APPENDIX G

COORDINATION EXAMPLES

G-1. General

This appendix contains nine coordination exampies. Figure G-1 shows the general arrangement of the electrical system examined by these examples. As shown in figure G-1, a 115kV double-ended commercial power substation transforms the incoming 115kV down to 12.47kV. Two, three-phase, 12.47kV aerial distribution lines supply 480V industrial facility loads through distribution transformers connected delta primary and solidly-grounded wye secondary. Two, impedance-grounded, on-site generators, rated 1250kVA at 12.47kV, are connected to the 15kV switchgear bus. A wye-delta, 12.47kV-4.l6kV transformer is shown supplying a 500Hp, 4000V motor using reduced-voltage motor control. Figure G-2 shows a detailed view of the various loads supplied by 15kV switchgear feeder number 4. Figure G-3 shows a detailed view of the various loads supplied by 15kV switchgear feeder number 7. A wide variety of protective equipment types is shown to illustrate the diversity of protective device applications and coordination requirements. Such a combination of protective devices might not normally be found in practice. Figure G-2 illustrates the application of low-voltage fuses, medium-voltage fuses, and motor circuit protectors. Figures G-3 illustrates the application of low-voltage circuit breakers and medium-voltage fuses. Other examples, using figure G-1, illustrate the application of medium-voltage motor protection, medium-voltage generator protection, and medium-voltage system protection using circuit breakers and relays. The following list summarizes the examples included in this appendix:

- Example 1— Low-voltage motor protection using inverse-time circuit breakers.
- Example 2 — Low-voltage motor protecting using motor circuit protectors (MCP).
- Example 3 — Low-voltage motor protection using fused switches.
- Example 4 — Low-voltage ground-fault protection.
- Example 5 — Impedance diagram and short-circuit calculations.
- Example 6 — Medium-voltage transformer protection using fuses.
- Example 7 — Medium-voltage motor protection using reduced-voltage motor control.
- Example 8 — Medium-voltage generator protection.
- Example 9 — Phase overcurrent protection using protective relays.

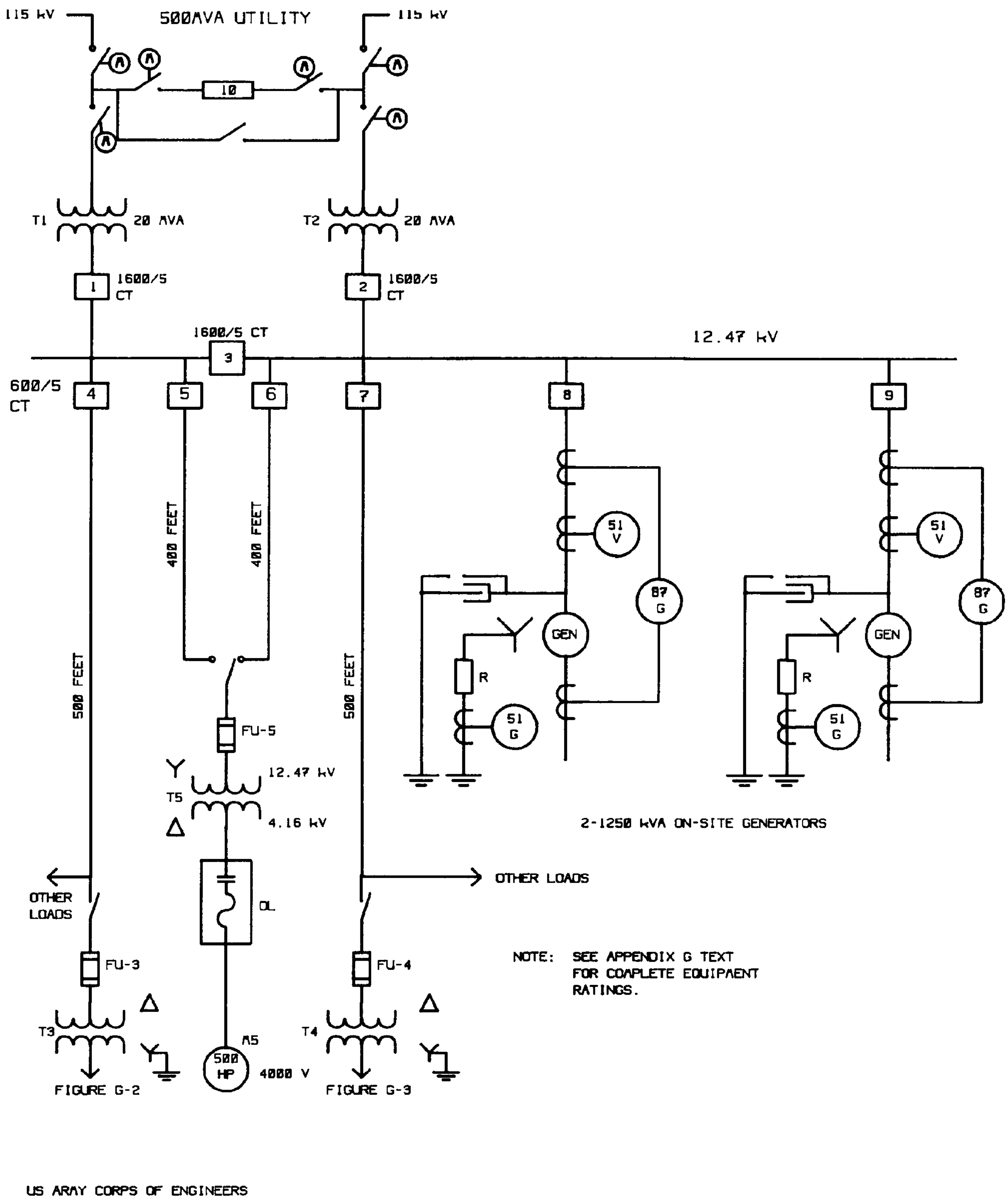


Figure G-1. Example electrical system.

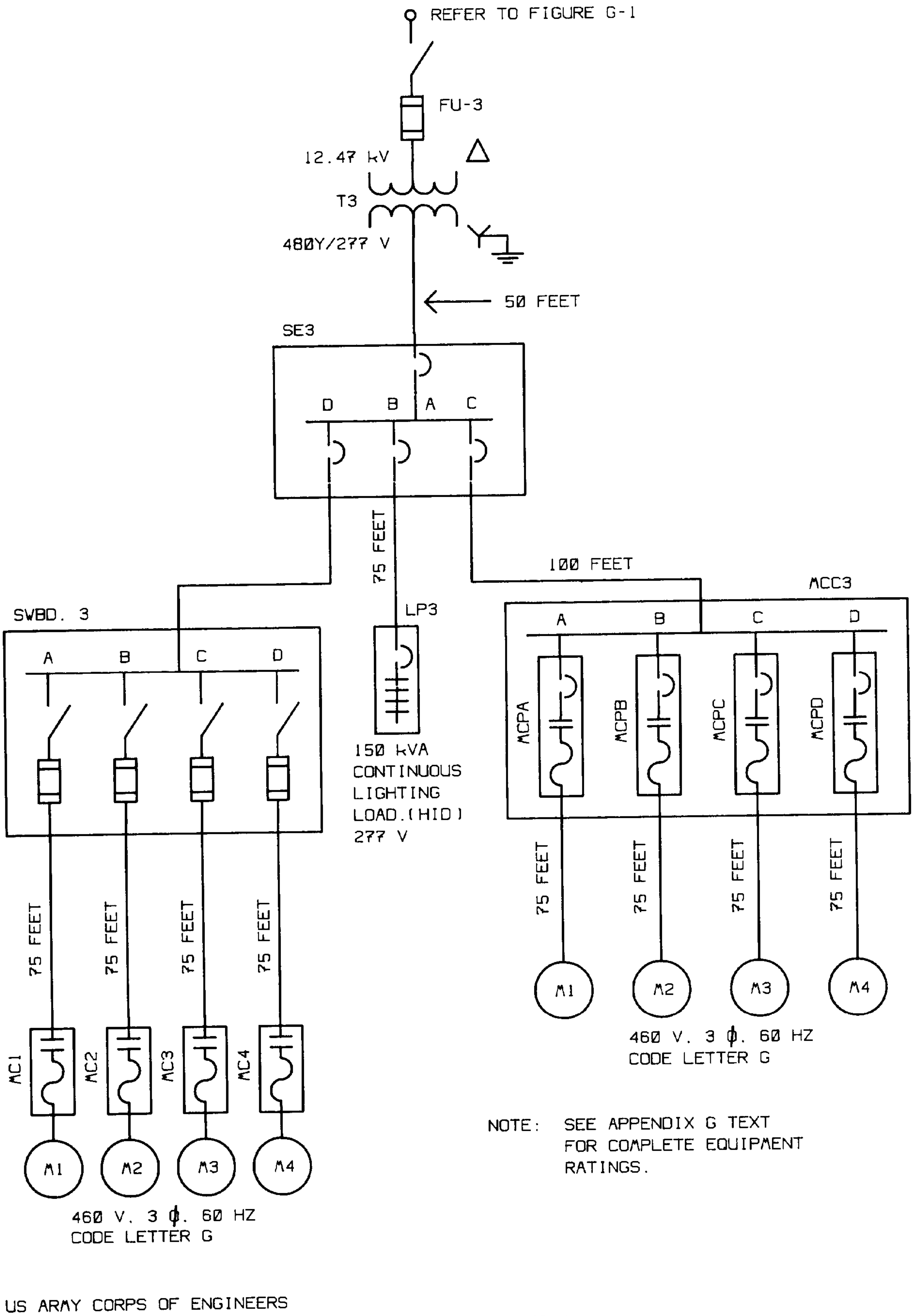


Figure G–2. 15kV switchgear feeder No. 4.

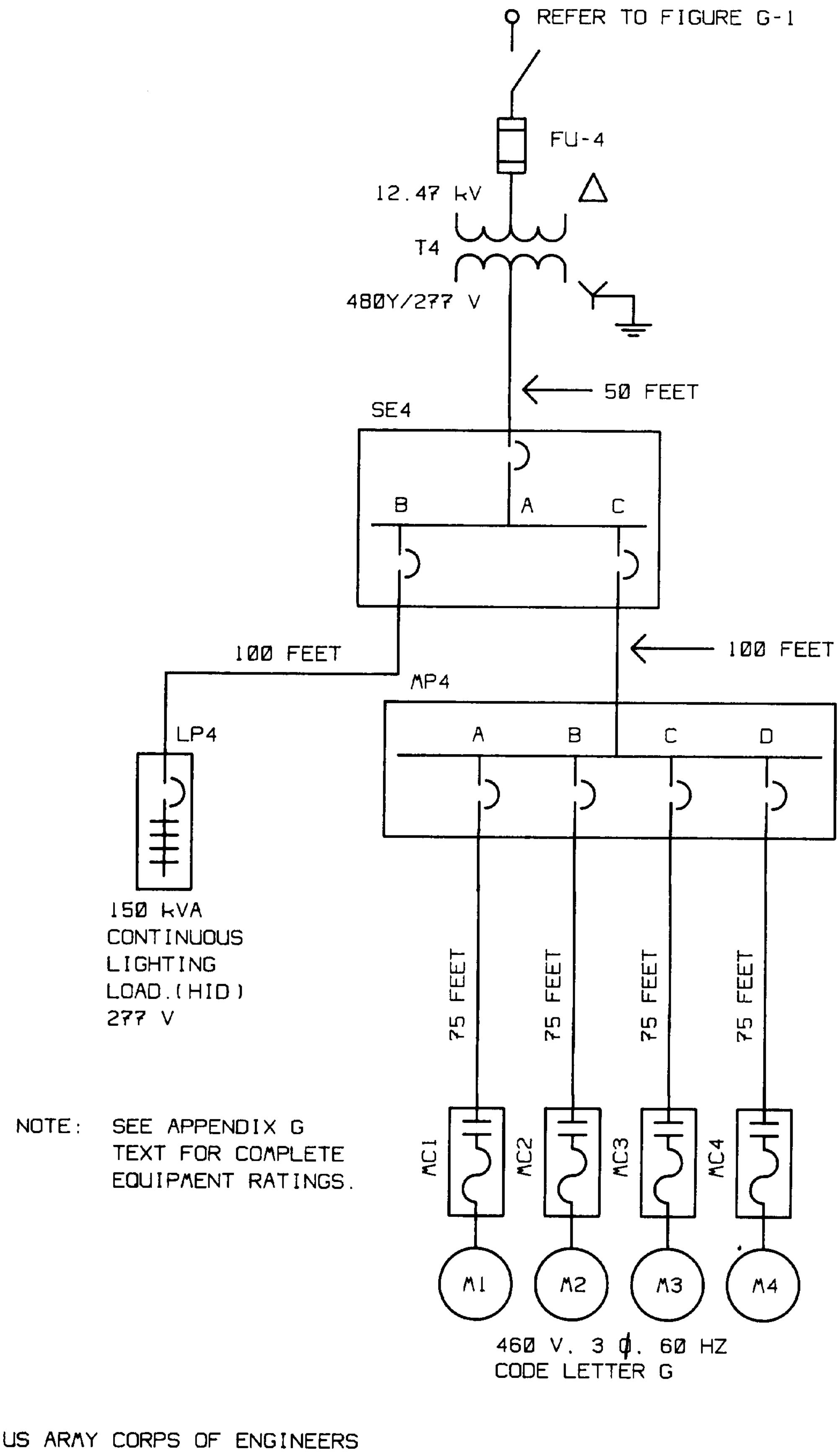


Figure G-3. 15kV switchgear feeder No. 7.

G-2. Equipment ratings

The following list summarizes the various equipment ratings used in figures G-1, G-2, and G-3:

M1— 15-HP Squirrel-cage induction motor (SCIM), 30, 60Hz, 460V, Code letter G.
M2 — 25-HP SCIM, 30, 60Hz, 460V, Code letter G.
M3 — 30-HP Wound-rotor induction motor (WRIM), 30, 60Hz, 460V, Code letter G.
M4 — 50-HP SCIM, 30, 60Hz, 460V, Code letter G.
MS — 500-HP SCIM, X"=20%, X'=50%, X=125%.
T1 — 20MVA, 8% impedance.
T2 — 20MVA, 8% impedance.
T3 — 750kVA, 5% impedance.
T4 — 500kVA, 4% impedance.
T5 — 500kVA, 4% impedance.
G1 — 1250kVA, 1000kW, 0.8 power factor, 12.47kV. Xd"=20%, Xd'=35%, Xd=100%.
G2 — 1250kVA, 1000kW, 0.8 power factor, 12.47kV. Xd"=20%, Xd'=35%, Xd=100%.

G-3. Example 1—Low-voltage motor protection using thermal-magnetic circuit breakers

a. Refer to figure G-3 for circuit diagram.

b. Using figure 5-13, the following step-by-step procedure for designing motor circuit protection can be developed:

(1) Step 1. Determine full load amps (FLA), locked rotor amps (LRA), and nameplate amps (NPA) for each motor, M1 through M4.

(a) $M1_{FLA}$= 21A (from NFPA 70)
$M2_{FLA}$= 34A (from NFPA 70)
$M3_{FLA}$= 40A (from NFPA 70)
$M4_{FLA}$= 65A (from NFPA 70)

(b) Locked-rotor kVA per horsepower for a code letter G motor is 6.29 (per NFPA 70). Equations G-1 through G-4 show how to calculate LRA for each motor M1 through M4.

