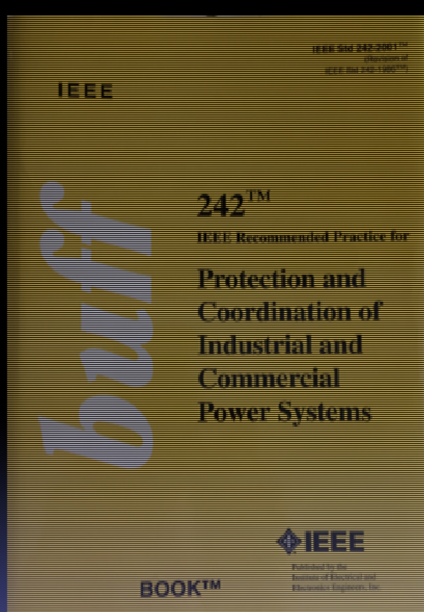
IEEE STD. 3004.8-2016
IEEE RP FOR MOTOR PROTECTION IN INDUSTRIAL & COMMERCIAL POWER SYSTEMS
OVERVIEW & WHAT'S NEW!

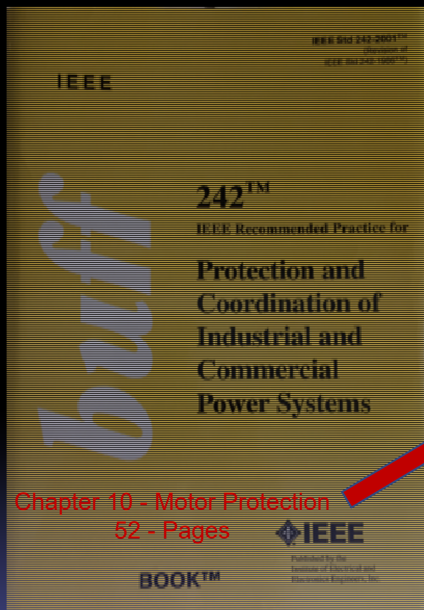
Lorraine K. Padden
Senior Member, IEEE
Padden Engineering, LLC
paddeneng@aol.com

John A. Kay
Fellow, IEEE
Rockwell Automation
jakay@ra.rockwell.com

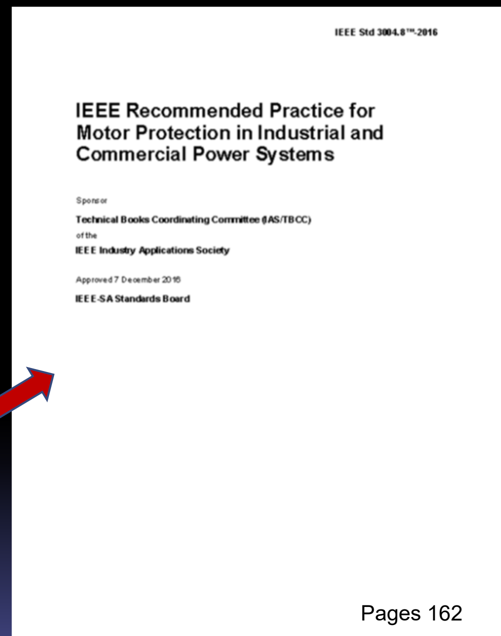


16 Chapters

- Principles
- Short-Circuit calculations
- Instrument transformers
- Selection of relays
- LV Fuses
- HV Fuses
- LV Circuit breaker
- Ground fault protection
- Conductor protection
- **10. Motor protection**
- Transformer protection
- Generator protection
- Bus & switchgear protection
- Service supply line protection
- Overcurrent coordination
- Maintenance, testing, calibrate



Chapter 10 - Motor Protection
52 - Pages



IEEE Std 3004.8™-2016

IEEE Recommended Practice for Motor Protection in Industrial and Commercial Power Systems

Sponsor

Technical Books Coordinating Committee (IAS/TBCC)
of the
IEEE Industry Applications Society

Approved 7 December 2016

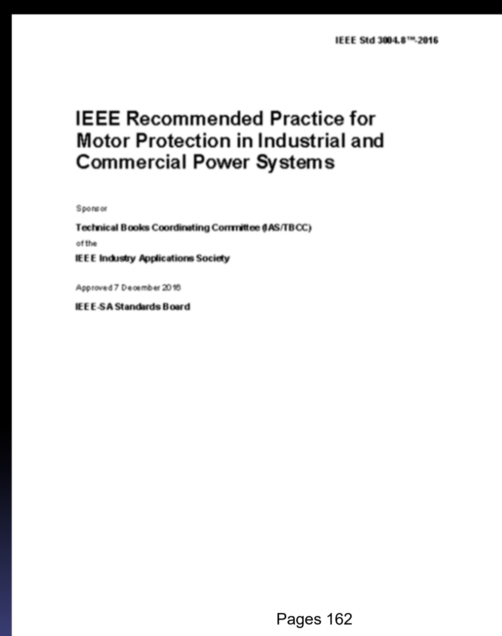
IEEE-SA Standards Board

Pages 162

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 3

PAR 2010 - 2016

- General update
- Reduced-voltage motor starting
- Recommended protection functions
- Single-line and three-line diagrams
- Adjustable speed drive applications
- DC motor protection
- Motor bus transfer
- Partial discharge monitoring
- Detailed example of motor protection using a multifunction motor protection relay



