between points. The graph paper used was somewhat transparent, so that with the use of a light box you could juxtapose various fuse curves with a particular damage curve to more quickly chose the appropriate fuses.

Personal desk top computers have developed comprehensive software that allows quick plotting of all the various fuses and protective relays, as well as standard damage characteristics for motors, transformers, cables, and other standard power system equipment. One consequence is that rigorous formulas have been developed for the operating characteristics of many devices whose characteristics were in the past determined empirically.

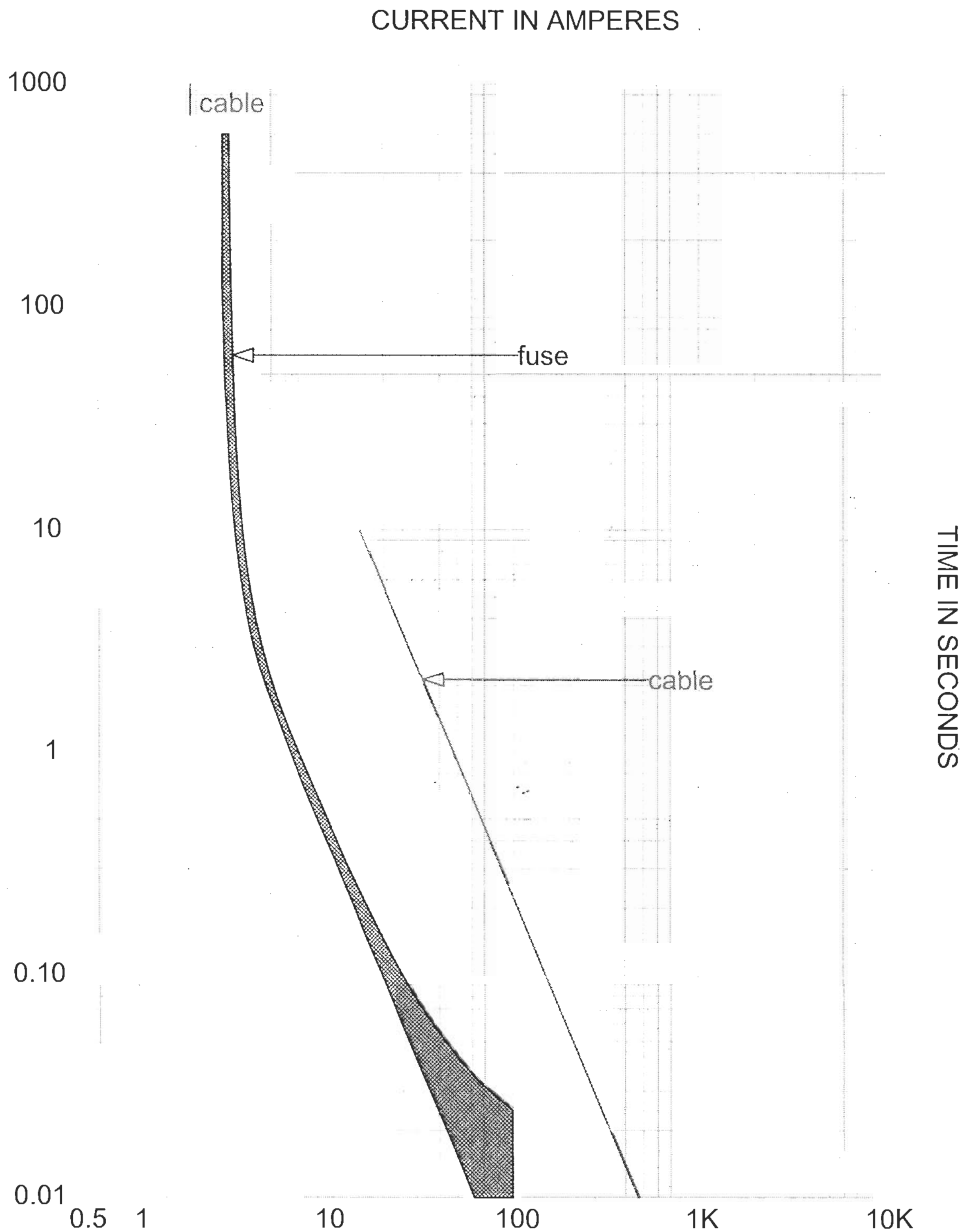
Time current coordination still requires a visual representation of the operating and damage characteristics, to allow the power engineer to pick the correct values for fuses and protective devices and make the proper engineering compromises where there is no clear "right answer". There is as much art as there is science to coordination studies, and we have not yet been able to develop software that can automate the entire system wide protective device coordination study.