$M1_{LRA}$=(LR kVA)/(1.73)(kV) . (eq G-1)
$M1_{LRA}$=(6.29)(15)/(1.73)(.460= 119A. (eq G-1)
$M2_{LRA}$=198A . . . . (eq G-2)
$M3_{LRA}$ = 237A . . . . (eq G-3)
$M4_{LRA}$=395A . . . . (eq G-4)

(c) Nameplate amperes must be determined directly from the motor nameplate. Since this information is not normally available early in the design stages, motor overload protection cannot be determined at this time. Motor overload protection cannot be determined until the motors are actually delivered to the site.

(2) Step 2 Select branch circuit conductors. Conductor ampacity = (1.25)(FLA). The following AWG sizes were selected subject to voltage drop and through-fault withstand.

Circuit MP4-A: (21A)(1 .25) 26.25A. Use #10 AWG.

Circuit MP4-B: (34A)(1.25)=42.5A. Use #6 AWG.

Circuit MP4-C: (40A)(1.25)=50.0A. Use #6 AWG.

Circuit MP4-D: (65A)(1 .25) 81 .25A. Use #3AWG.

(3) Step 3. Select feeder circuit conductors. Conductor ampacity = (1.25) (Largest FLA) + (Remaining FLAs). Of course, circuit conductors should be selected to match bus ratings to obtain optimum system capacity.

SE4-C: (65A)(1.25) + 40A + 34A + 21A = 176.25A. Use 250 MCM minimum since feeder circuit breaker will be set at 250A.

(4) Step 4. Select branch circuit short-circuit protection. Maximum setting is (2.50)(FLA) for squirrel-cage induction motors and (1.50)(FLA) for wound-rotor induction motors per NFPA 70.

Circuit MP4-A: (21A)(2.50) = 52.5A. Use 60A maximum.

Circuit MP4-B: (34A)(2.50) 85.0A. Use 90A maximum.

Circuit MP4-C: (40A)(1.50) = 60.OA. Use 60A maximum.

Circuit MP4-D: (65A)(2.50) = 162.5A. Use 175A maximum.

(5) Step 5. Select feeder circuit short-circuit protection. Maximum setting is (Largest branch circuit device setting) + (Remaining FLAs).

SEA-C, 175A + 40A + 34A + 21A = 270A. Therefore, use 250A maximum unless future capacity is designed into the feeder circuit.

(6) Step 6. Select disconnecting means in accordance with NFPA 70.

(7) Step 7. Using NPA, select overload protection in accordance with NFPA 70. For these motors, overload protection should not exceed (1.25)(NPA).

c. Figures G-4 through G-7 show motor starting curve, motor overload curve, and motor short-circuit protection curve for each motor. As can be seen from the coordination curves, the NFPA 70 settings that were selected are maximum settings and, in many cases, largely oversized. The trip rating of each circuit breaker can be reduced as long as the respective characteristic curves do not overlap with the respective motor starting curves. If adjustable magnetic (instantaneous) trips are available on the circuit breakers, then overcurrent protection can be "fine-tuned," with this adjustment, by overlaying the time-current characteristic curves.

d. Lighting circuit. FLA for the continuous lighting load of the LP4 lighting panel is calculated as shown in equation G-5. Overcurrent protection for LP4 and SEC4-B is shown below:

$LP4_{FLA}$ = (kVA)/(1.73)(kV) = (150)/(1.73)(.480)=180A (eq G-5)

Circuit LP4: (180AX1.25)=225A.

Circuit 5E4-B: Use 225A circuit breaker and #4/0 AWG feeder circuit conductors.

e. Main transformer and service entrance equipment. For 5E4-A, 175A + 40A + 34A + 21A + (125)(180A)=495A. Therefore, use 450A circuit breaker unless future capacity is designed into the system. Use 2-#4/0 AWG in parallel for service conductors. For transformer T4, (450A)(.480kV)(1.73) = 374kVA. Therefore, use 500kVA.

f. Figure G-8 shows the composite, time-current curves for this system. For simplicity, the starting curve, overload protection curve, and short-circuit protection curve for motor M4 only is shown. As discussed in the TM, these device ratings are NFPA 70 maximums. The time-current curves show that lower values can be used. Remember, the objective is to select optimum time and current settings, not to comply with NFPA 70 maximums. Refer to example 6 for procedures for selecting FU-4.

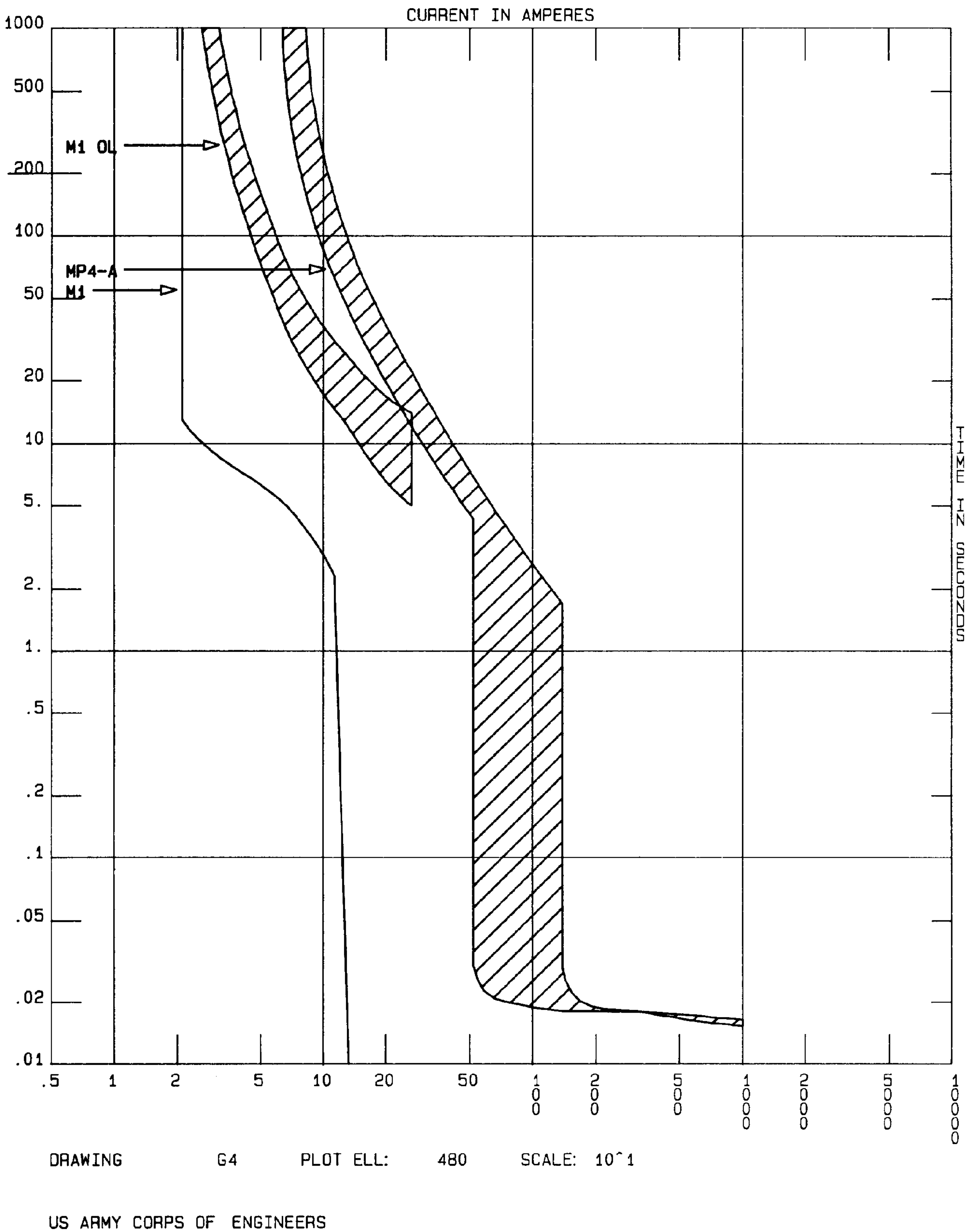


Figure G-4. M1 starting, overload, and CB short-circuit protection curves.

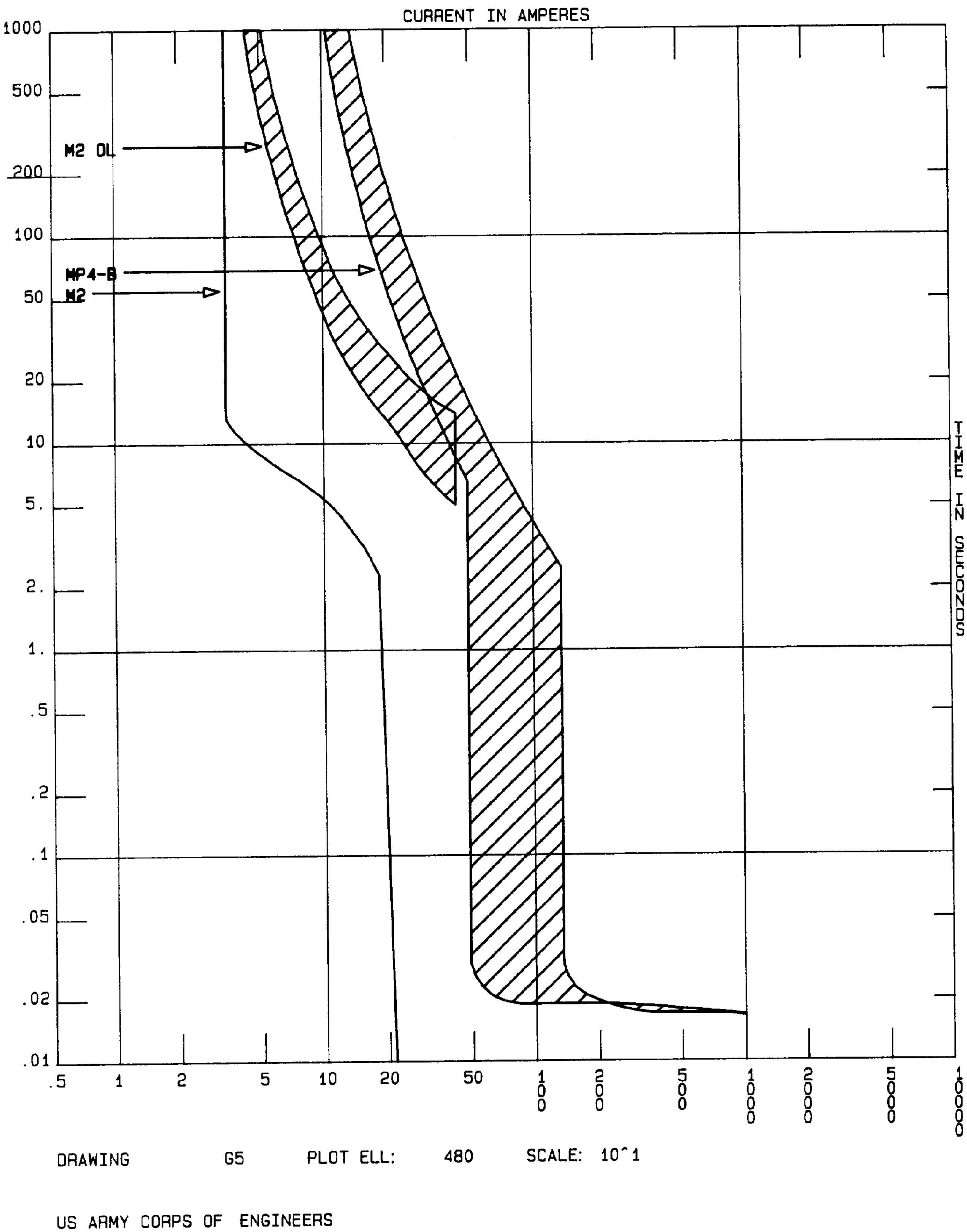


Figure G–5. M2 starting, overload, and CB short-circuit protection curves.

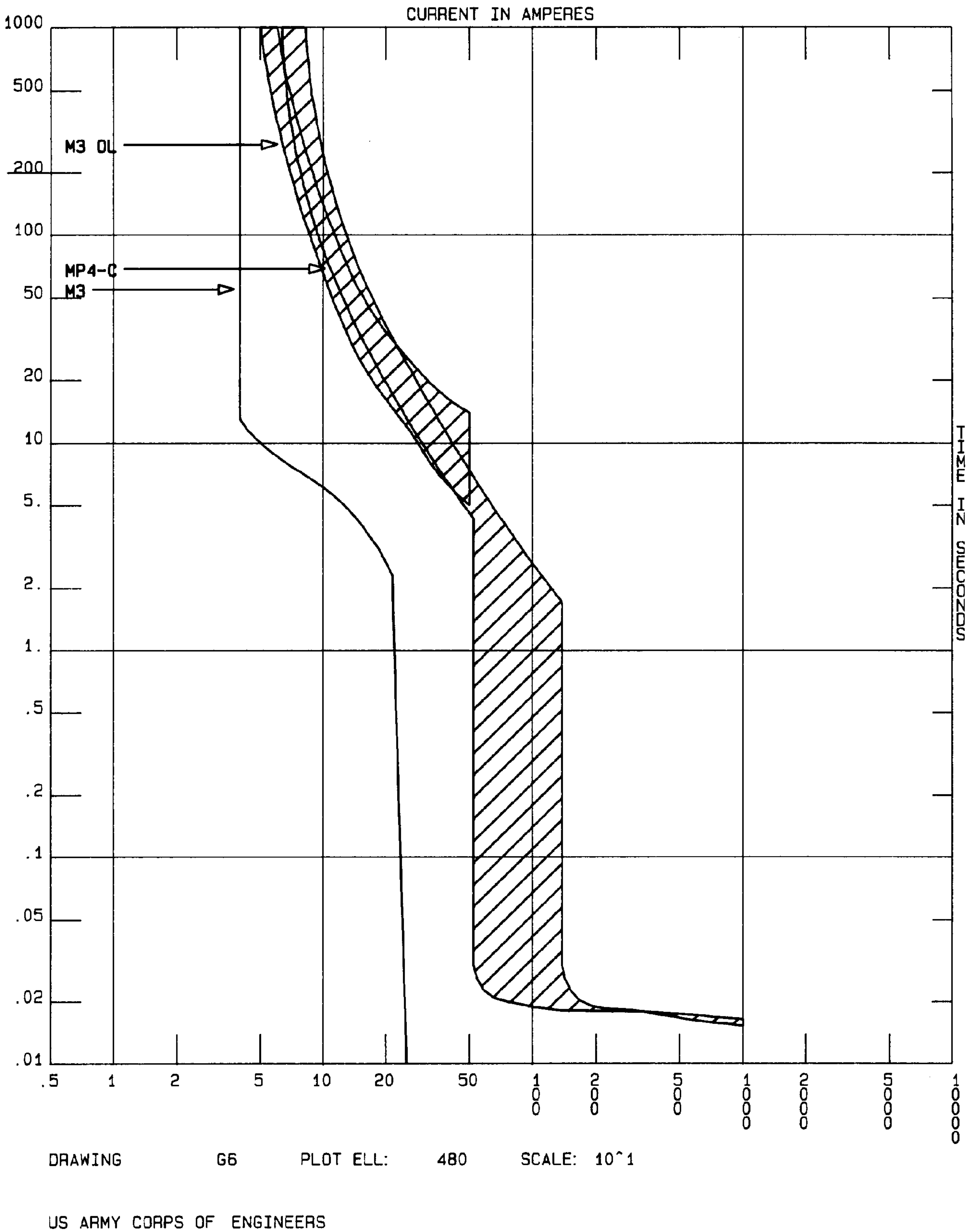


Figure G-6. M3 starting, overload, and CB short-circuit protection curves.