IEEE Std 3004.8™-2016

IEEE Recommended Practice for Motor Protection in Industrial and Commercial Power Systems

Sponsor

Technical Books Coordinating Committee (IAS/TBCC)
of the
IEEE Industry Applications Society

Approved 7 December 2016

IEEE-SA Standards Board

Pages 162

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 4

PAR 2010 - 2016

- General update
- Reduced-voltage motor starting
- Recommended protection functions
- Single-line and three-line diagrams
- Adjustable speed drive applications
- DC motor protection
- Motor bus transfer
- Partial discharge monitoring
- Detailed example of motor protection using a multifunction motor protection relay

- ➢ Update Table 4
- ➢ Three-line diagrams
- ➢ In-depth discussions

- ➢ New Table 6
  - ➢ Minimum
  - ➢ Fused, Critical Service
  - ➢ Synchronous

- ➢ C37.96
- ➢ Zones of Protection

- ➢ New Annex C

- ➢ C37.96
- ➢ One-line diagram & TCC
- ➢ Detailed setting Tables

LP
- General overview
  - Low-voltage motor protection
  - Medium-voltage motor protection

JK
- Multifunction motor protection relays (11M)
  - MV Contactor controlled fused starters
  - MV Breaker controlled starters

JK
- Adjustable Speed Drives (ASD)

LP
- Motor monitoring - prefailure
  - Vibration, winding temperature
  - On-line partial discharge, others

JK/LP
- Information
  - Reduced voltage starting; Motor bus transfer
  - Hazardous locations; Arc flash hazards

General overview

Low-voltage Medium-voltage

General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. Factors to consider …
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

IEEE Std 3004.8™-2016

IEEE Recommended Practice for Motor Protection in Industrial and Commercial Power Systems

Sponsor

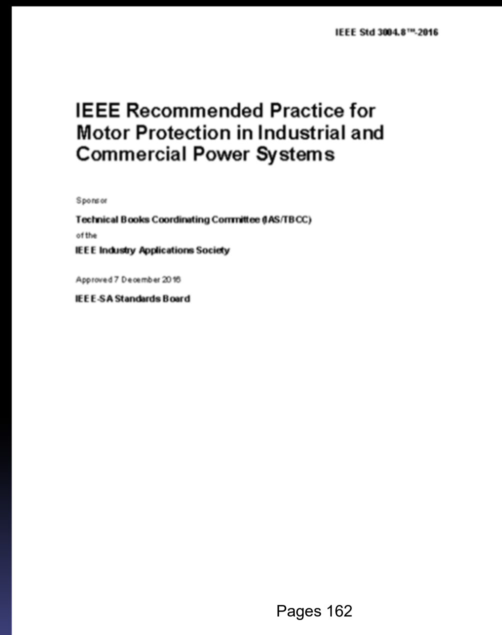
Technical Books Coordinating Committee (IAS/TBCC)
of the
IEEE Industry Applications Society

Approved 7 December 2016
IEEE-SA Standards Board

Pages 162

General overview

- Annex A - Bibliography
- Annex B – IEEE device designations
- Annex C – Motor condition monitoring, on-line
- Annex D – Motor protection example
- Annex E – Motor open circuit time constant


IEEE Std 3004.8™-2016

IEEE Recommended Practice for Motor Protection in Industrial and Commercial Power Systems

Sponsor

Technical Books Coordinating Committee (IAS/TBCC)

of the

IEEE Industry Applications Society

Approved 7 December 2016

IEEE-SA Standards Board

Pages 162

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 9

General overview

1. **Scope**
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. Factors to consider …
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

- **Protection of motors**
- **Industrial & commercial power systems**

✓ **Power-oriented engineer**
  - ✓ **Limited experience**
  - ✓ **All engineers doing electrical design**

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 10

General overview

1. Scope
2. **Normative references**
3. Definitions, abbreviations
4. General discussion
5. Factors to consider …
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

- **Motor standards**
  - ✓ **IEEE Std. 841, TEFC**
  - ✓ **API 541, 546, 547**
  - ✓ **NEMA MG 1-2011**
- **Testing standards, IEEE**
  - ✓ **112, Induction**
  - ✓ **115, Synchronous**
  - ✓ **43, Insulation resistance**
  - ✓ **620, Thermal limit curves**
  - ✓ **1349, Rotor temperature**

