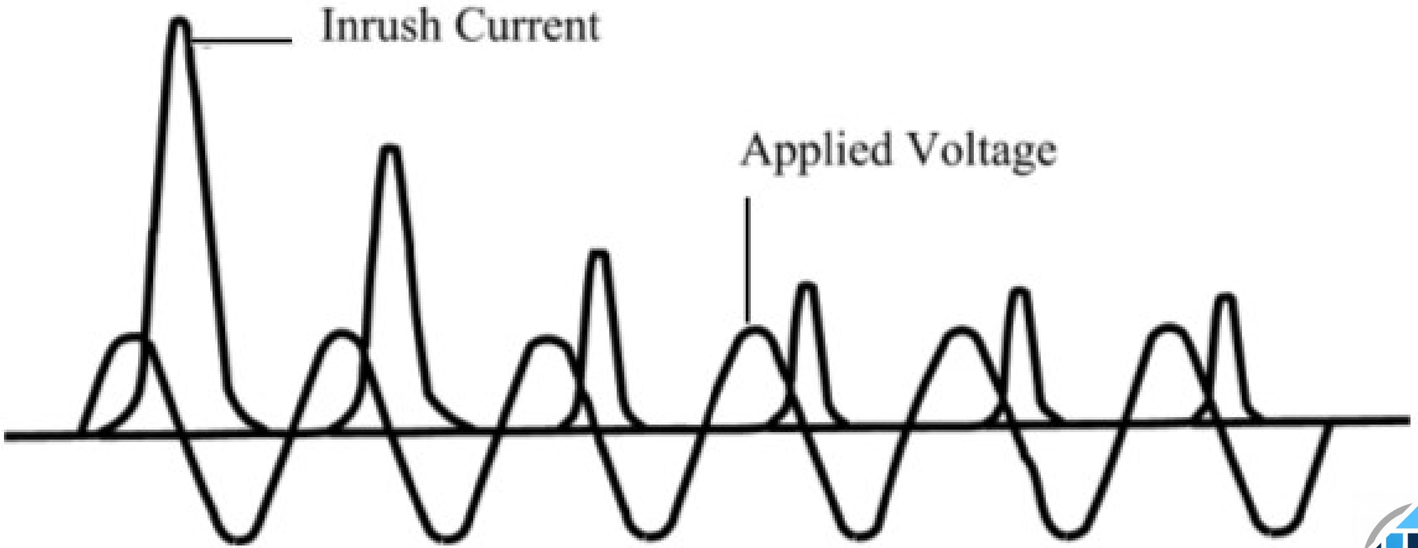
Overview of IEEE Std C37.91 Through Fault Protection

IEEE Guide for Protective Relay Applications to Power Transformers



IEEE Device Numbers

- 24 V/Hz relay
- 26 Thermal device
- 49 Thermal relay
- 50N Instantaneous neutral overcurrent relay
- 51 AC time overcurrent relay
- 51G AC time overcurrent relay
- 51N AC time neutral overcurrent relay
- 51NB AC time neutral overcurrent relay, backup
- 51NT AC time neutral overcurrent relay, torque controlled
- 52 AC circuit breaker
- 59 Overvoltage relay
- 60 Voltage or current balance relay
- 63 Pressure switch or relay
- 67 AC directional overcurrent relay
- 67G AC directional overcurrent relay, neutral
- 86 Lockout relay
- 87 Differential relay
- 87G Ground differential relay

Types of transformer failures

- This guide deals primarily with the application of electrical relays and over-current protective devices to detect the fault current that results from an insulation failure.
- Winding failures
- Tap changer failures
- Bushing failures
- Terminal board failures
- Core failures
- Miscellaneous failures

Complications to detection of internal faults

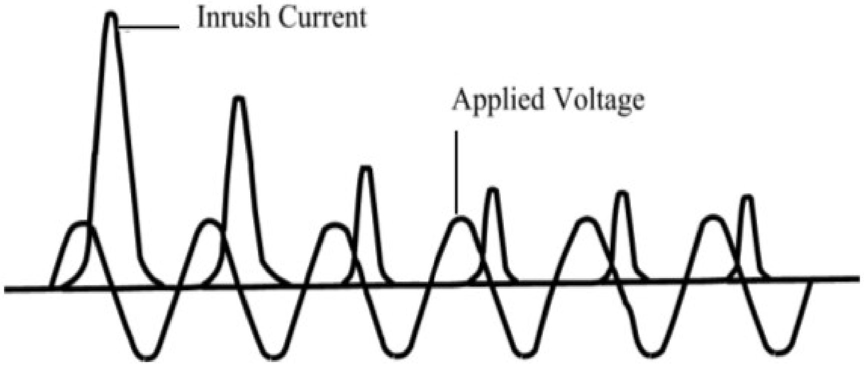
- The change in magnitude of current at the transformer terminals may be very small when a limited number of turns are shorted within the transformer.
- When a transformer is energized, magnetizing inrush current that flows in one set of terminals may equal many times the transformer rating.

Minimum internal faults

- The most difficult transformer winding fault for which to provide protection is the fault that initially involves one turn. A turn-to-turn fault will result in a terminal current of much less than rated full-load current.
- For example, as much as 10% of the winding may have to be shorted to cause full-load terminal current to flow.
- Therefore, a single turn-to-turn fault will result in an undetectable amount of current.