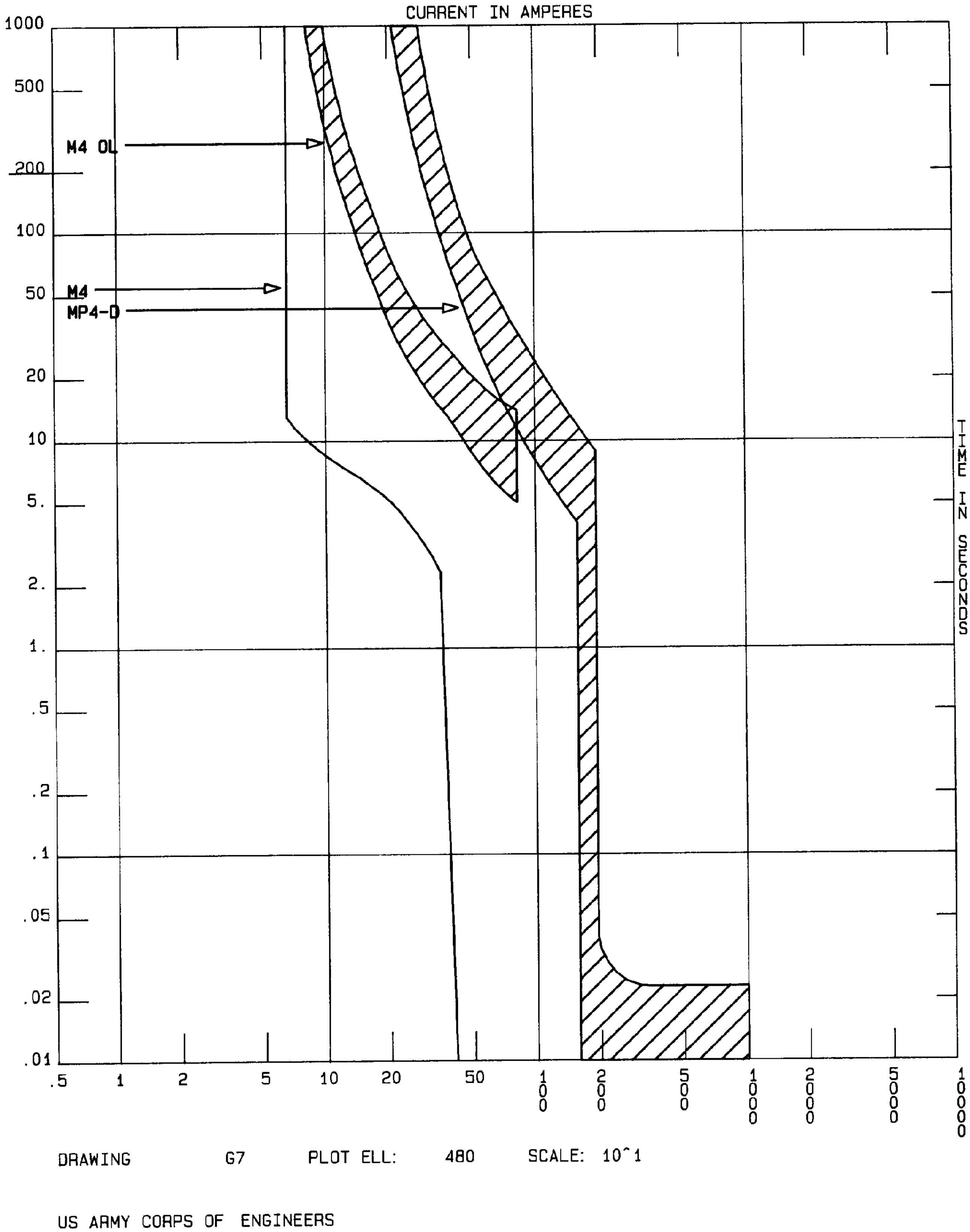
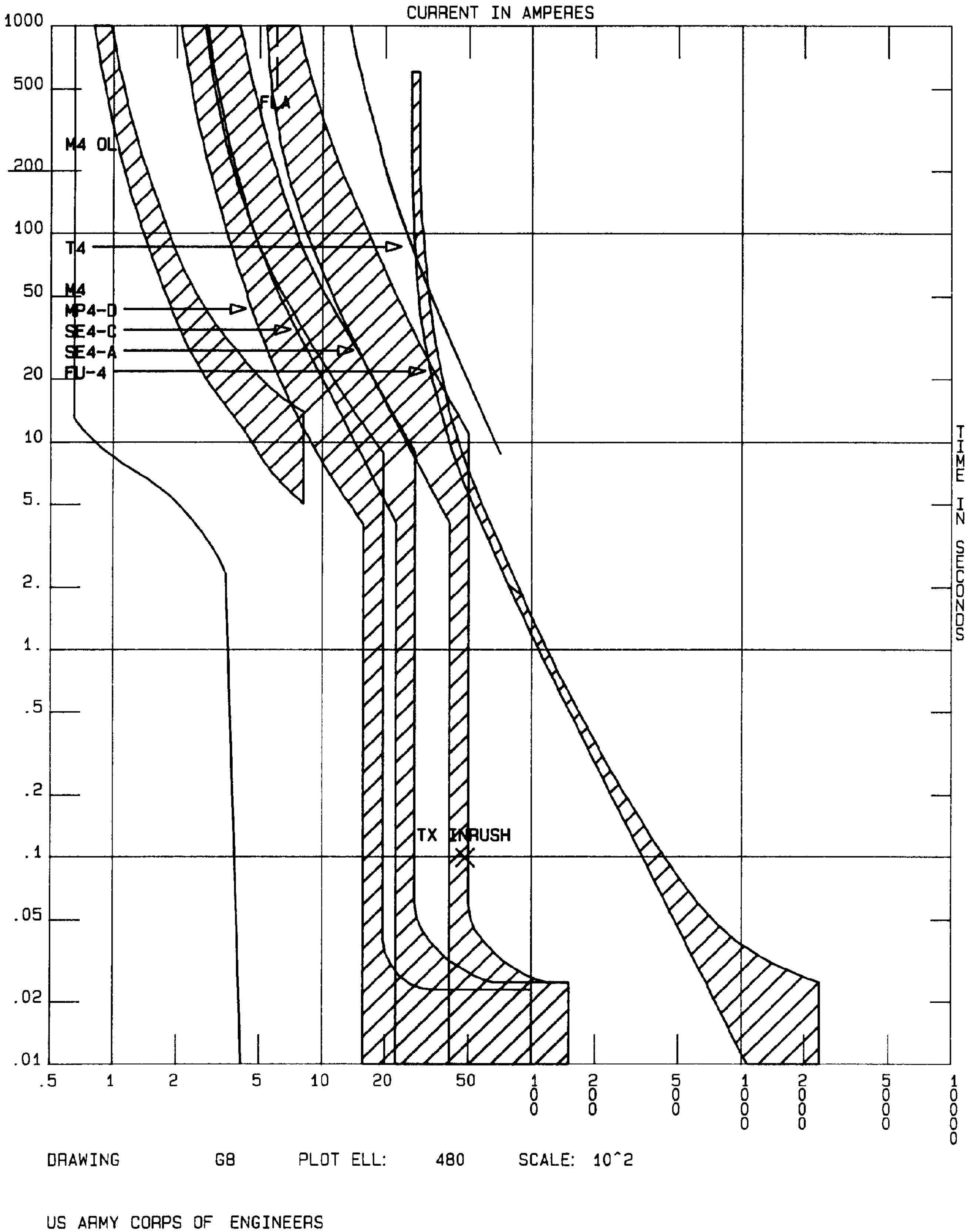


Figure G-7. M4 starting, overload, and CB short-circuit protection curves.



G–8. Composite time-current curves for Example 1.

G-4. Example 2—Low-voltage motor protection using motor circuit protectors.

a. Refer to figure G-2 for circuit diagram.

b. Using figure 5-13, the following step-by-step procedure for selecting motor circuit protection can be developed:

(1) Step 1. Determine full-load amps (FLA), locked rotor amps, and nameplate amps (NPA) for each motor, M1 through M4.

(a) $M1_{FLA}$ = 21A (from NFPA 70).
$M2_{FLA}$ =34A (from NFPA 70).
$M3_{FLA}$ = 40A (from NFPA 70).
$M4_{FLA}$ = 65A (from NFPA 70).

(b) Locked-rotor kVA per horsepower for a code letter G motor is 6.29 (per NFPA 70). Equations G-6 through G-9 show how to calculate LRA for each motor M1 through M4.

$M1_{LRA}$ = (LRkVA)/(1.73)(kv) (eq G-6)
$M1_{LRA}$ = (6.29)/(15/(1.73)(.460)=119A (eq G-6)
$M2_{LRA}$ = 198A (eq G-7)
$M3_{LRA}$ = 237A (eq G-8)
$M4_{LRA}$ = 395A (eq G-9)

(c) Nameplate amperes must be determined directly from the motor nameplate. Since this information is not normally available early in the design stages, motor overload protection cannot be determined at this time. Motor overload protection cannot be determined until the motors are actually delivered to the site.

(2) Step 2. Select branch circuit conductors. Conductor ampacity = (1.25)(FLA). The following AWG sizes were selected subject to voltage drop and through-fault withstand:

Circuit MCC3-A: (21A)(1 .25) = 26.25A. Use #10 AWG.

Circuit MCC3-B: (34A)(1.25)=42.5A. Use #6 AWG.

Circuit MCC3-C: (40A)(l.25)=50.0A. Use #6 AWG.

Circuit MCC3-D: (65AX1 .25) = 81.25A. Use #3 AWG.

(3) Step 3. Select feeder circuit conductors. Conductor ampacity=(1.25)(Largest FLA) + (Remaining FLAs). For 5E4-C, (65A)(1.25%) + 40A + 34A + 21A = 176.25A. Therefore, use 25 MCM minimum since feeder circuit breaker will be set at 250A.

(4) Steps 4, 6, and 7. Motor circuit protectors (MCP) must be large enough (frame rating) to qualify as a motor disconnecting means. Therefore, frame rating requirements for each motor will be as follows:

M1: (1.15X21A)=24.15A. Use l00A frame.
M2: (1.15)(34A)=39.01A. Use l00A frame.
M3: (1.15)(40A)=46.0A. Use 100A frame.
M4: (1.15)(65A)=74.75A. Use l00A frame.

(5) Each pole of the MCP contains a current sensing element to trip the circuit breaker instantaneously when this current setting is exceeded. It is recommended that the MCP be set not less than two times the motor locked rotor amperes (LRA). NFPA 70 limits the maximum setting of the MCP to not greater than 13 times the motor full-load amperes (FLA). Therefore, MCP settings for each motor will be as follows:

Circuit MCC3-A: (119A)(2.0)=238A. Std. setting 240A.

Circuit MCC3-B: (198A)(2.0) = 396A. Std. setting 390A.

Circuit MCC3-C: (237A)(2.0)=474A. Std. setting 420A.

Circuit MCC3-D: (395A)(2.0)=790A. Std. setting 804A.

(6) The MCP must include motor overload protection and short-circuit protection in the same enclosure. Overload protection for these motors should not exceed 125 percent of motor nameplate amperes (NPA).

(7) Step 5. Select feeder short-circuit protection. Maximum setting should not exceed that calculated in step 5, example 1. Use 250A maximum unless future capacity is designed into the system.

c. Figures G-9 through G-12 show motor starting curve, motor overload curve, and MCP short-circuit protection curve for each motor.

d. Main transformer and service entrance equipment. Main circuit breaker, 5E3-A, must supply the four motors at SWBD3, the four motors at MCC3, and the 150kVA lighting load. The largest fuse in SWBD3 is 200A (SWBD3-D). Refer to example 3. For 5E3-A, 200A+65A+2(40A)+2(34 A) + 2(21A) + (l.25)(180A) = 680A. Therefore, use 600A circuit breaker unless future capacity is designed into the system. For transformer T3, (600A)(.480kV)(1 .73) = 518.4kVA. Therefore, use 750 kVA.

e. Figure G-13 shows the composite, time-current curves for this system using MCPs. For simplicity, only motor M4 is shown. As discussed in the TM, these device ratings are NFPA 70 maximums. The time-current curves show that lower values can be used. Remember, the objective is to select optimum time and current settings, not to comply with NFPA 70 maximums. Refer to Example 6 for procedures for selecting FU-3.

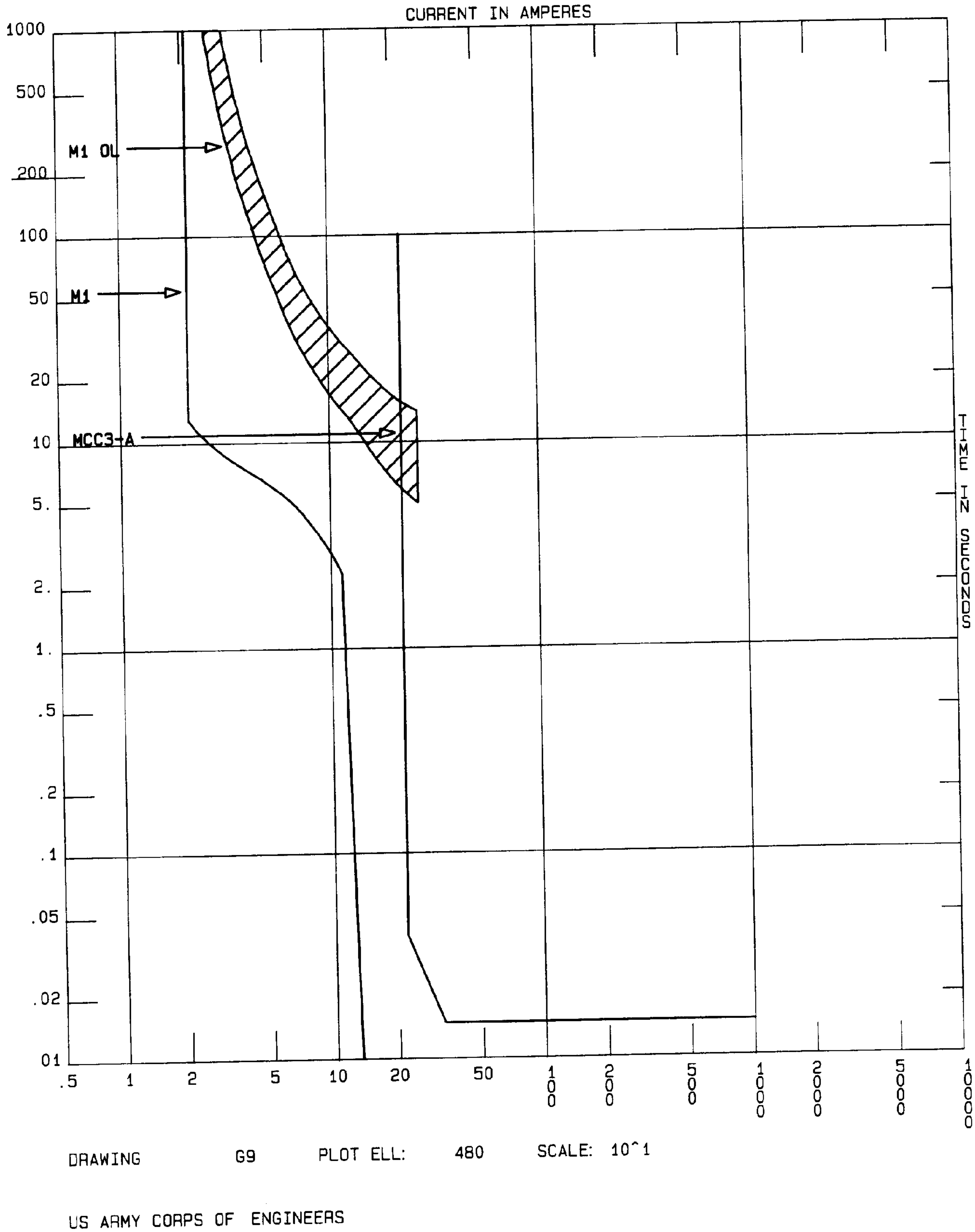


Figure G–9. M1 starting, overload, and MCP short-circuit protection curves.