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 11

General overview

1. Scope
2. **Normative references**
3. Definitions, abbreviations
4. General discussion
5. Factors to consider …
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

- **Protection standards, IEEE**
  - ✓ **C37.2, Device functions**
  - ✓ **C37.96, Motor protection**
  - ✓ **C37.110, CTs for relaying**
  - ✓ **C62.21, Surge protection motors, 1000 V & greater**
  - ✓ **3004.1, Instrument transformers**
  - ✓ **3004.5, LV Circuit breakers**

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 12

General overview

1. Scope
2. **Normative references**
3. Definitions, abbreviations
4. General discussion
5. Factors to consider …
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

- **Equipment standards, IEEE**
  - ✓ **C37.06, Breaker >1000 V**
  - ✓ **C37.13, LVPCB**
  - ✓ **C37.14, DC power CB**
  - ✓ **C37.17, Trip systems**
  - ✓ **C37.46, HV Fuses**
  - ✓ **1015, Blue Book, LVCB**
  - ✓ **1683, MCCs, Electric hazard reducing**

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 13

General overview

1. Scope
2. **Normative references**
3. Definitions, abbreviations
4. General discussion
5. Factors to consider …
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

- **Equipment standards, NEMA**
  - ✓ **ICS 2, Contactors, controllers, overload relays; 600 V**
- **Equipment standards, UL**
  - ✓ **347, MV AC contactors, controllers, and control centers**
  - ✓ **845, MCCs**

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 14

General overview

1. Scope
2. Normative references
3. **Definitions, abbreviations**
4. General discussion
5. Factors to consider …
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

Almost 60 definitions

✓ **normal operating condition:**
As applied to motors, a normal operating condition is operating at rated full-load steady state conditions.

(See NFPA 70, *National Electrical Code, Section 500.8(B)(5)*)
Locked-rotor, starting, single-phasing, and operating above base nameplate kilowatt or horsepower are not normal operating conditions

✓ **abnormal operating condition:**
As applied to motors, including, but not limited to, starting, locked rotor, voltage unbalance, overload, and short-circuit. As applied to equipment in classified locations, equipment failure is considered to be an abnormal operating condition.

General overview

1. Scope
2. Normative references
3. **Definitions, abbreviations**
4. General discussion
5. Factors to consider …
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

Over 75 abbreviations

LV	Low-voltage
MV	Medium-voltage
FLC	full-load current
LRC	locked rotor current
FLT	full load torque
CT	Current Transformer
VT	Voltage Transformer
SF	service factor
TEFC	totally enclosed fan-cooled
IOC	instantaneous overcurrent
TOC	time overcurrent
HRG	High Resistance Ground
NEC®	National Electrical Code
ASD	adjustable speed drive

General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. **General discussion**
5. Factors to consider …
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

Voltage drop across the conductors

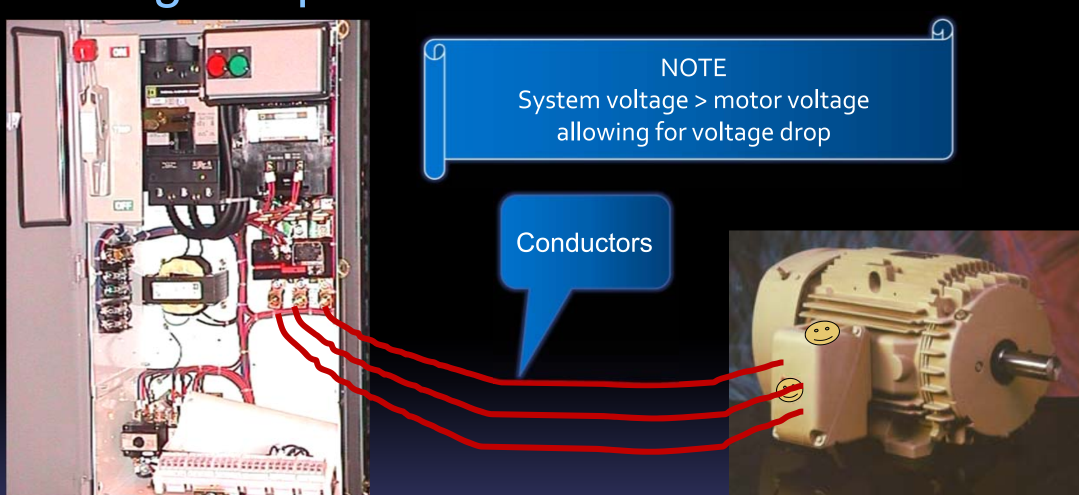


Table 1 Nameplate voltage of LV motors

Nominal System Voltage	Typical Motor Nameplate Voltage
Single-phase System	Single-phase Motor
120 V	115 V
240 V	230 V
Three-phase System	Three-phase Motor
208 V	200 V
240 V	230 V
480 V	460 V
600 V	575 V