Important characteristics of magnetizing inrush current

- It contains substantial harmonics, particularly the second harmonic. These harmonics are not always present in high quantities in all three phases
- There is always a time during each cycle where the current magnitude is almost zero. This time is always greater than a quarter cycle.



Magnetizing current during overexcitation

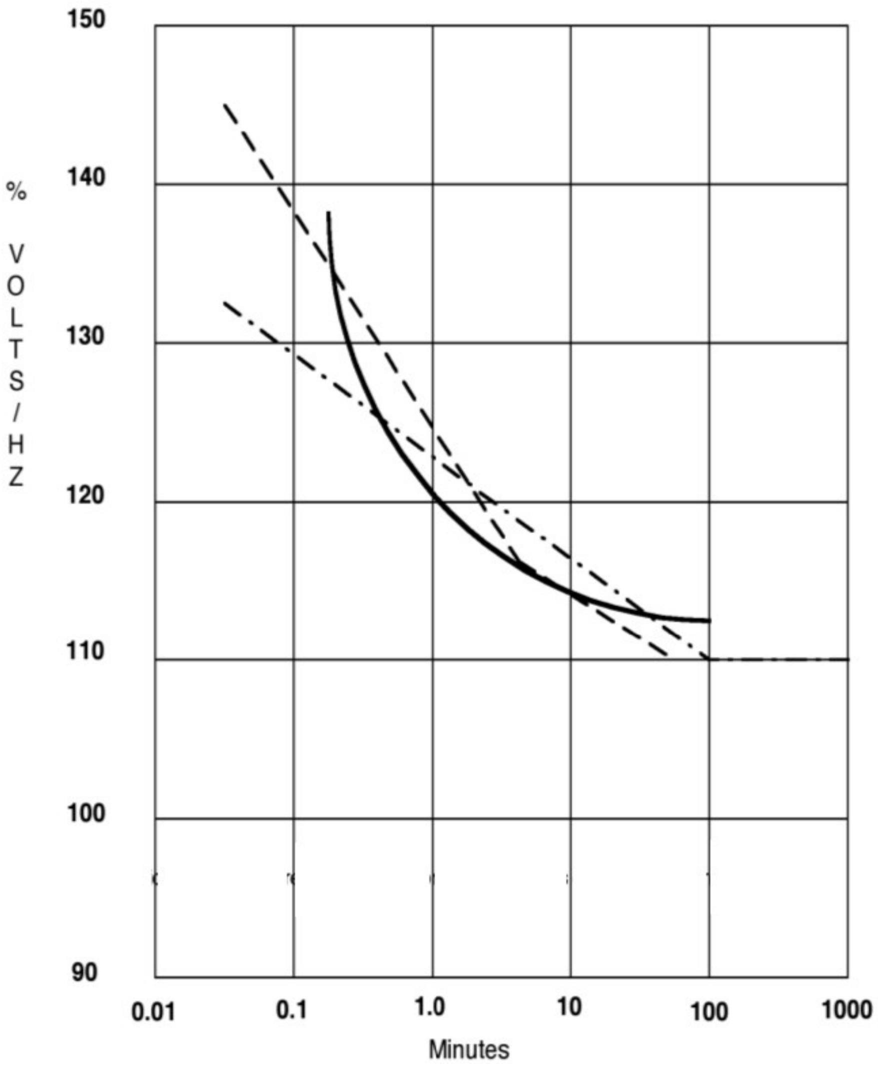
- Sudden loss of load can subject the generator step-up transformer to substantial overvoltage.
- This can also occur during start-up or shutdown of the generator if nominal voltage is maintained while the speed is below normal (an overexcitation condition).
- If saturation occurs, substantial exciting current will flow, which may overheat the core and damage the transformer severely.
- The waveform will be distorted and again the wave will have harmonic content and current zero periods.

Overexcitation protection

- Overexcitation of a transformer can occur whenever the ratio of the per unit voltage to per unit frequency (V/Hz) at the secondary terminals of a transformer exceeds its rating of 1.05 per unit (PU) on transformer base at full load and 0.8 power factor.
- Or 1.1 PU at no load.

Transformer overexcitation limits of three manufacturers

- Figure 1



Through Fault Protection

- Overcurrent protective devices such as relays and fuses have well-defined operating characteristics that relate fault-current magnitude to operating time. It is desirable that the characteristic curves for these devices be coordinated with comparable curves that reflect their through-fault withstand capability.
- Category I, II, III, and IV curves apply to transformers designed to IEEE Std C57.12.00

Through Fault Protection

- Category I transformers (5–500 kVA single-phase, 15–500 kVA three-phase)
- Category II transformers (501–1667 kVA single-phase, 501–5000 kVA three-phase)
- Category III transformers (1668–10 000 kVA single-phase, 5001–30 000 kVA three-phase)
- Category IV transformers (above 10 000 kVA single-phase, and above 30 000 kVA three-phase)