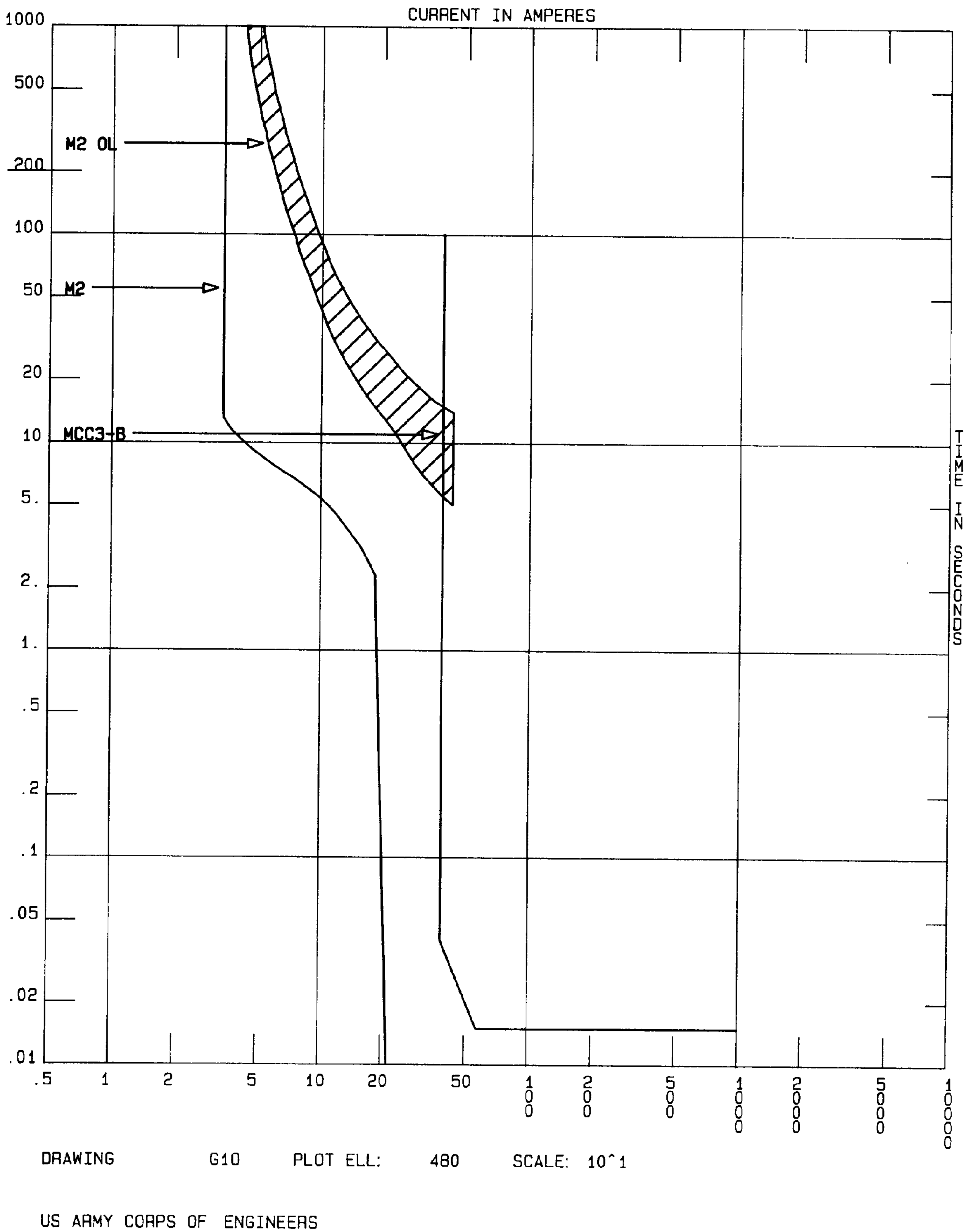


Figure G–10. M2 starting, overload, and MCP short-circuit protection curves.

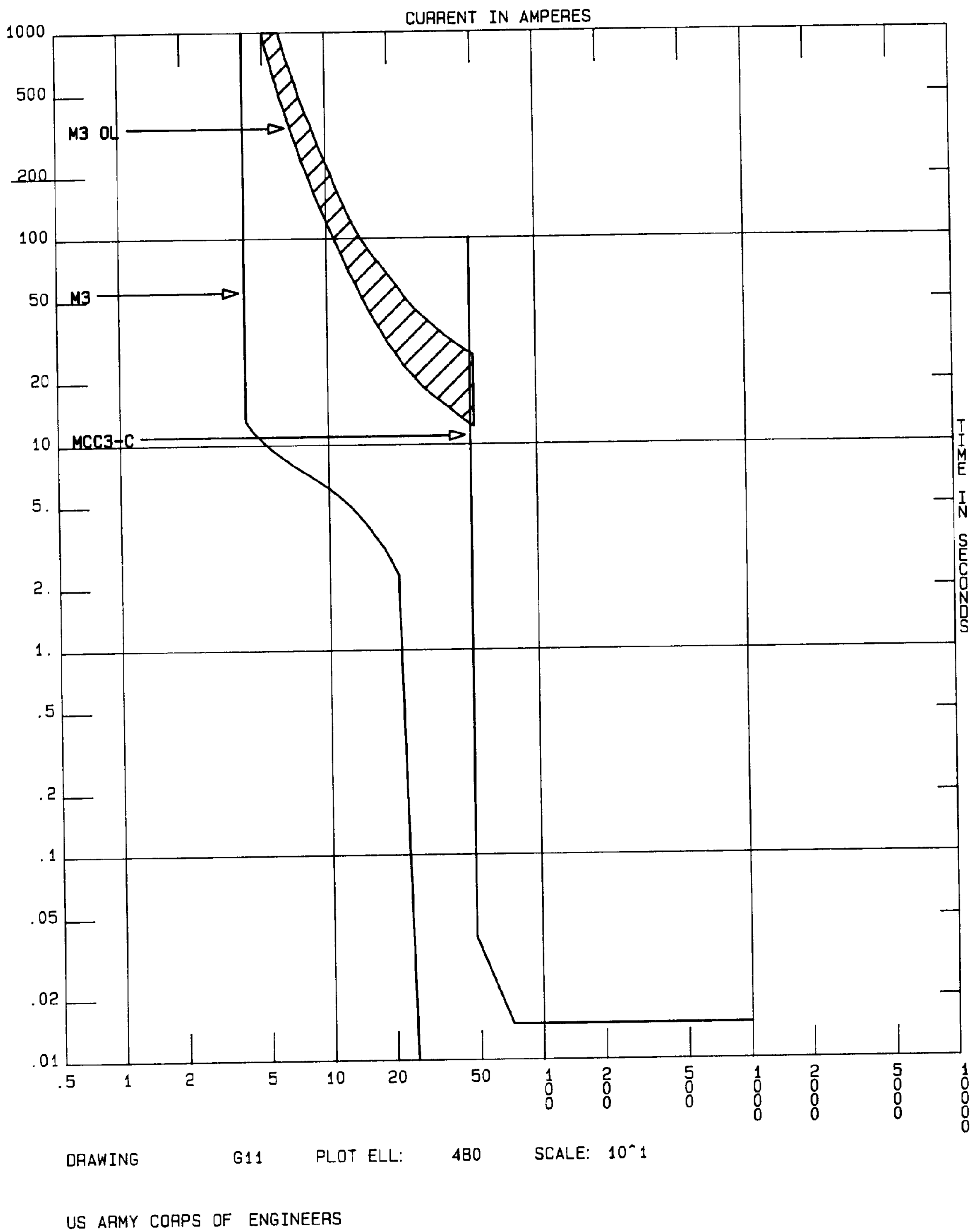


Figure G-11. M3 starting, overload, and MCP short-circuit protection curves.

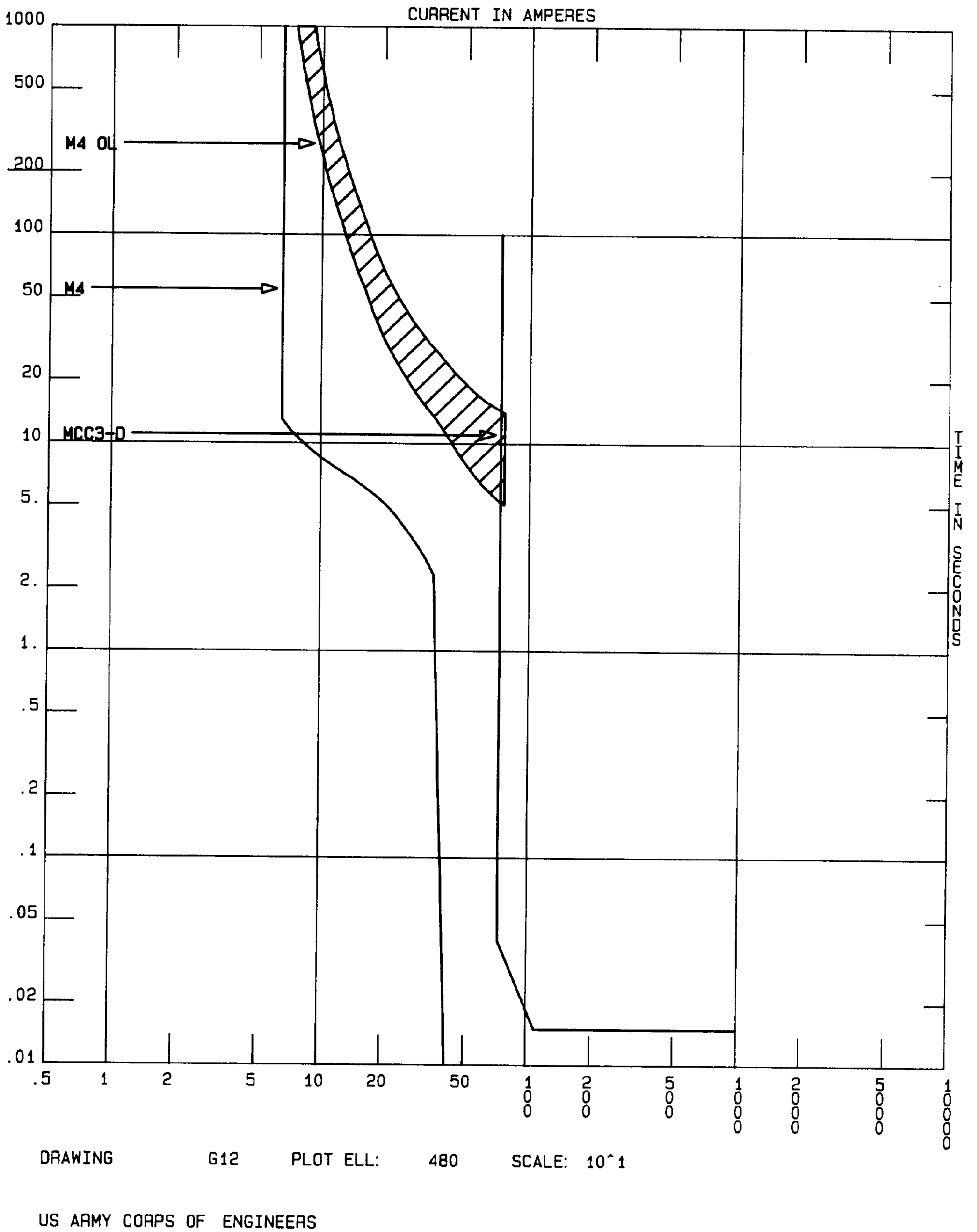


Figure G-12. M4 starting, overload, and MCP short-circuit protection curves.

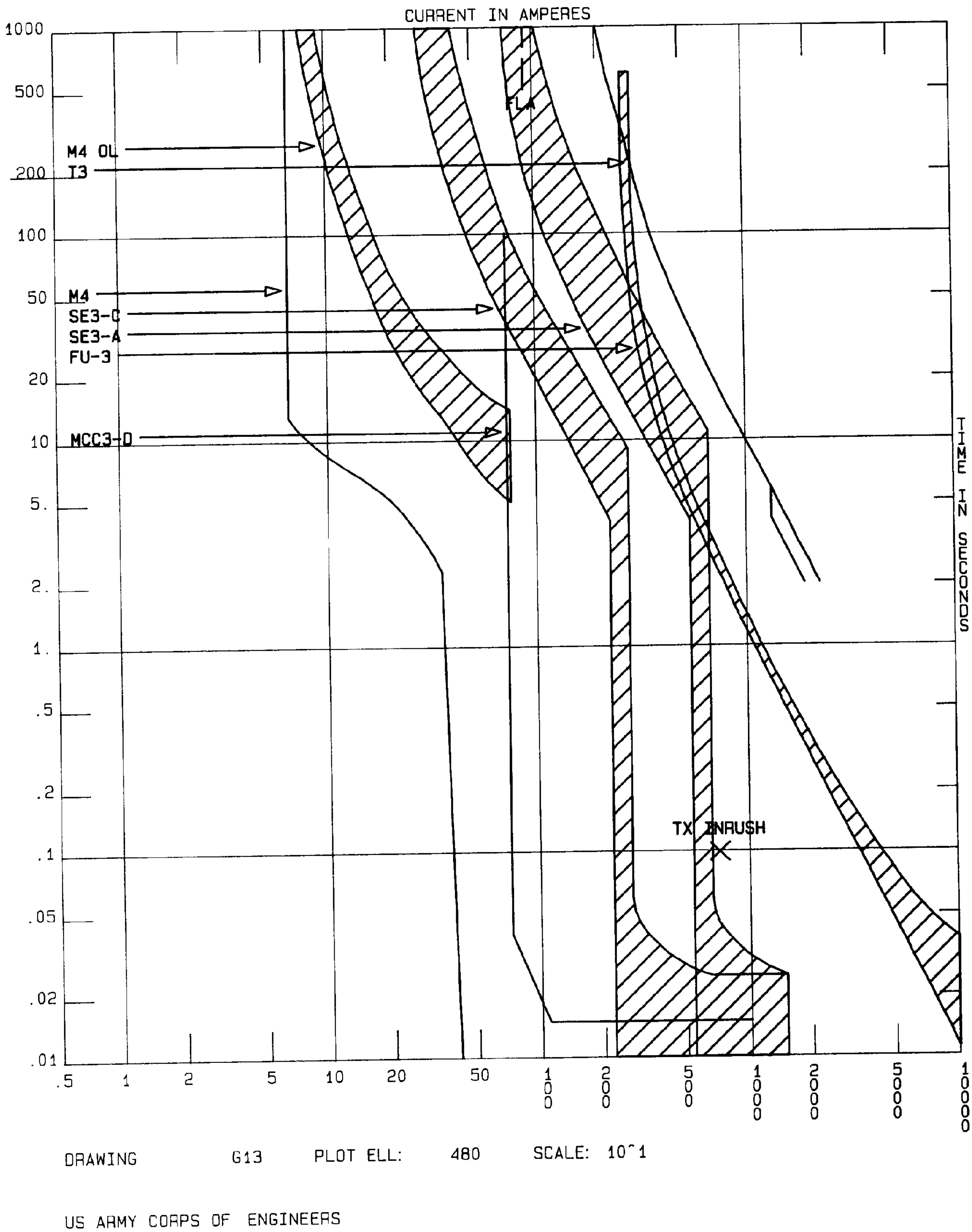


Figure G-13. Composite time-current curves for Example 2.