Recent developments in the graphical displays of hand held calculators present a very real opportunity to perform or check protective device coordination in the field. The mathematical representation of operating and damage curves now by and large exists and could very straightforwardly be programmed into a hand held graphical calculator. The displays are clear and precise enough to quickly and accurately display the required curves and show the curves' response to changes in settings and device characteristics.

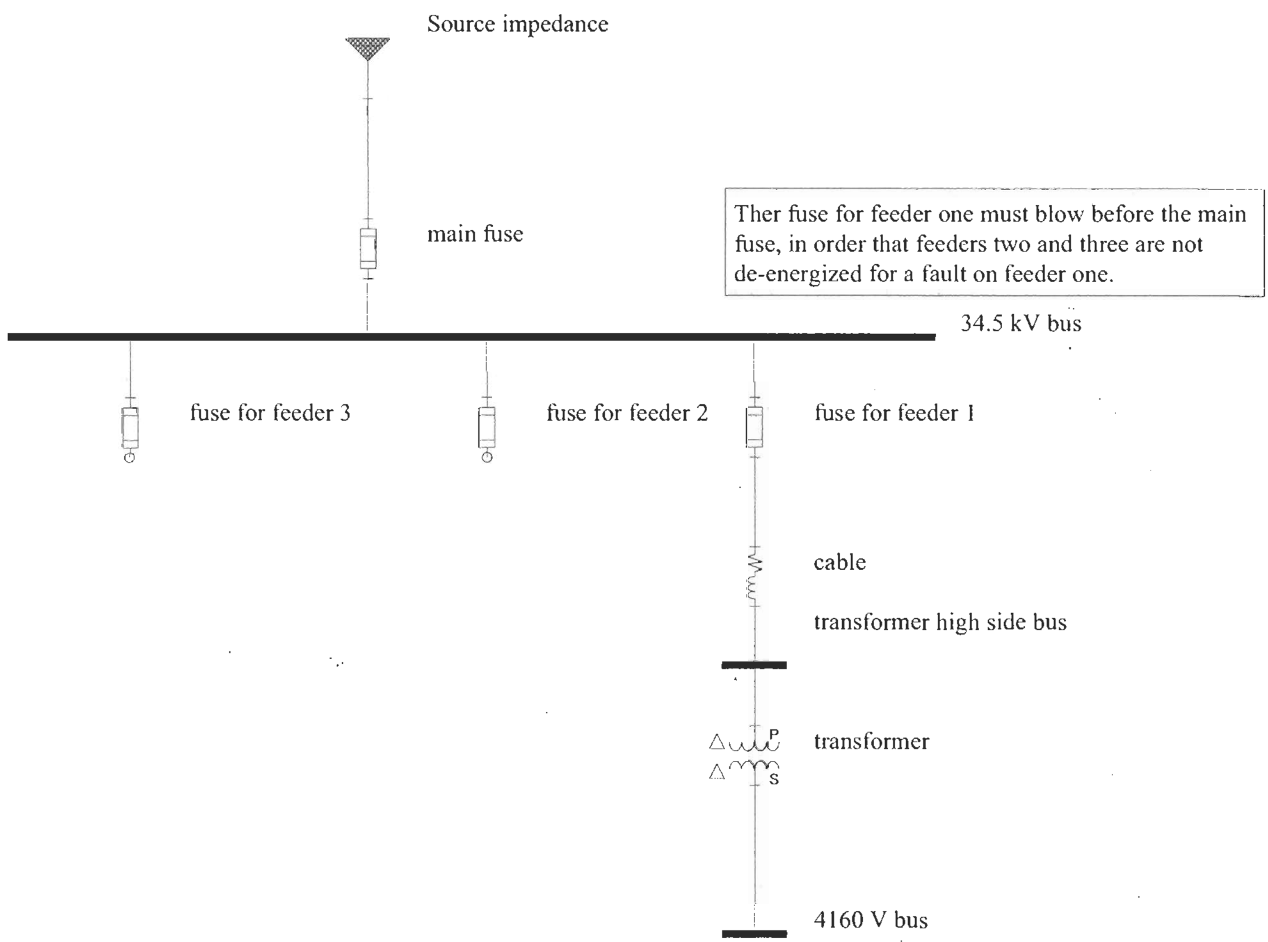
At present the coordination is done at the engineers desk, using a digital model of the power system, and the results are communicated to field technicians, who then apply the device settings and required fuses. Any unexpected field conditions, unforseen equipment limitations, or system data anomalies discovered in the field are communicated back to the engineers, who then make the setting changes necessary and send the results back to the field. Graphical calculators enabled with time current coordination software would provide the following advantages:

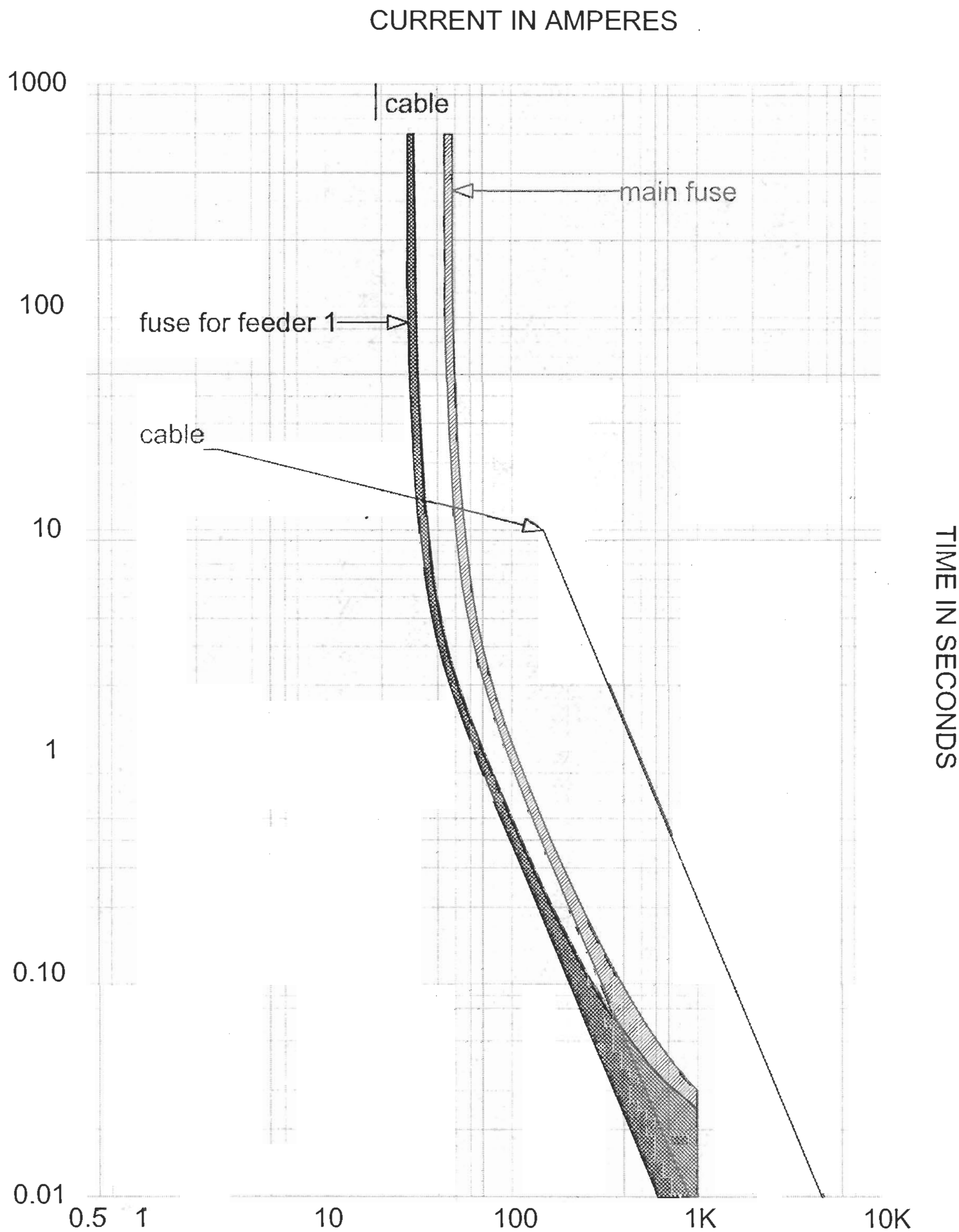
- Field engineers could determine setting changes while still in the field, upon discovery of unforseen circumstances that need to be accommodated.
- Old facilities where equipment may have been upgraded or replaced can be field inspected, and any changes to fuses or protective devices could be determined on the spot.
- Specific "what if" analysis could be accomplished in the field when questions arise, rather than waiting for desk engineers to "get back to you".

In all fields, hand held calculators are invaluable even to the desk bound engineer. The calculator is used to add accuracy to the engineers' on the fly judgements and ball park estimations. Later the desk top software is used to confirm or more finely tune the answers. A calculator enabled with time current coordinating and graphing ability would enhance the engineers' abilities to quickly respond to real power system problems in a discipline still very tied to sophisticated comprehensive analysis software.



fuse & cable.tcc Ref. Voltage: 34500 Current in Amps x 100


Source impedance
main fuse
Ther fuse for feeder one must blow before the main fuse, in order that feeders two and three are not de-energized for a fault on feeder one.
34.5 kV bus
fuse for feeder 3
fuse for feeder 2
fuse for feeder 1
cable
transformer high side bus
P
S
transformer
4160 V bus



main fuse coordination.tcc   Ref. Voltage: 34500   Current in Amps x 10