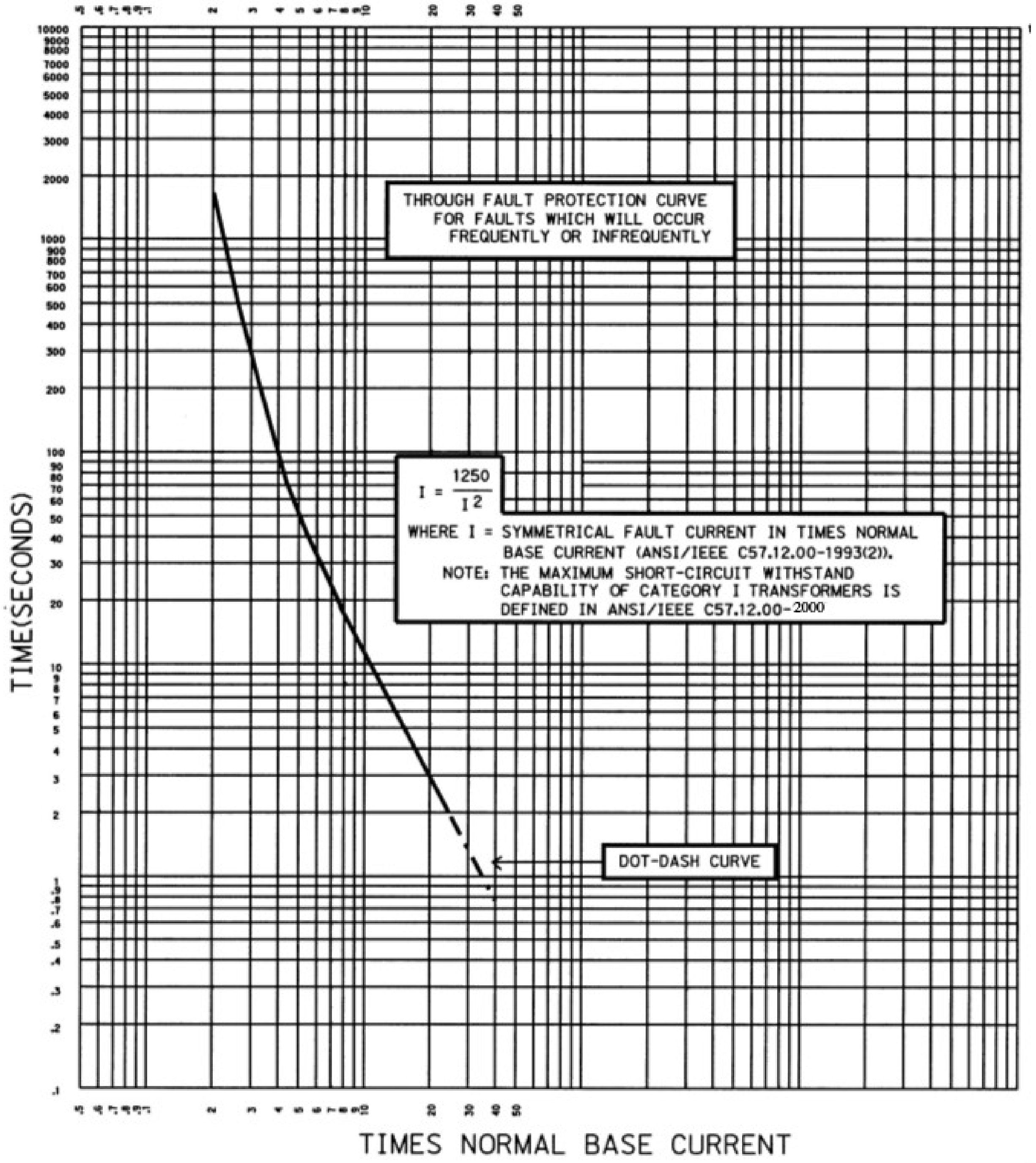
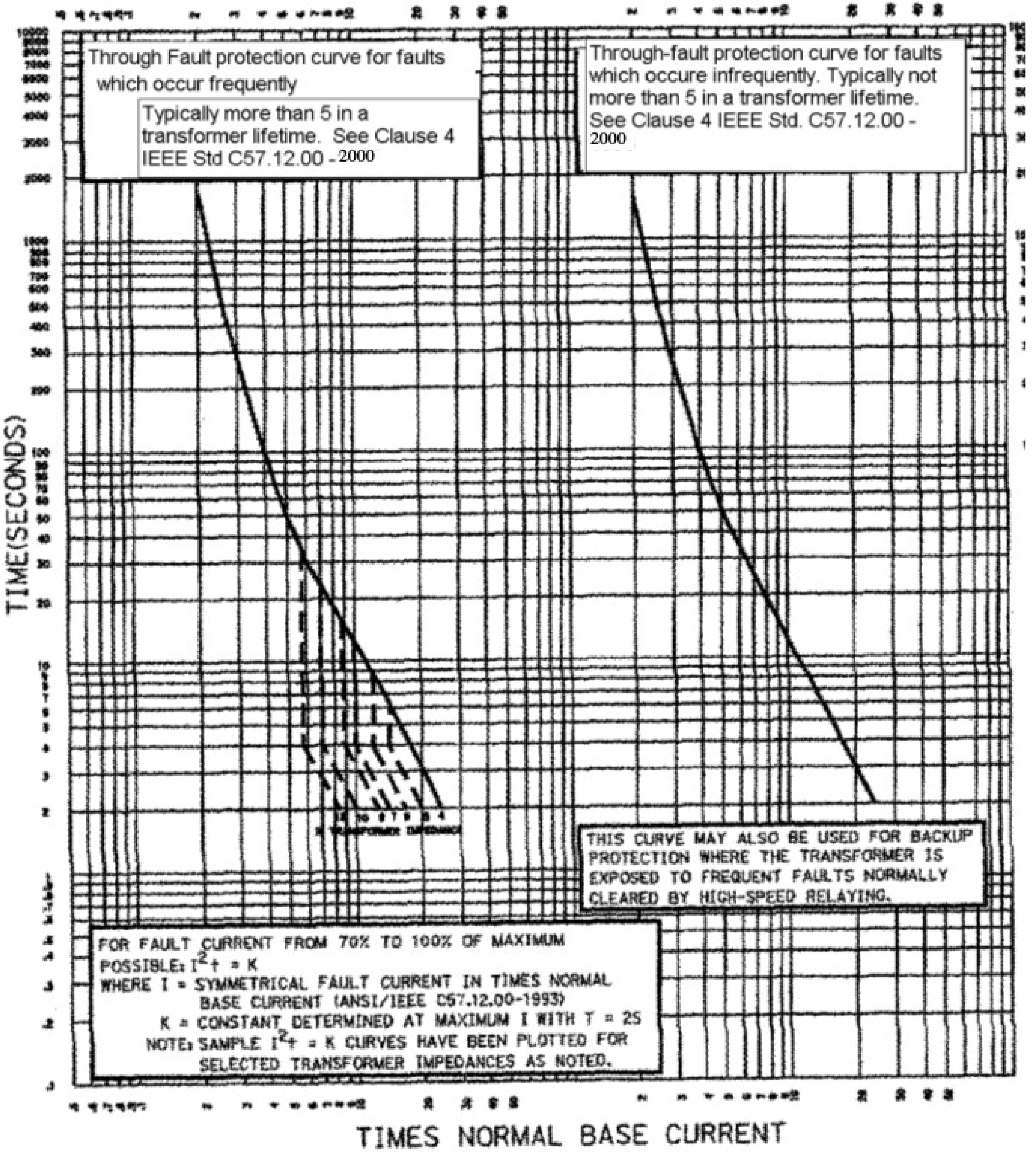