G-5. Example 3—Low-voltage motor protection using fused switches

a. Refer to figure G-2 for the circuit diagram.

b. Using figure 5-13, the following step-by-step procedure for selecting motor circuit protection can be developed:

(1) Step 1. Determine full load amps (FLA), locked rotor amps (LRA), and name plate amps (NPA) for each motor, M1 through M4.

(a) $M1_{FLA}$ = 21A (from NFPA 70).
$M2_{FLA}$ =34A (from NFPA 70).
$M3_{FLA}$ = 40A (from NFPA 70).
$M4_{FLA}$ = 65A (from NFPA 70).

(b) Locked-rotor kVA per horsepower for a code letter G motor is 6.29 (per NFPA 70). Equations G-10 through G-13 show how to calculate LRA for each motor M1 through M4.

$M1_{LRA}$ = (LRkVA)/(1.73)(kv) (eq G-10)
$M1_{LRA}$ = (6.29)/(15/(1.73)(.460)=119A (eq G-10)
$M2_{LRA}$ = 198A (eq G-11)
$M3_{LRA}$ = 237A (eq G-12)
$M4_{LRA}$ = 395A (eq G-13)

(c) Nameplate amperes must be determined directly from the motor nameplate. Since this information is not normally available early in the design stages, motor overload protection cannot be determined at this time. Motor overload protection cannot be determined until the motors are actually delivered to the site.

(2) Step 2. Select branch circuit conductors. Conductor ampacity = (1 .25)(FLA). The following AWG values were selected subject to voltage drop and through-fault withstand:

Circuit SWBD3-A: (21A)(1 .25) = 26.25A Use #10 AWG.

Circuit SWBD3-B: (34A)(1 .25) = 42.5A Use #6 AWG.

Circuit SWBD3-C: (40A)(1.25) = 50.0A Use #6 AWG.

Circuit SWBD3-D: (65A)(1 .25) = 81.25A Use #3 AWG.

(3) Step 3. Select feeder circuit conductors. Conductor ampacity = (1.25) (Largest FLA) + (Remaining FLAs). For SE3-D, (65A)(1.25) + 40A + 34A + 21A = 176.25A. Therefore, use 250 MCM minimum since feeder circuit breaker will be set at 250A.

(4) Step 4. Select branch circuit short-circuit protection. Maximum setting is (3.00)(FLA) for non-time delay fuses and (1.75)(FLA) for time-delay fuse per NFPA 70. Since NFPA 70 recognizes both time delay and non-time delay fuses for low--voltage motor circuit protection, both types are included in this example. However, it is recommended that only time-delay fuses be used for motor, transformer, and other inductive loads. The disadvantages of non-time delay fuses were discussed in this TM and will be readily obvious from this example.

SWBD 3-A: Use Class RK-5, time delay fuses.

(21A)(1.75)=36.75A. Use 40A fuses and 60A switch.

SWBD 3-B: Use Class RK-5, time delay fuses.

(34A)(1.75)=59.5A. Use 60A fuses and 60A switch.

SWBD 3-C: Use Class RK-5, non-time delay fuses.

(40A)(3.00) = 120A. Use 125A fuses and 200A switch.

SWBD 3-D: Use Class RK-5, non-time delay fuses.

(65A)(3.00)= 195A. Use 200A fuses and 200A switch.

(5) Step 5. Select feeder circuit short-circuit protection. Maximum setting is (Largest branch circuit device setting) + (Remaining FLAs). For 5E3-D, 200A + 40A + 34A + 21A = 295A. Therefore, use 250A unless future capacity is designed into the system.

(6) Step 6. Select disconnecting means in accordance with NFPA 70.

(7) *Step* 7. Using NPA, select overload protection in accordance with NFPA 70. For these motors, overload protection should not exceed (1.25)(NPA).

c. Due to the fact that the non-time delay fuses must be oversized by 300 percent, larger switches are required to accommodate the oversized fuses. For this and other reasons discussed in this TM, time delay fuses should be specified for motor, transformer, and other inductive loads.

d. Figures G-14 through G-17 show the motor starting curve, motor overload curve, and fuse short-circuit protection curves for each motor:

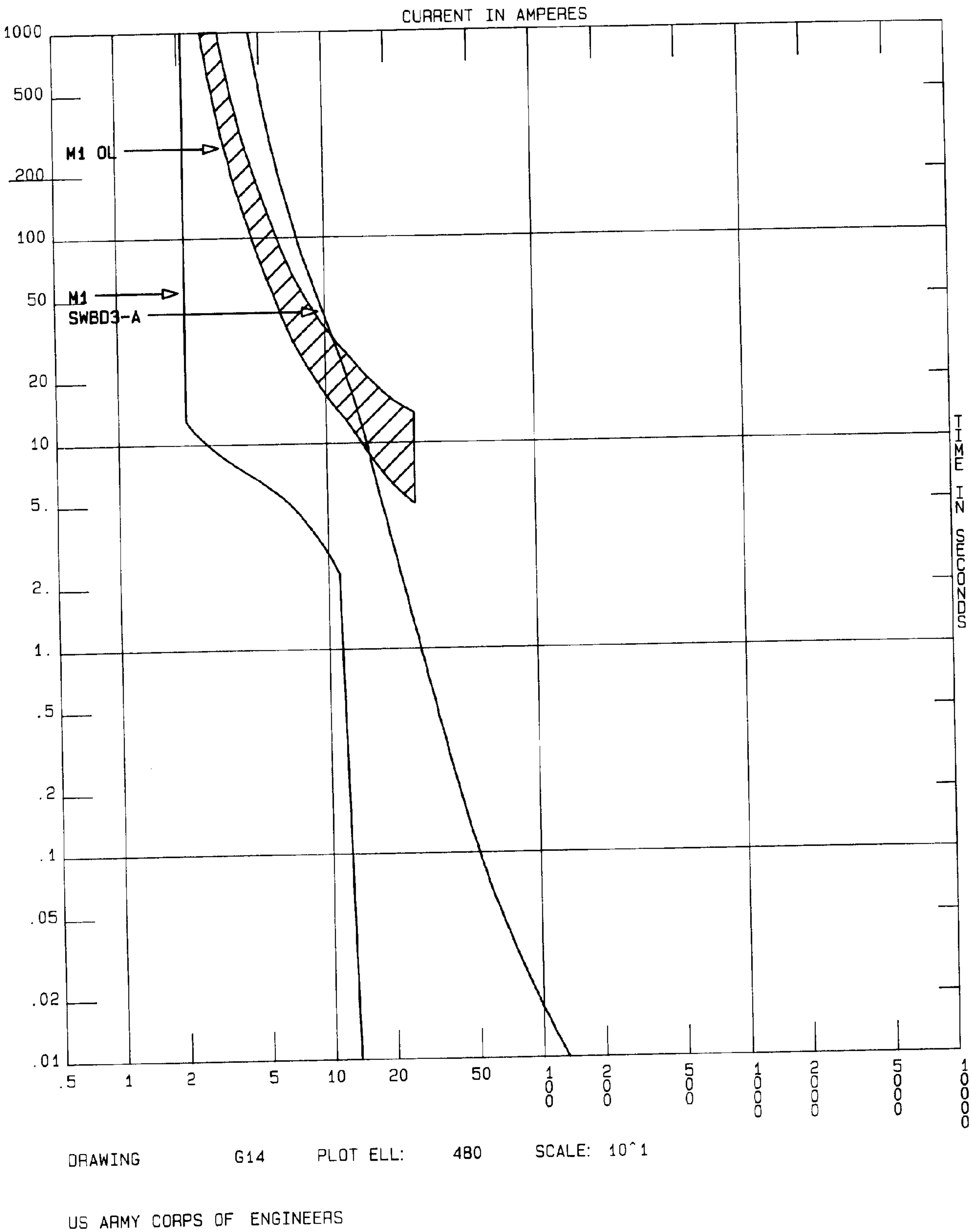


Figure G-14. M1 starting, overload, and fuse short-circuit protection curves.

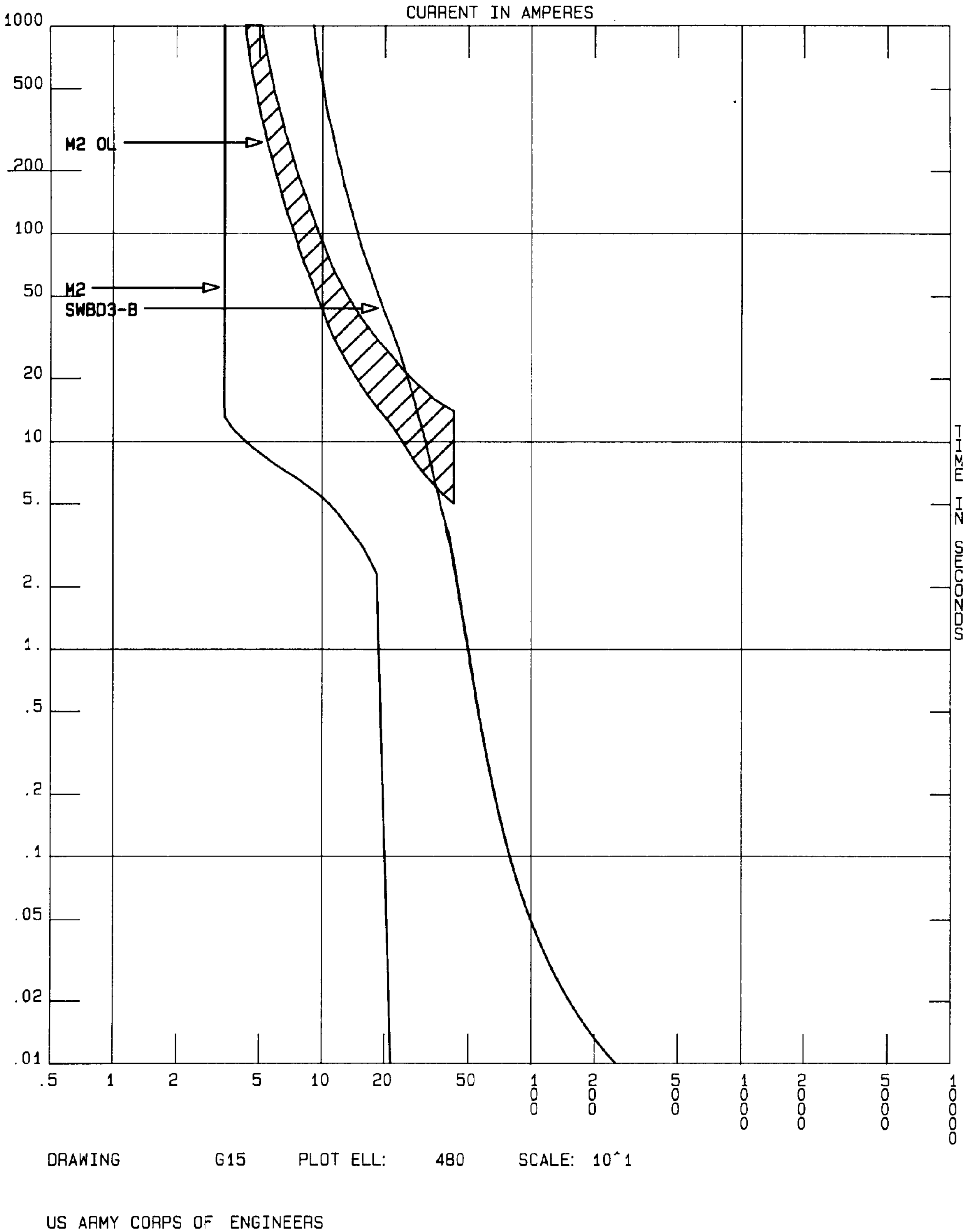


Figure G-15. M2 starting, overload, and fuse short-circuit protection curves.

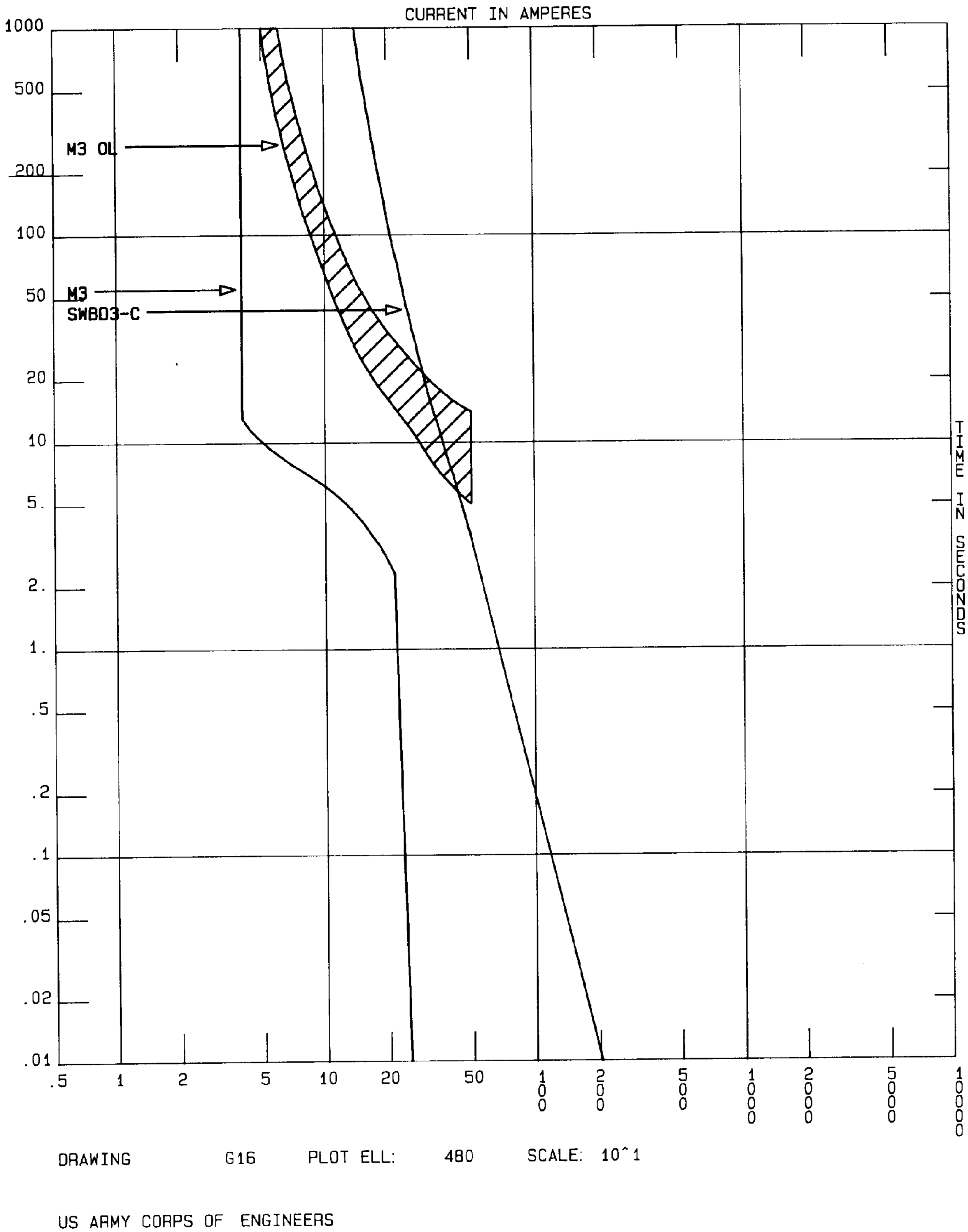


Figure G-16. M3 Starting, overload, and fuse short-circuit protection curves.