Table 2 Nameplate voltage of MV motors

Nominal System Voltage	Typical Motor Nameplate Voltage
Three-phase System	Three-phase Motor
2400 V	2300 V
4160 V	4000 V
6900 V	6600 V
13.8 kV	13.2 kV

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 19

General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. **Factors to consider …**
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

5.1 Motor characteristics
5.2 Motor starting conditions
5.3 Ambient conditions
5.4 Driven equipment
5.5 Power system quality
5.6 Motor importance
5.7 Load side faults for motor controllers
5.8 Ground faults
5.9 Maintenance capability & schedule
5.10 Service factor
5.11 Application considerations
5.12 Motor & conductor protection
5.13 Fixed capacitor applications

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 20

Table 3
Typical characteristics and applications of fixed frequency medium ac squirrel-cage induction motors
(NEMA MG 10-2013)

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 21

Polyphase characteristics	Locked-rotor torque (percent rated load torque)	Pull-up torque (percent rated load torque)	Breakdown torque (percent rated load torque)	Locked-rotor current (percent rated load current)	Slip	Typical applications	Relative efficiency
Design A Normal locked rotor torque and high locked rotor current	70–275[a]	65–190[a]	175–300	Not defined	0.5–5%	Fans, blowers, centrifugal pumps and compressors, motor-generator sets, etc., where starting torque requirements are relatively low	Medium or high
Design B Normal locked-rotor torque and normal locked-rotor current	70–275[a]	65–190[a]	175–300[a]	600–800	0.5–5%	Fans, blowers, centrifugal pumps and compressors, motor-generator sets, etc., where starting torque requirements are relatively low	Medium or high
Design C High locked-rotor torque and normal locked-rotor current	200–285[a]	140–195[a]	190–225[a]	600–800	1–5%	Conveyors, crushers, stirring machines, agitators, reciprocating pumps and compressors, etc., where starting under load is required	Medium

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 22

Polyphase characteristics	Locked-rotor torque (percent rated load torque)	Pull-up torque (percent rated load torque)	Breakdown torque (percent rated load torque)	Locked-rotor current (percent rated load current)	Slip	Typical applications	Relative efficiency
Design D High locked-rotor torque and high slip	275	Not defined	275	600–800	≥5%	High peak loads with or without flywheels such as punch presses, shears, elevators, extractors, winches, hoists, oil-well pumping and wire-drawing machines	Medium
IEC Design H High locked rotor torque and high locked rotor current	200–285[a]	140–195[a]	190–225[a]	800–1000	1–5%	Conveyors, crushers, stirring machines, agitators, reciprocating pumps and compressors, etc., where starting under load is required	Medium
IEC Design N Normal locked-rotor torque and high locked rotor current	75–190[a]	60–140[a]	160–200[a]	800–1000	0.5–3%	Fans, blowers, centrifugal pumps and compressors, motor-generator sets, etc., where starting torque requirements are relatively low	Medium or high

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 23

General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. **Factors to consider …**
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

5.1 Motor characteristics
5.2 Motor starting conditions
5.3 Ambient conditions
5.4 Driven equipment
5.5 Power system quality
5.6 Motor importance
5.7 Load side faults for motor controllers
5.8 Ground faults
5.9 Maintenance capability & schedule
5.10 Service factor
5.11 Application considerations
5.12 Motor & conductor protection
5.13 Fixed capacitor applications

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 24

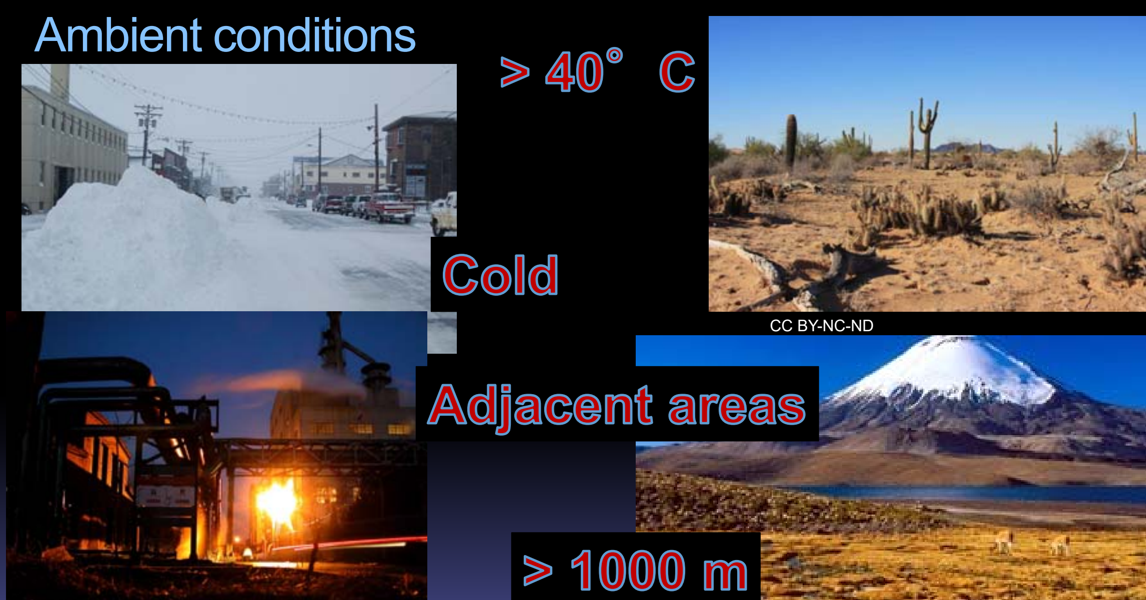
General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. **Factors to consider …**
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