Figure A.1—Category I transformers: 5–500 kVA single-phase; 15–500 kVA three-phase



Through Fault protection curve for faults which occur frequently

Typically more than 5 in a transformer lifetime. See Clause 4 IEEE Std C57.12.00 - 2000

Through-fault protection curve for faults which occure infrequently. Typically not more than 5 in a transformer lifetime. See Clause 4 IEEE Std. C57.12.00 - 2000

THIS CURVE MAY ALSO BE USED FOR BACKUP PROTECTION WHERE THE TRANSFORMER IS EXPOSED TO FREQUENT FAULTS NORMALLY CLEARED BY HIGH-SPEED RELAYING.

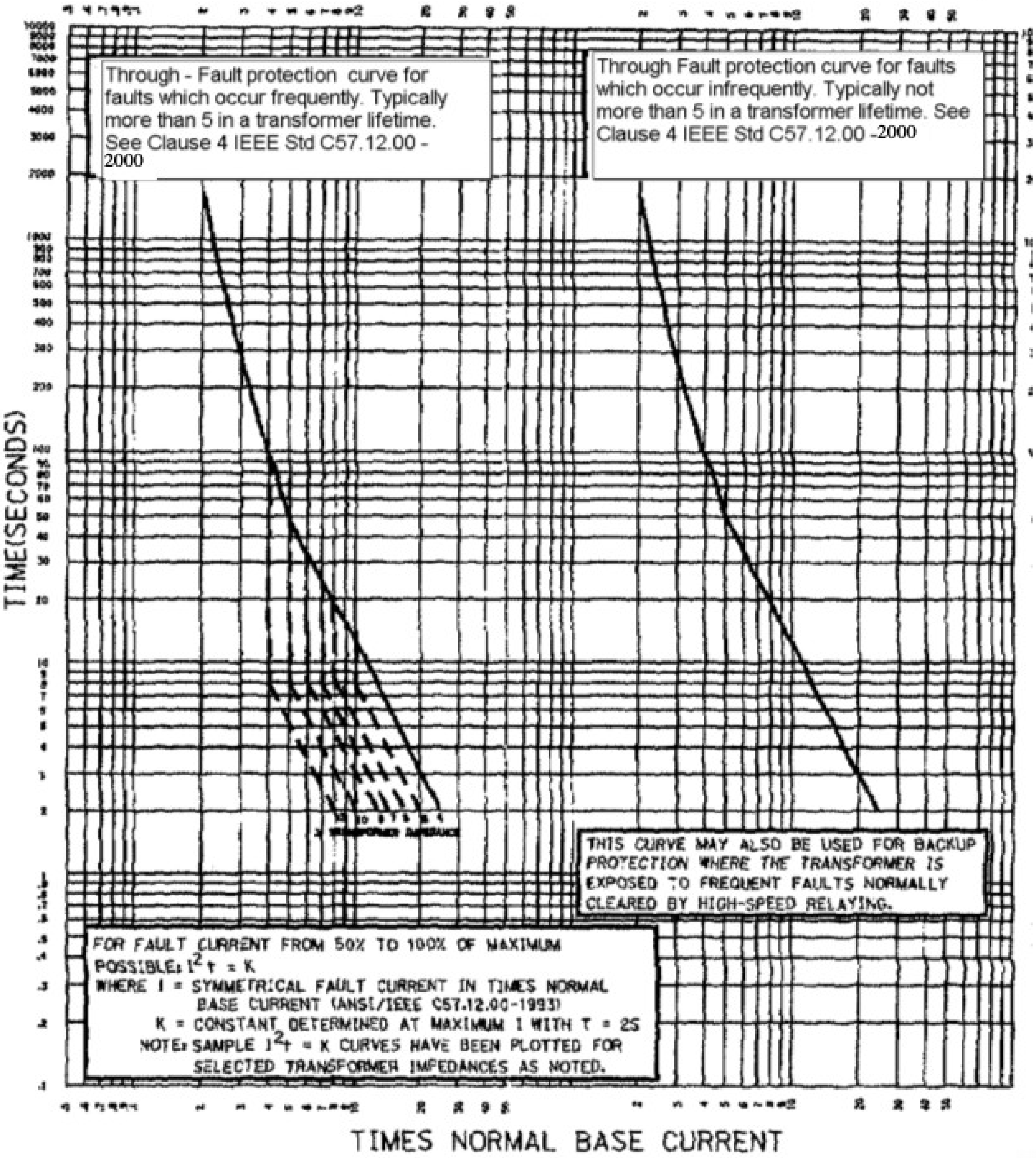
FOR FAULT CURRENT FROM 70% TO 100% OF MAXIMUM POSSIBLE: $I^2t = K$