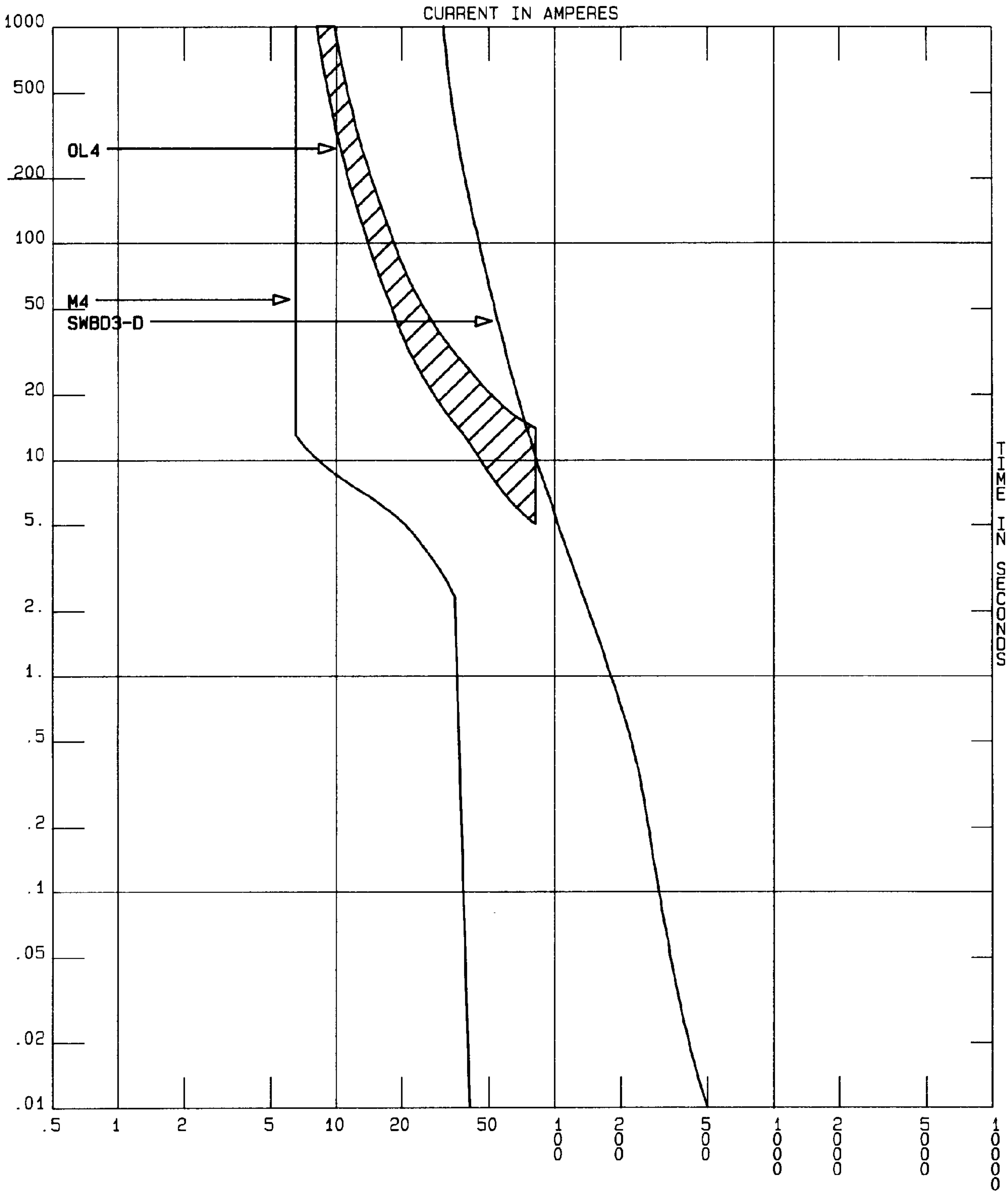


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Figure G–17. M4 starting, overload, and fuse short-circuit protection curves.

G-6. Example 4—Low-voltage ground-fault protection

a. Refer to figure G-3 for the circuit diagram.

b. Since the main circuit breaker, SE4-A, is rated at only 450A, separate ground-fault protection is not required by NFPA 70. Recall that NFPA 70 requires separate ground-fault protection on 480Y/277V services rated 1000A or more. However, this example illustrates the application of ground-fault protection at services in general. Figure G18 shows time-current curves for ground-fault protection at the main only. The ground-fault protection is shown with three different time-current values: GFP1, GFP2, and GFP3. GFP1 is the maximum ground-fault setting permitted by NFPA 70 (i.e., 1200A pick-up and one second time delay for ground-fault currents greater than 3000A). However, the GFP1 setting is not coordinated with the motor feeder (SE4-C) or the motor branch circuit (MP4-D) standard protection de- vices. A 1500A ground-fault, for example, at motor M4 terminals will trip the main circuit breaker on ground-fault, shutting down the entire system. If a ground-fault occurs in the service equipment, extensive damage may occur before the GFP1 trips the main. In order to improve coordination, the ground-fault protection can be reduced to either GFP2 or GFP3. Figure G-19 shows time-current curves for coordinated ground-fault protection at the main (SE4-A), feeder (SE4-C), and branch (MP4-D).

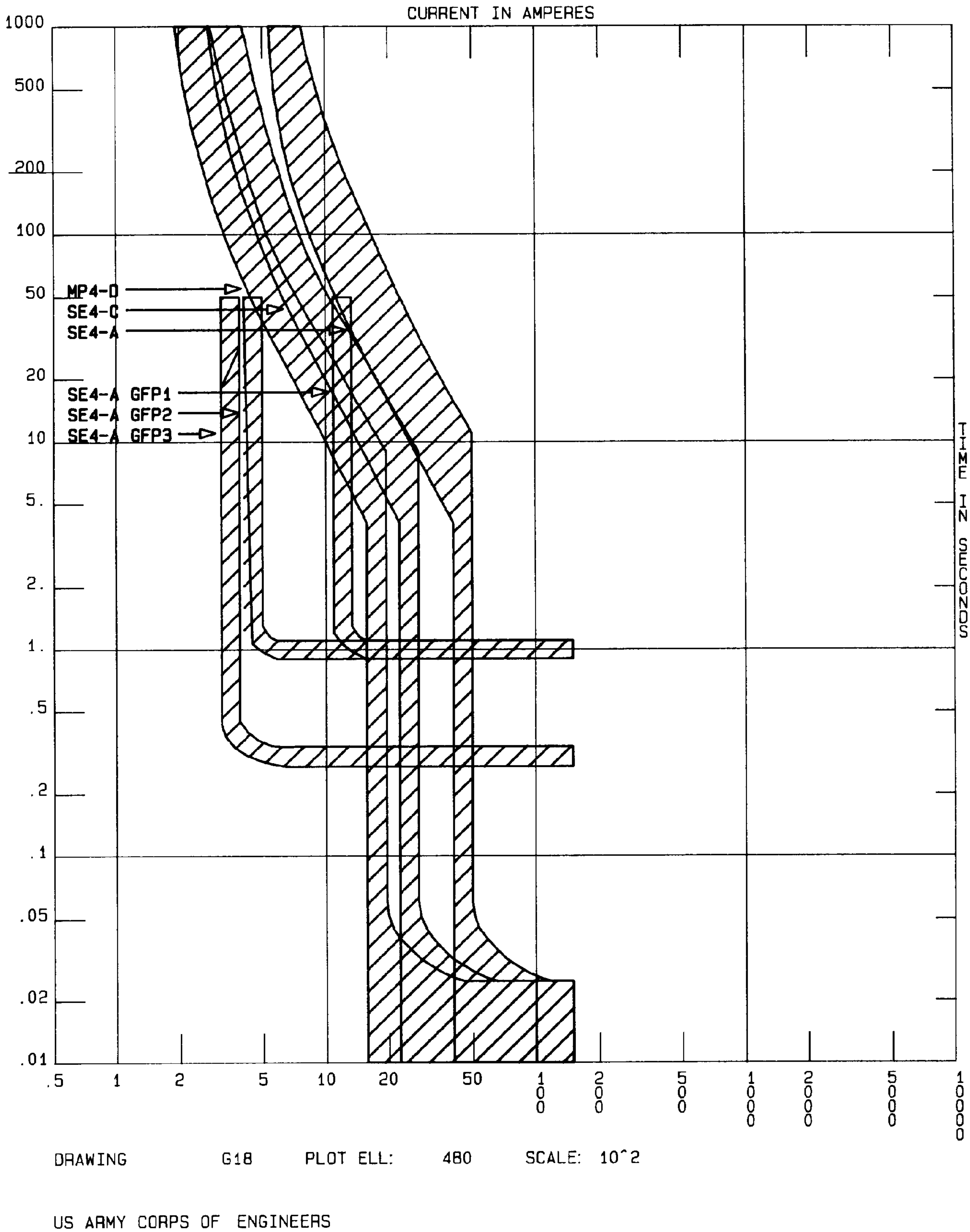


Figure G–18. Ground-fault protection at main only (nonselective, single-zone).

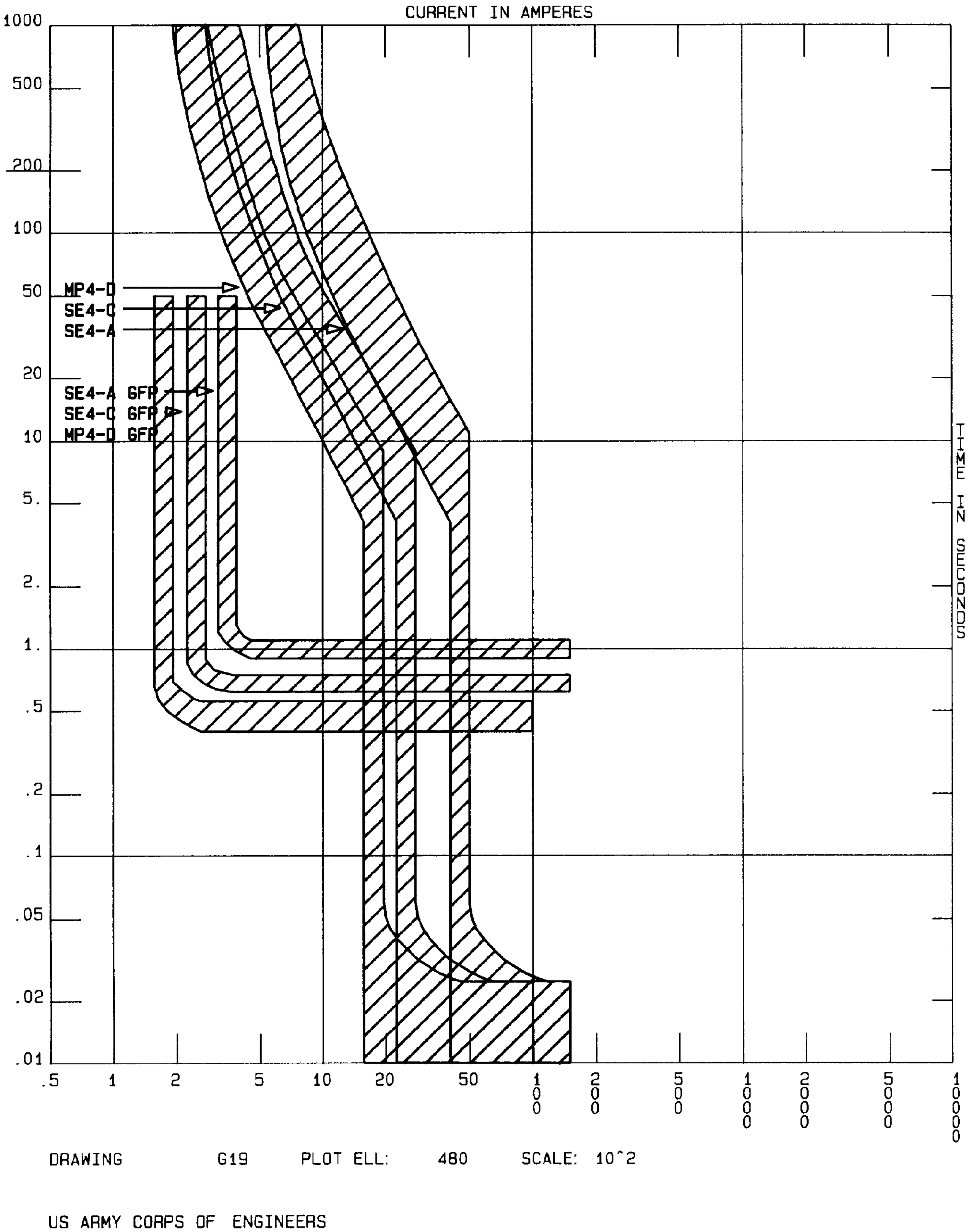


Figure G–19. Ground-fault protection at main, feeder, and branch (selective, time-coordinated).

G-7. Example 5—Impedance diagram and short-circuit calculation

a. Refer to figure G-20 for the overall system impedance diagram of figure G-1.

b. Only items with significant impedance values are considered in this example. They are the utility, transformer, generators, and conductors. The impedances of switches, circuit breakers, busses, and similar items were excluded. Xd' represents machine subtransient reactance (first few cycles following short circuit), Xd" represents machine transient reactance (up to about 30 cycles after short circuit), and Xd represents the machine synchronous reactance (steady state short-circuit current).

c. Standard per unit equations.

X utility=Xu=Base kVA/Utility kVA. (eq G-14)

X new=(X old) (Base kVA new) $(kV\ old)^2$/(Base kVA old) $(kV\ new)^2$. (eq G-15)

X pu=(X ohms)Base $kVA)^2$/1000 $(Base\ kV)^2$. (eq G-16)

d. Impedance Calculations.

(1) Assume Base kVA=2000kVA.

(2) Assume Base kV=12.47kV;4.16kV;480V.