5.1 Motor characteristics
5.2 Motor starting conditions
5.3 Ambient conditions
5.4 Driven equipment
5.5 Power system quality
5.6 Motor importance
5.7 Load side faults for motor controllers
5.8 Ground faults
5.9 Maintenance capability & schedule
5.10 Service factor
5.11 Application considerations
5.12 Motor & conductor protection
5.13 Fixed capacitor applications

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 25

Ambient conditions



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 26

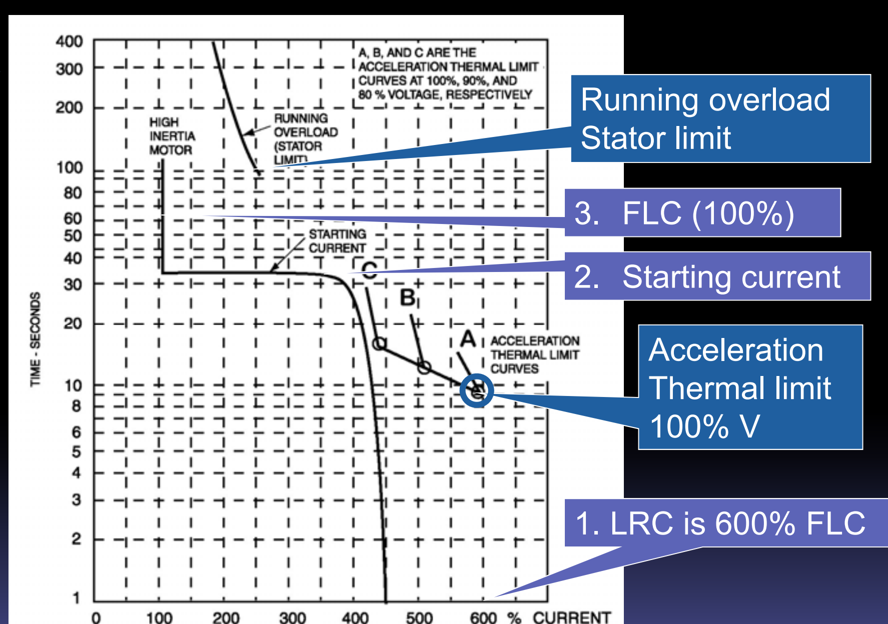
General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. **Factors to consider …**
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

5.1 Motor characteristics
5.2 Motor starting conditions
5.3 Ambient conditions
5.4 Driven equipment
5.5 Power system quality
5.6 Motor importance
5.7 Load side faults for motor controllers
5.8 Ground faults
5.9 Maintenance capability & schedule
5.10 Service factor
5.11 Application considerations
5.12 Motor & conductor protection
5.13 Fixed capacitor applications

High inertia motor

Fig. 6
Typical time-current and thermal limit characteristic curves



General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. **Factors to consider …**
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

5.1 Motor characteristics
5.2 Motor starting conditions
5.3 Ambient conditions
5.4 Driven equipment
5.5 Power system quality
5.6 Motor importance
5.7 Load side faults for motor controllers
5.8 Ground faults
5.9 Maintenance capability & schedule
5.10 Service factor
5.11 Application considerations
5.12 Motor & conductor protection
5.13 Fixed capacitor applications

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 29

Maintenance capability and schedule


CC BY-NC-ND

Complex protection
- Cannot or will not be maintained

Selecting & setting overload protection
- Inadvertent setting changes
- Non-ambient compensated

Critical motors
- Proper condition monitoring

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 30

General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. **Factors to consider …**
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

5.1 Motor characteristics
5.2 Motor starting conditions
5.3 Ambient conditions
5.4 Driven equipment
5.5 Power system quality
5.6 Motor importance
5.7 Load side faults for motor controllers
5.8 Ground faults
5.9 Maintenance capability & schedule
5.10 Service factor
5.11 Application considerations
5.12 Motor & conductor protection
5.13 Fixed capacitor applications

General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. **Factors to consider …**
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