WHERE I = SYMMETRICAL FAULT CURRENT IN TIMES NORMAL BASE CURRENT (ANSI/IEEE C57.12.00-1993)

K = CONSTANT DETERMINED AT MAXIMUM I WITH T = 2S

NOTE: SAMPLE $I^2t = K$ CURVES HAVE BEEN PLOTTED FOR SELECTED TRANSFORMER IMPEDANCES AS NOTED.

Figure A.2—Category II transformers:
501–1667 kVA single-phase;
501–5000 kVA three-phase



Through - Fault protection curve for faults which occur frequently. Typically more than 5 in a transformer lifetime. See Clause 4 IEEE Std C57.12.00 - 2000

Through Fault protection curve for faults which occur infrequently. Typically not more than 5 in a transformer lifetime. See Clause 4 IEEE Std C57.12.00 -2000

THIS CURVE MAY ALSO BE USED FOR BACKUP PROTECTION WHERE THE TRANSFORMER IS EXPOSED TO FREQUENT FAULTS NORMALLY CLEARED BY HIGH-SPEED RELAYING.

FOR FAULT CURRENT FROM 50% TO 100% OF MAXIMUM POSSIBLE: $I^2t = K$

WHERE I = SYMMETRICAL FAULT CURRENT IN TIMES NORMAL BASE CURRENT (ANSI/IEEE C57.12.00-1993)

K = CONSTANT DETERMINED AT MAXIMUM I WITH T = 2S

NOTE: SAMPLE $I^2t = K$ CURVES HAVE BEEN PLOTTED FOR SELECTED TRANSFORMER IMPEDANCES AS NOTED.

Figure A.3—Category III transformers:
1668–10 000 kVA single-phase;
5001–30 000 kVA three-phase