$X_{u1}=X_{u2}$=2000kVA/ 500,000kVA=.004 pu. (eq G-17)

$X''_{G1}=X''_{G2}$=(.2)(2000)/ 1250=.32p u. (eq G-18)

$X'_{G1}=X'_{G2}$=(.35)(2000)/ 1250=.56p u. (eq G-19)

$X_{G1}=X_{G2}$=(1)(2000)/12.50=1.6 p u. (eq G-20)

$X_{T1}=X_{T2}$=(.08)(2000)/ 20,000=.008p u. (eq G-21)

X_{T3}=(.05)(2000)/50=.133 pu . (eq G-22)

X_{T4}=(.04)(2000)/50=.16 pu . . (eq G-23)

X_{T5}=(.04)(2000)/50=.16 pu . . (eq G-24)

X'_{m5}=(.2)(2000)/$(4160)^2$ (500)$(4000)^2$=.866p u. (eq G-25)

X'_{m5}=(.5)(2000)/$(4160)^2$ (500)$(4000)^2$=2.165p u. (eq G-26)

X'_{m5}=(1.25)(2000)/$(4160)^2$ (500)$(4000)^2$=5.41p u. (eq G-27)

X'_{m4}=(.25)(2000)/$(480)^2$ (50)$(460)^2$=10.89p u. (eq G-28)

X'_{m3}=(.25)(2000)/$(480)^2$ (30)$(460)^2$=18.15p u. (eq G-29)

X'_{m2}=(.25)(2000)/$(480)^2$ (25)$(460)^2$=21.78p u. (eq G-30)

X'_{m1}=(.25)(2000)/$(480)^2$ (15)$(460)^2$=36.29p u. (eq G-31)

$X'_{L4}=X_{L7}$=(.5)(.2)(2000)/ $(12.47)^2$(1000)=.0012p u. (eq G-32)

$X'_{L5}=X_{L6}$=(.4)(.2)(2000)/ $(12.47)^2$(1000)=.00103p u. (eq G-33)

$X_{SE3\text{-}A}$=0 . . . . (eq G-34)

$X_{SE4\text{-}A}$=0 . . . . (eq G-35)

$X_{SE3\text{-}B}$=(.1)(.0355)(2000)/$(.480)^2$ (1000)=.031 pu. (eq G-36)

$X_{SE3\text{-}Dd}$=(.15)(.0355)(2000)/ $(.480)^2$(1000)=.046 pu. (eq G-37)

X_{LA}=(.075)(1.2)(2000)/$(.480)^2$ (1000)=.78 pu. (eq G-38)

X_{LB}=(.075)(.52)(2000)/$(.480)^2$ (1000)=.34 pu. (eq G-39)

X_{Lc}=.34 pu (eq G-40)

X_{LD}=(.075)(.28)(2000)/$(.480)^2$ (1000)=.18 pu. (eq G-41)

$X_{SE4\text{-}C}=X_{SE3\text{-}B}$=.031 pu (eq G-42)

e. Figure G-21 shows the reduced impedance diagram. This diagram can be used to calculate short-circuit current at any point within the system. I"sc represents the current during the first few cycles following a short-circuit. I'sc represents the current up to about 30 cycles, and Isc represents the steady-state short-circuit current.

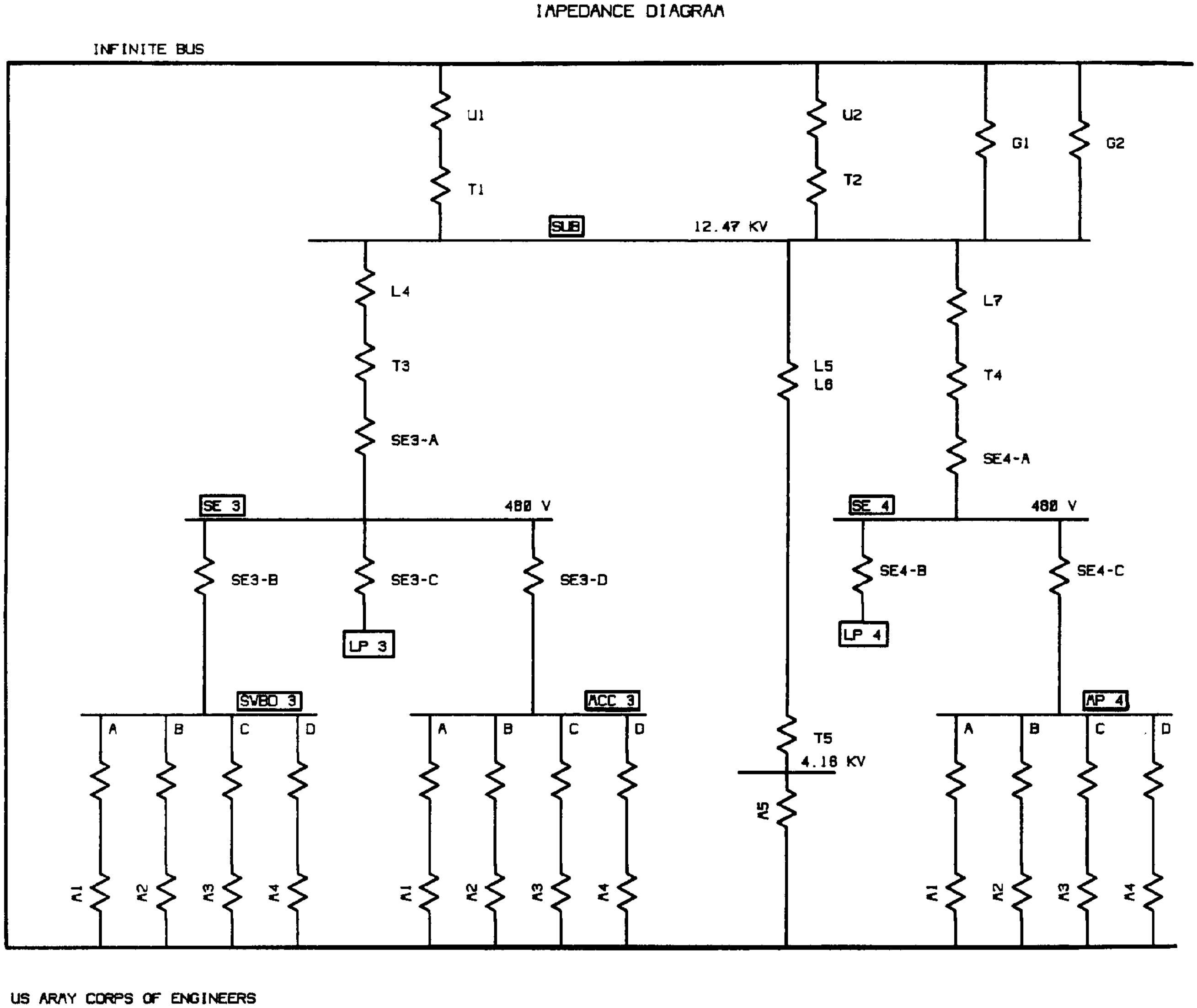
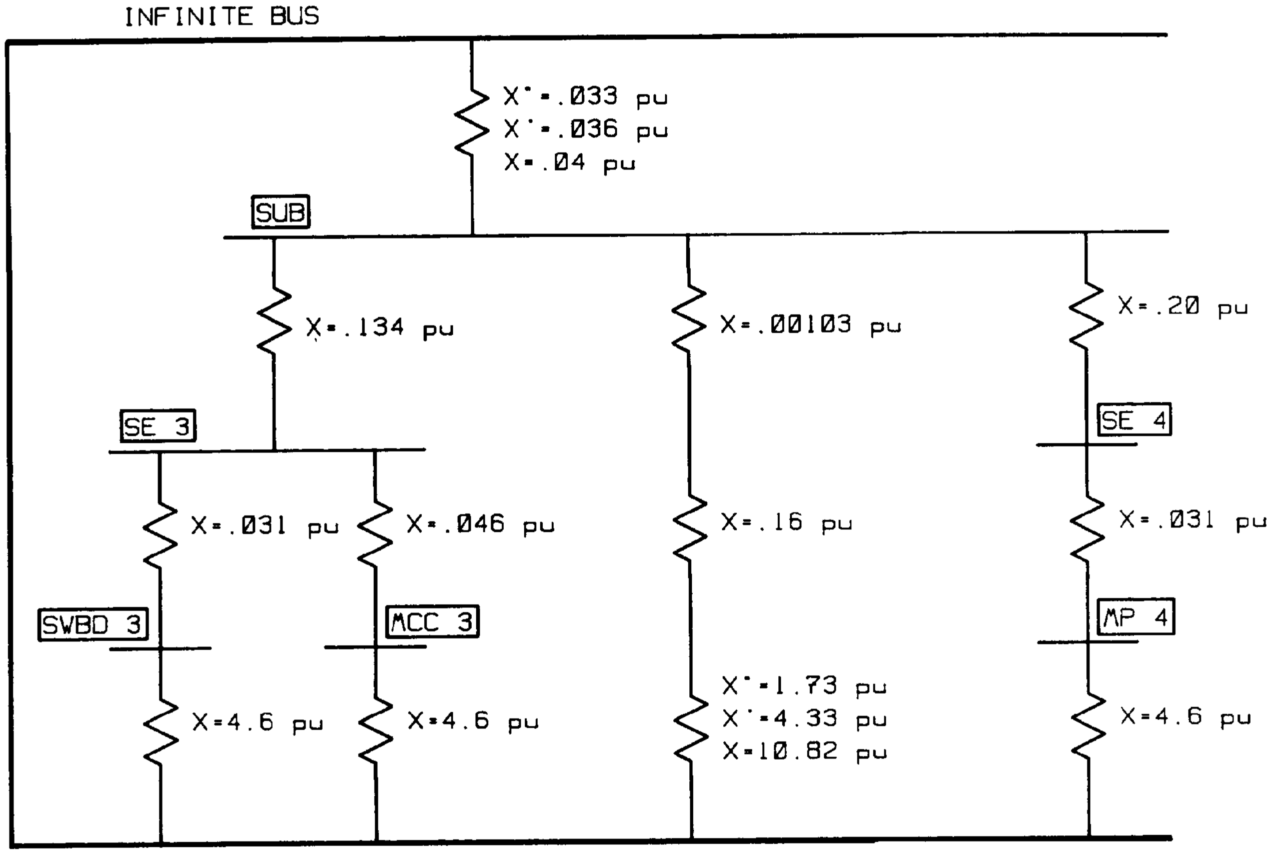
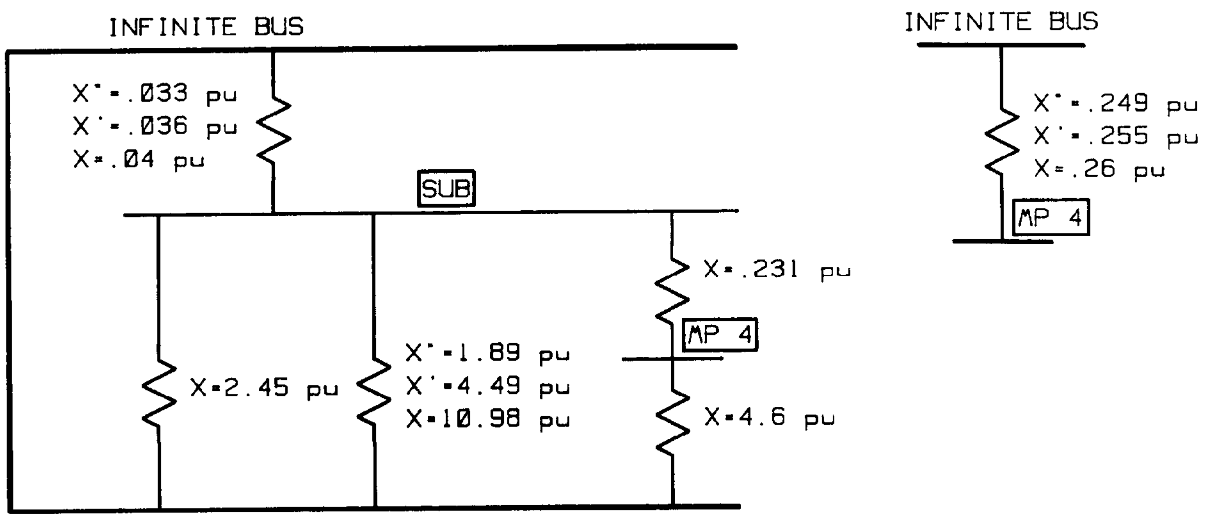


Figure G-20. Impedance diagram.



CONSIDER A FAULT AT MP 4 BUS.



$I_{BASE} = 2405.6$ A

$I'_{SC} = 2405.6/.255 = 9434$ A

$I''_{SC} = 2405.6/.249 = 9661$ A

$I_{SC} = 2405.6/.26 = 9252$ A

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***Figure G-21.** Per unit diagram.*

G-8. Example 6 — Medium-voltage (MV) fuse protection for transformers T3 and T4. See figures G-I, G-2, and G-3

a. General. For the single transformer installa--tions of T3 (figure G-2) and T4 (figure G-3), fuse manufacturers may supply recommended fuse ratings. To insure adequate fuse ratings, always select the smallest continuous current rating that will carry the load and tolerate temporary overloads without fuse damage. Figure G-8 shows the composite time-current curves for Example 1. This illustration also includes the curve for the transformer T4 primary fuse (FU-4). Figure G-13 shows the composite time-current curves for Example 2. This illustration also includes the curve for the transformer T3 primary fuse (FU-3). Since FU-3 and FU-4 protect their associated transformers, each fuse must be selected so that the rating is above and to the right of the transformer inrush point, and below and to the left of the transformer through-fault curves. Additionally, the fuse continuous current ratings must comply with the limits of NFPA 70. Referring to table 4-1, FU-3 and FU4 must not exceed 3.00 times transformer full-load amperes (FLA), since the transformers also have secondary protection. Although the primary voltage rating of transformers T3 and T4 is 12.4kV, the primary FLA is calculated on a 480V base. This value must be used because figures G-8 and G-13 are plotted using a 480V base.

$T3_{FLA} = (kVA)/(1.73)(kV) = (750)/(1.73)(.480) = 902.1A.$ (eq G–43)

$T3_{6X} = (T3_{FLA})(3) = 2706.3A$ .... (eq G–44)

$T4_{FLA} = (kVA/(1.73)(kV) = (500)/(1.73)(.480) = 601.4A.$ (eq G–45)

$T4_{3X} = (T4_{FLA})(3) = 1804.2A$ .... (eq G–46)

Locate the above NFPA 70 limits at the top of the appropriate time-current curves as shown in figures G-8 and G-13. The primary fuses time-cur-rent characteristic curves must conform to the following:

(1) Be greater than transformer FLA at 1000 seconds (steady-state).

(2) Not exceed (3.00)(FLA) at 1000 seconds.

(3) Be above and to the right of the transformer inrush point.

(4) Be below and to the left of the transformer through-fault curve.

(5) Coordinate with downstream devices.

b. As can be seen from the time-current curves of figures G-8 and G-13, meeting all the above requirements is difficult or sometimes impossible. Figures G-8 and G-13 show some overlap with the transformer secondary circuit breaker protection curves. Also, the fuse curves exceed the NFPA 70 limits and the through-fault protection curves. To satisfy protection and coordination requirements, the circuit breaker ratings should be reduced and smaller primary fuses should be specified.