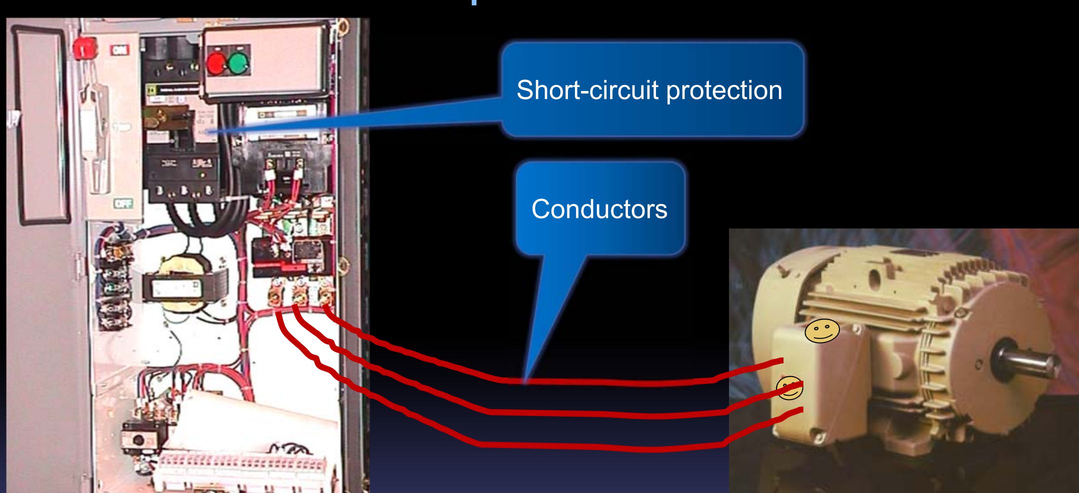
5.1 Motor characteristics
5.2 Motor starting conditions
5.3 Ambient conditions
5.4 Driven equipment
5.5 Power system quality
5.6 Motor importance
5.7 Load side faults for motor controllers
5.8 Ground faults
5.9 Maintenance capability & schedule
5.10 Service factor
5.11 Application considerations
5.12 Motor & conductor protection
5.13 Fixed capacitor applications

General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. **Factors to consider …**
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

5.1 Motor characteristics
5.2 Motor starting conditions
5.3 Ambient conditions
5.4 Driven equipment
5.5 Power system quality
5.6 Motor importance
5.7 Load side faults for motor controllers
5.8 Ground faults
5.9 Maintenance capability & schedule
5.10 Service factor
5.11 Application considerations
5.12 Motor & conductor protection
5.13 Fixed capacitor applications

Motor & conductor protection



General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. **Factors to consider …**
6. Types of protection
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

5.1 Motor characteristics
5.2 Motor starting conditions
5.3 Ambient conditions
5.4 Driven equipment
5.5 Power system quality
5.6 Motor importance
5.7 Load side faults for motor controllers
5.8 Ground faults
5.9 Maintenance capability & schedule
5.10 Service factor
5.11 Application considerations
5.12 Motor & conductor protection
5.13 Fixed capacitor applications

Fixed capacitor applications

- Modify overload setting if on the load side
- Extend the motor open circuit time constant
- Motor capacitor application may not be recommended for re-acceleration motors

General overview

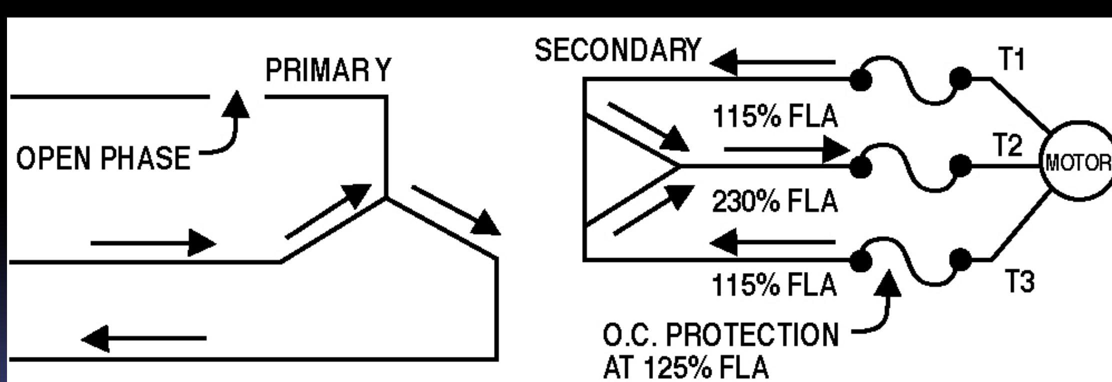
1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. Factors to consider …
6. **Types of protection**
7. LV motor protection
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