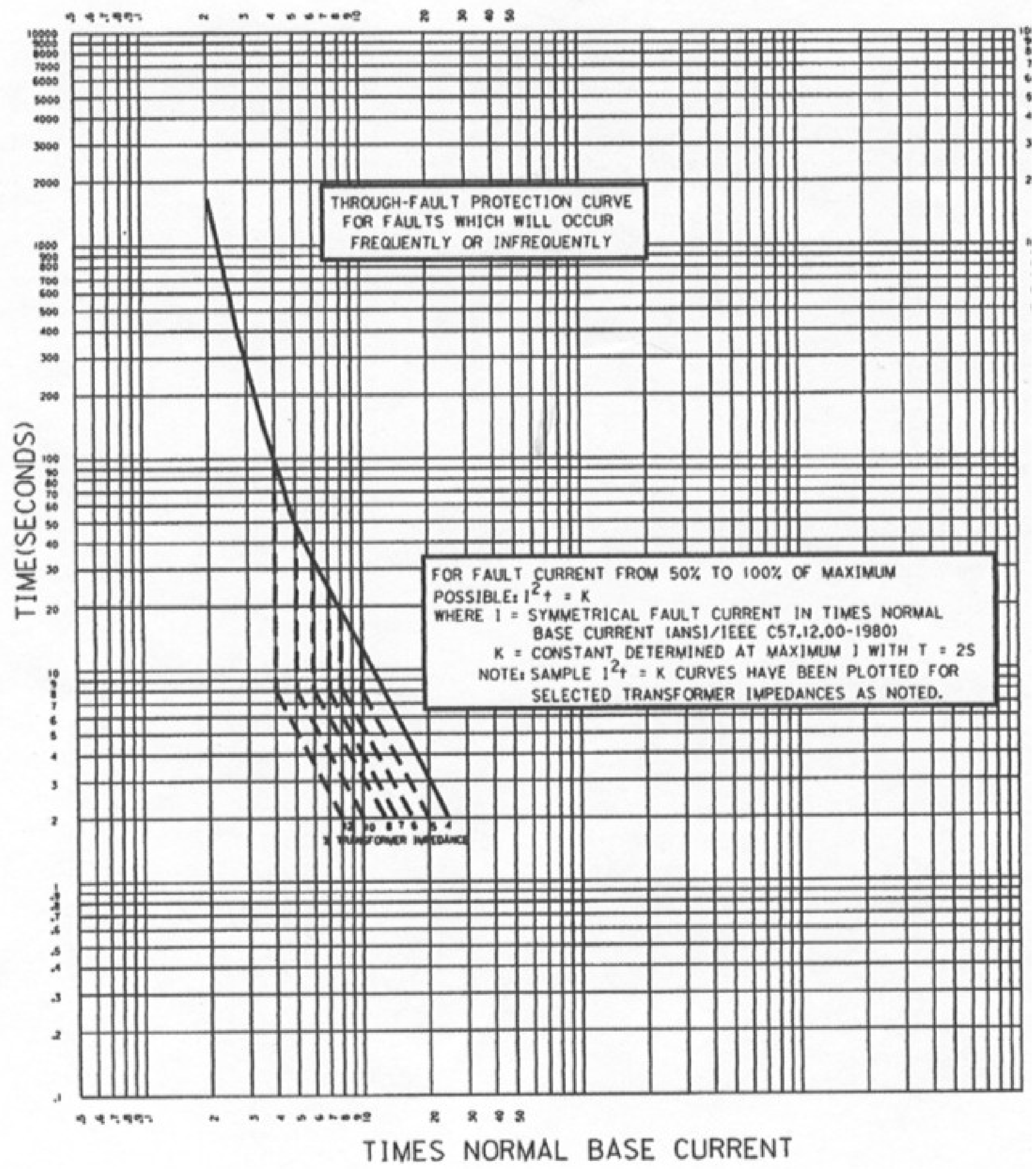


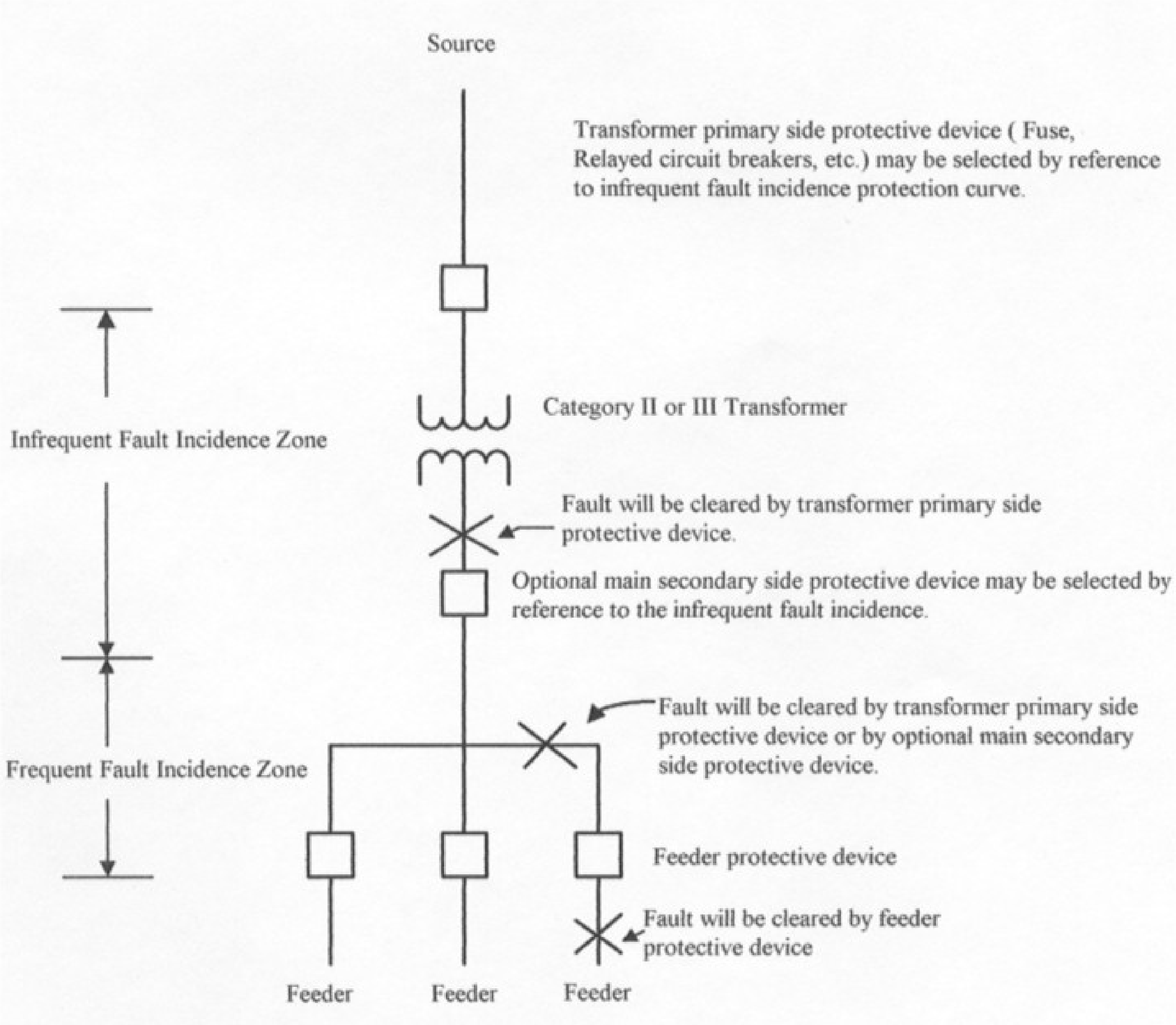
Figure A.4—Category IV transformers: above 10 000 kVA single-phase; above 30 000 kVA three-phase

Through Fault Protection

- It is widely recognized that damage to transformers from through-faults is the result of thermal and mechanical effects. The latter have recently gained increased recognition as a major concern of transformer failure. Though the temperature rise associated with high magnitude through-faults is typically quite acceptable, the mechanical effects are intolerable if such faults are permitted to occur with any regularity. This results from the cumulative nature of some of the mechanical effects, particularly insulation compression, insulation wear, and friction-induced displacement. The damage that occurs as a result of these cumulative effects is a function of not only the magnitude and duration of through-faults, but also the total number of such faults.