G-9. Example 7 — Medium-voltage (MV) motor-circuit protection with reduced-voltage motor controller (RVMC). See figure G-1

a. General. It is assumed that a wye-delta type reduced voltage motor controller is used. Closed-circuit transition is recommended to minimize inrush voltage disturbances.

b. Starting current is 33.3 percent of the starting current using full-voltage starting. For large motors—

$M5_{FLA} = (kVA)/(1.73)(kV) = (500)/(1.73)(4.16) = 69.4A.$ (eq G–47)

$M5_{LRA} = M5_{FLA}/Xd'' = 69.4/.2 = 347A.$ (eq G–48)

$T5_{FLA} = (kVA)/(1.73)(kV)$ .... (eq G–49)

$T5_{FLA} = (1000)/(1.73)(4.16) = 138.79A$ .. (eq G–49)

$T5_{3X} = (T5_{FLA})(3) = 416.37A$.................. (eq G–50)

c. Figure G-22 shows composite time-current curves for the medium-voltage motor circuit supplied by transformer T5.

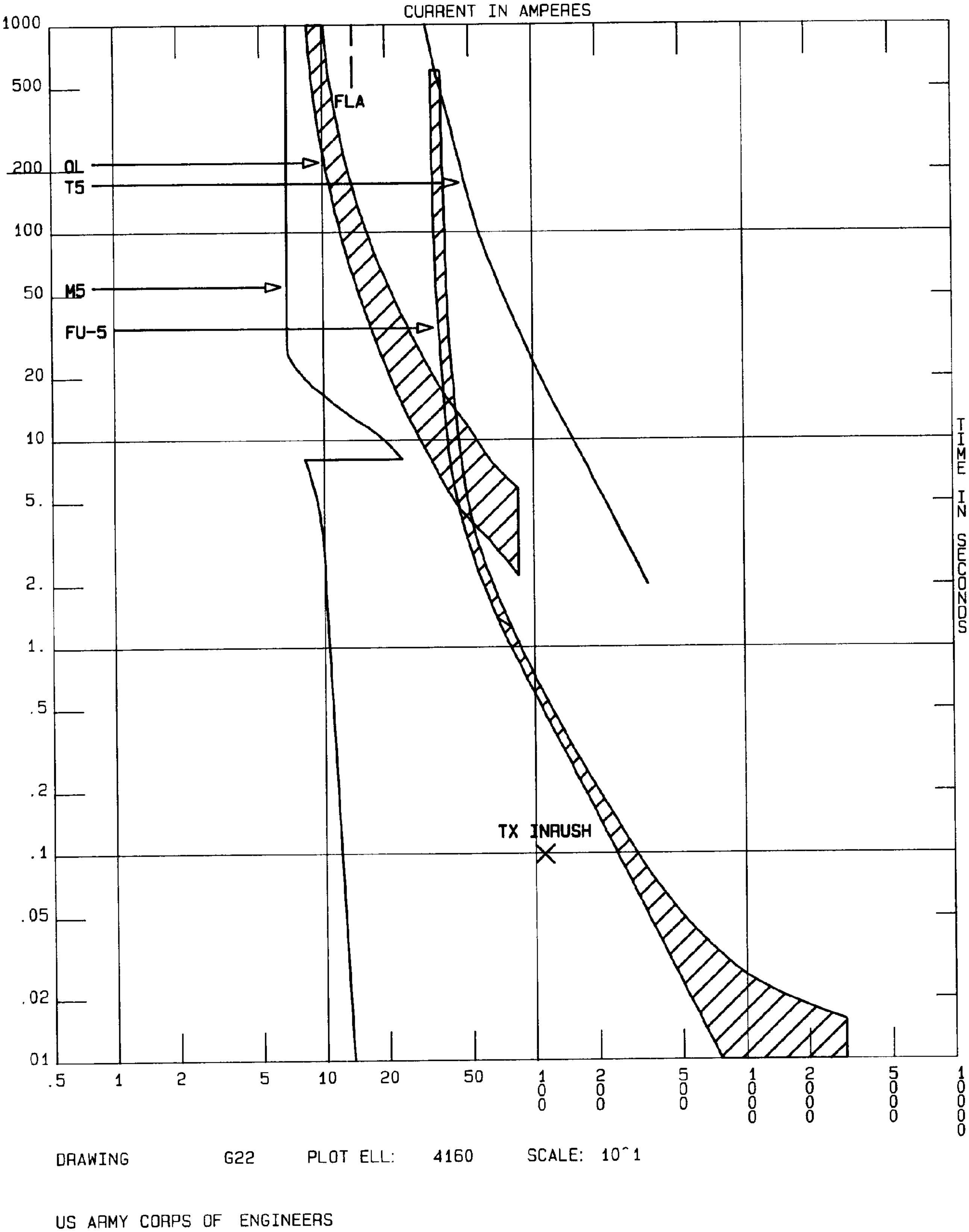

Figure G-22. M5 starting, overload, and fuse short-circuit curves.

G-10. Example 8—Medium-voltage (MV) generator protection

a. As shown in figure G-1, the example incorporates two 1250kVA, 13.8kV, on-site generators. These generators would be classified as multiple isolated generators as described in chapter 5 of this TM. The basic minimum protection is listed below.

b. Device 51V, voltage-controlled or voltage-restrained backup overcurrent relay. Short-circuits on generators usually result in low voltage. Thus when overcurrents are accompanied by low volt-age, the relay will operate. If overcurrent is not accompanied by low voltage, the condition is probably an overload and the generator remains connected since the relay will not operate. This allows the relay to be set lower than generator FLA.

c. Device 51G, backup ground time-overcurrent relay. Since the generator is grounded, a time overcurrent relay in the neutral circuit can be used in much the same manner as a transformer neutral ground relay. Care should be exercised in selecting line-to-line voltage rating on the potential transformers used for protection and synchronizing. Furthermore, a voltage relay would be used for ground detection on a high resistance grounded neutral. Where necessary, surge protection should be provided in the generator.

d. Device 87 and 87G, differential relays.

e. Device 32, reverse power relay for antimotoring protection.

f. Device 40, impedance relay, offset mho type for loss of field protection.

g. Device 81, under frequency relays can be used to drop load or sectionalize buses in order to keep remaining generation and load in operation during disturbances.

G-11. Example 9—Phase Overcurrent Protection Using Protective Relays

a. Figure G-22 shows the time-current curves for the medium-voltage motor circuit. As shown in figure G-1, this circuit is supplied by 15kV switchgear feeders number 5 and 6. Circuit breakers 5 and 6 in the 15kV switch-gear must be set above the rating of FU-5 to achieve coordination. Additionally, the tie-breaker and the main circuit breakers must coordinate with the feeder breakers. Since the tie-breaker and the main breakers are equally rated, relay tap and time dial settings can be adjusted to achieve coordination. Figure G23 shows the curves for FU-5, feeder breakers 5 and 6, tie-breaker 3, and main breaker 1 and 2. Selected settings are shown in table G-1.

Table G–1. Summary of device settings for figure G–23

Device	Setting
FU–5	100E
5/6	CT=200/5, tap=5.0, time dial=5.0, Inst=maximum
3	CT=1600/5, tap=3.0, time dial=3.0
1/2	CT=1600/5, tap=5.0, time dial=5.0

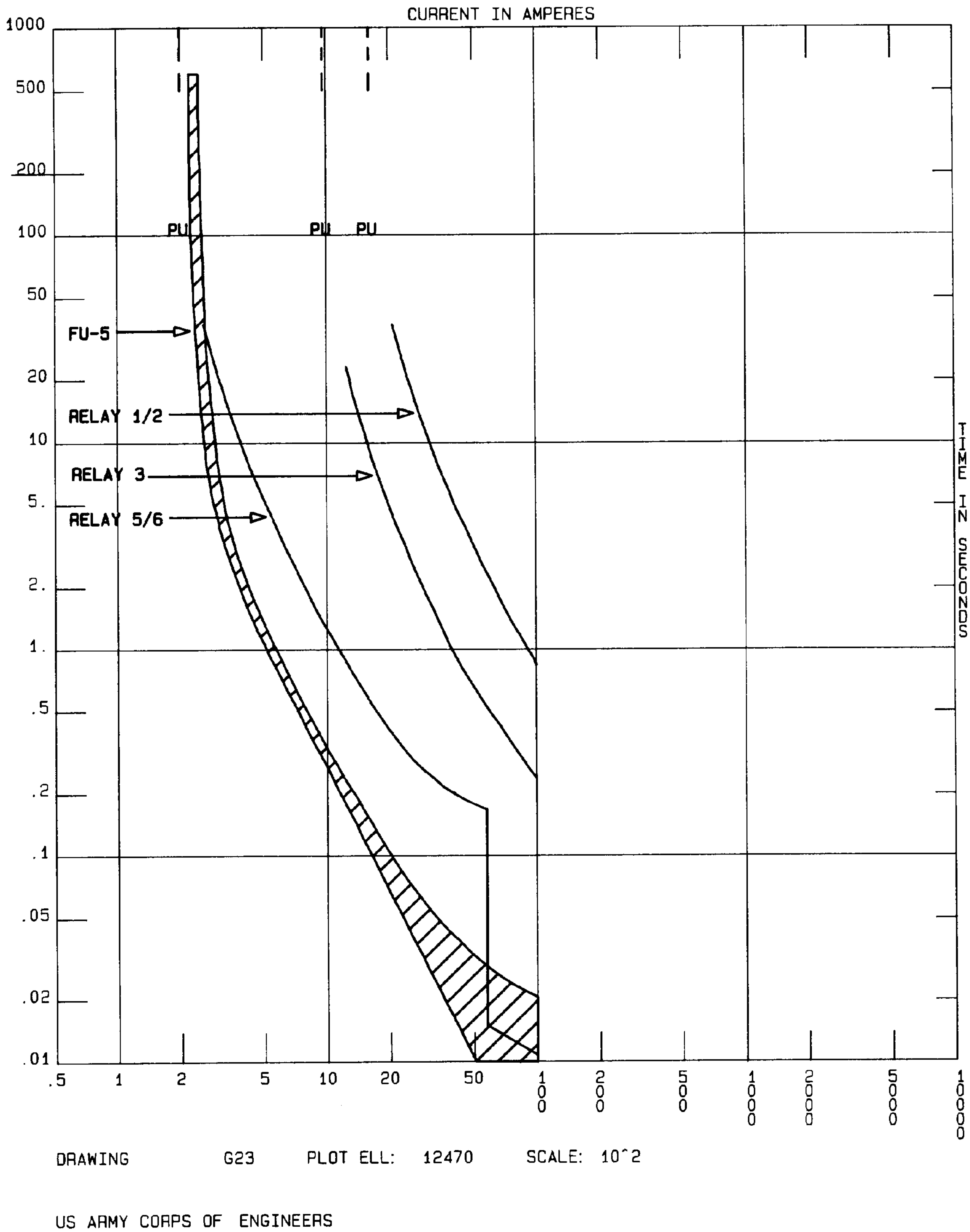

Figure G-23. Protective relays 1, 2, 3, 5, 6.

b. Figure G-24 shows the curves for main breakers 1 and 2, tie-breaker 3, and feeder breakers 4 and 7. Selected settings are shown in table G-2.

Table G-2. Summary of device settings for figure G-24

Device	*Setting*
4/7	CT=600/5, tap=3.0, time dial=3.0, inst=60.0
3	CT=1600/5, tap=3.0, time dial=3.0
1/2	CT=2000/5, tap=5.0, time dial=5.0

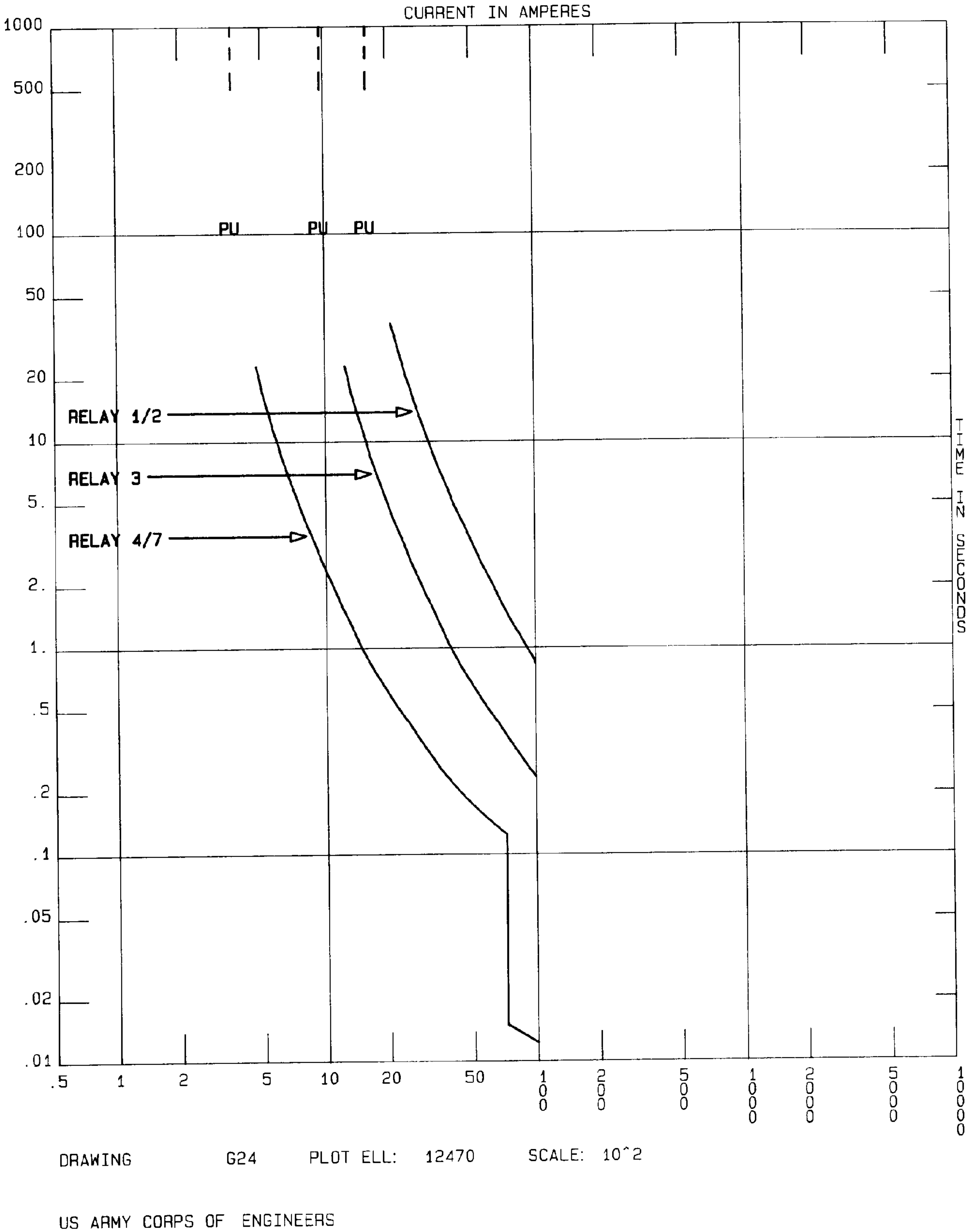

Figure G-24. Protective relays 1, 2, 3, 4, 7.