- **Recommended protection functions**
  - ✓ **New Table 6**
    - ✓ **Minimum**
    - ✓ **Fused, Critical Service**
    - ✓ **Synchronous**
- **Single-line and three-line diagrams**

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 37

Fig. 10 Loss-of-phase current

b) wye-delta connected transformer with wye or delta connected motor



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 38

General overview

1. Scope
2. Normative references
3. Definitions, abbreviations
4. General discussion
5. Factors to consider …
6. Types of protection
7. **LV motor protection**
8. MV motor protection
9. Protection for ac ASD applications
10. LV dc motor protection
11. Hazardous (classified) locations

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 39

General overview

Low-voltage **Medium-voltage**

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 40

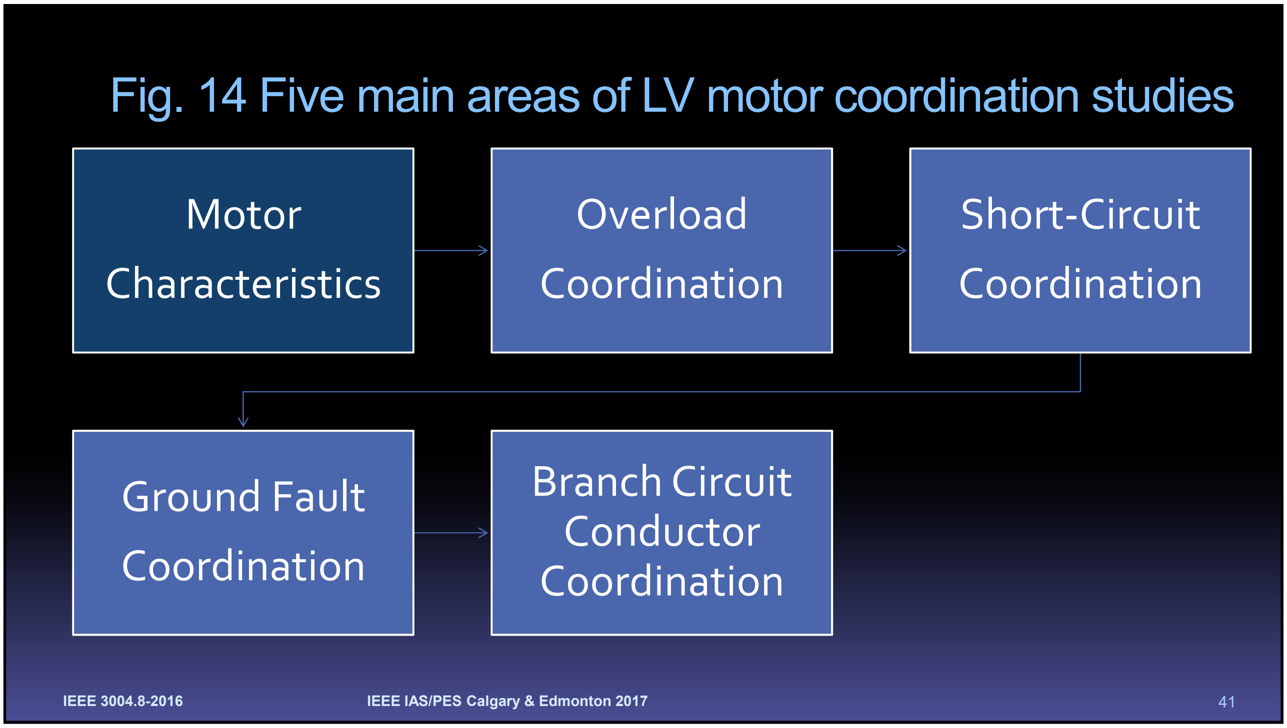


Fig. 14 Five main areas of LV motor coordination studies
Motor Characteristics
Overload Coordination
Short-Circuit Coordination
Ground Fault Coordination
Branch Circuit Conductor Coordination
IEEE 3004.8-2016
IEEE IAS/PES Calgary & Edmonton 2017
41