Through Fault Protection

- Infrequent- and frequent-fault incidence zones



Transformer primary side protective device (Fuse, Relayed circuit breakers, etc.) may be selected by reference to infrequent fault incidence protection curve.

Fault will be cleared by transformer primary side protective device.

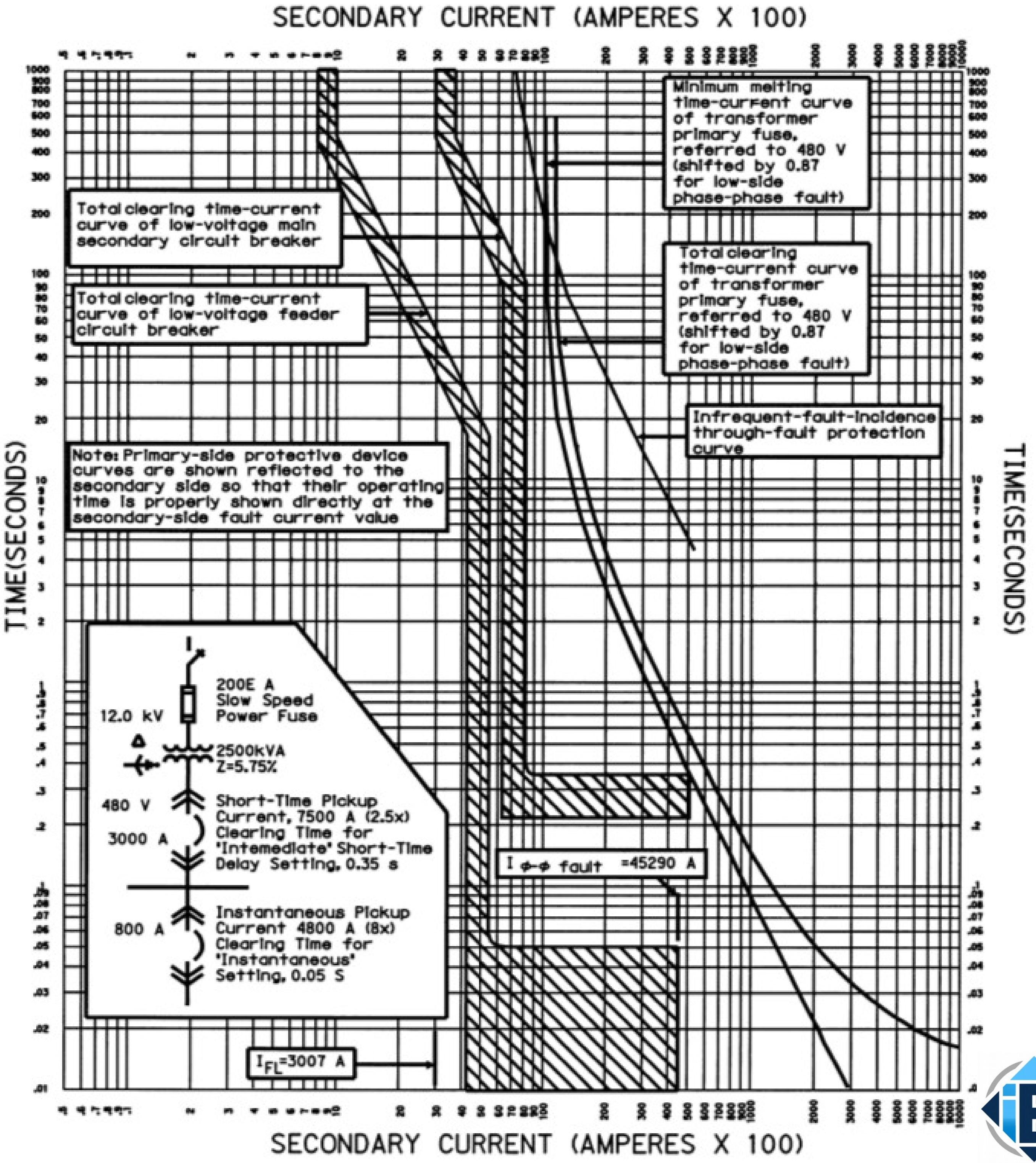
Optional main secondary side protective device may be selected by reference to the infrequent fault incidence.

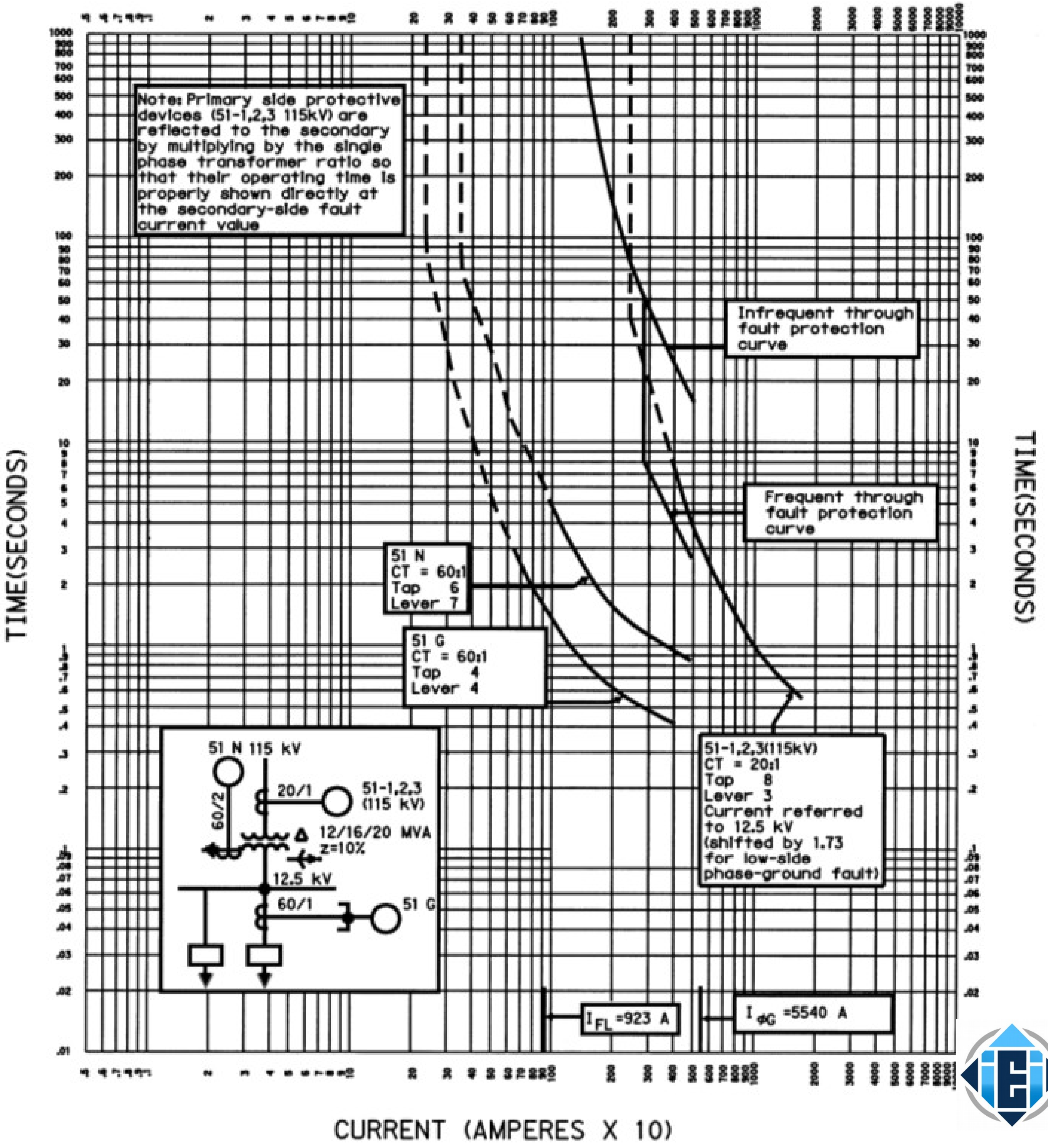
Fault will be cleared by transformer primary side protective device or by optional main secondary side protective device.

Fault will be cleared by feeder protective device

Infrequent vs. Frequency Fault Protection of Transformers

- Infrequent - Protected secondary-side conductors
- Frequent – Overhead lines


SECONDARY CURRENT (AMPERES X 100)
TIME(SECONDS)
Total clearing time-current curve of low-voltage main secondary circuit breaker
Total clearing time-current curve of low-voltage feeder circuit breaker
Minimum melting time-current curve of transformer primary fuse, referred to 480 V (shifted by 0.87 for low-side phase-phase fault)
Total clearing time-current curve of transformer primary fuse, referred to 480 V (shifted by 0.87 for low-side phase-phase fault)
Infrequent-fault-incidence through-fault protection curve
Note: Primary-side protective device curves are shown reflected to the secondary side so that their operating time is properly shown directly at the secondary-side fault current value
12.0 kV
200E A Slow Speed Power Fuse
2500kVA Z=5.75%
480 V
3000 A
Short-Time Pickup Current, 7500 A (2.5x) Clearing Time for 'Intemediate' Short-Time Delay Setting, 0.35 s
800 A
Instantaneous Pickup Current 4800 A (8x) Clearing Time for 'Instantaneous' Setting, 0.05 S
$I_{\phi-\phi}$ fault =45290 A
I_{FL}=3007 A
1000
100
10
1
.1
.01
10
100
1000
10000


Note: Primary side protective devices (51-1,2,3 115kV) are reflected to the secondary by multiplying by the single phase transformer ratio so that their operating time is properly shown directly at the secondary-side fault current value
Infrequent through fault protection curve
Frequent through fault protection curve
51 N
CT = 60:1
Tap 6
Lever 7
51 G
CT = 60:1
Tap 4
Lever 4
51-1,2,3(115kV)
CT = 20:1
Tap 8
Lever 3
Current referred to 12.5 kV (shifted by 1.73 for low-side phase-ground fault)
51 N 115 kV
60/2
20/1
51-1,2,3 (115 kV)
Δ 12/16/20 MVA
z=10%
12.5 kV
60/1
51 G
I_{FL}=923 A
$I_{\phi G}$=5540 A
TIME(SECONDS)
TIME(SECONDS)
CURRENT (AMPERES X 10)
1000
100
10
1
.1
.01
10
100
1000
10000