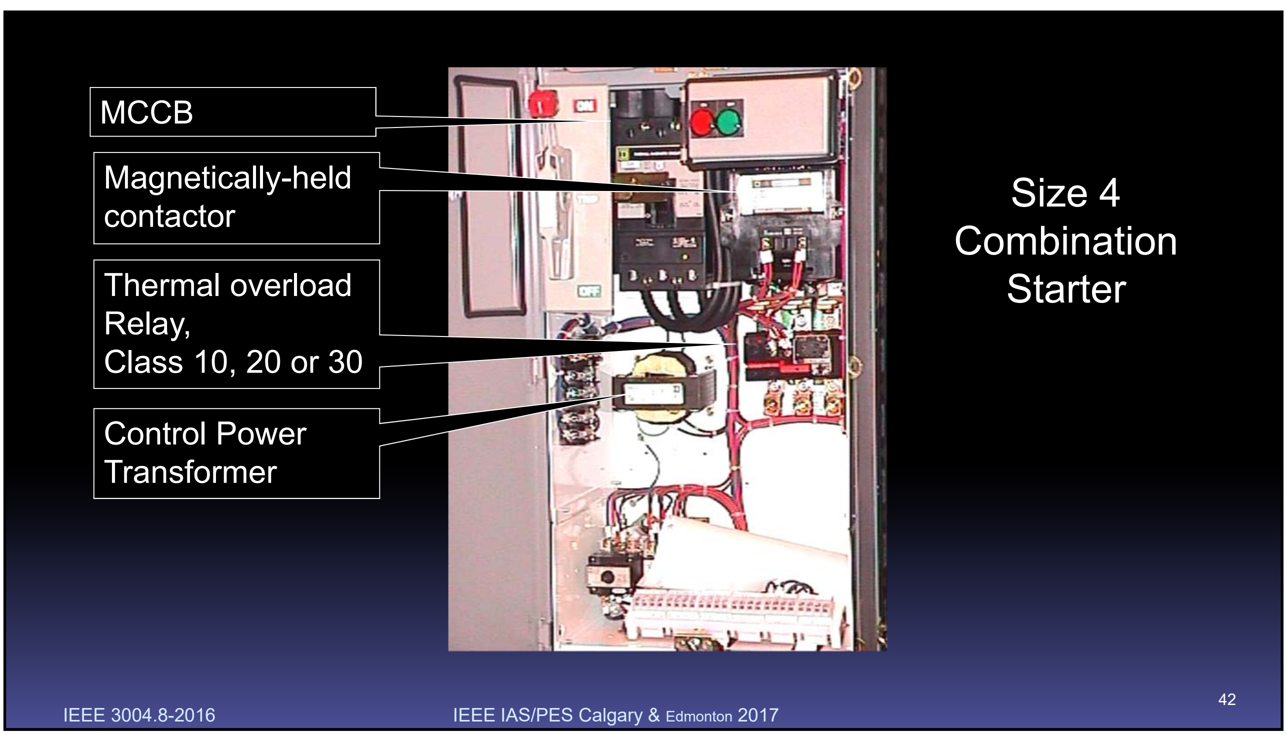
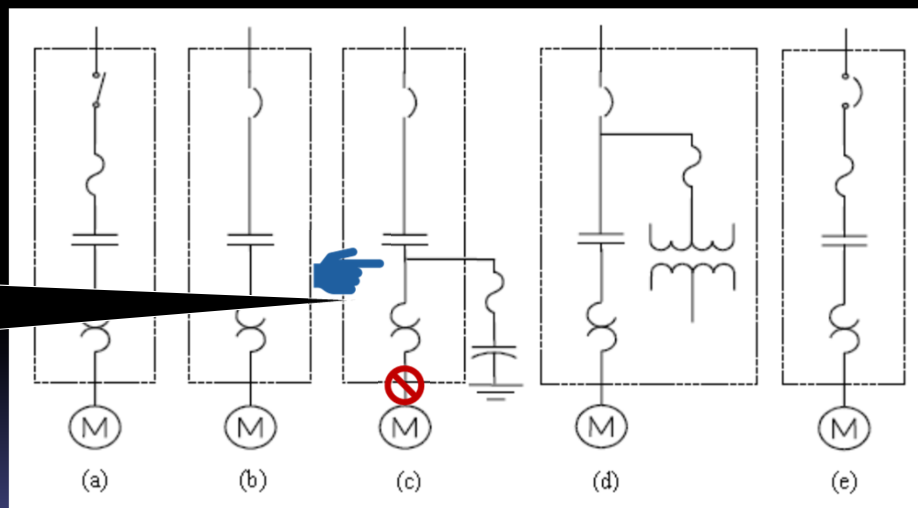

MCCB
Magnetically-held contactor
Thermal overload Relay,
Class 10, 20 or 30
Control Power Transformer
Size 4 Combination Starter
42
IEEE 3004.8-2016
IEEE IAS/PES Calgary & Edmonton 2017

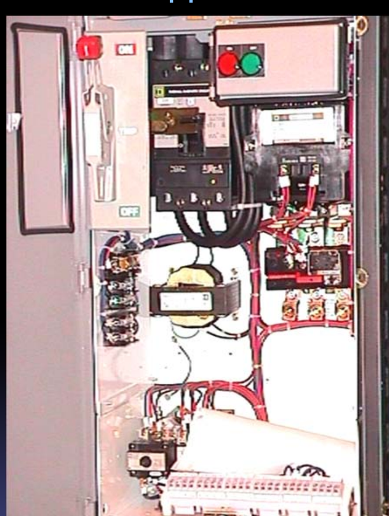
Fig. 15 Typical low-voltage starter one-line diagrams for industrial applications using MCCs or combination starters



c) Typical location for power factor correction capacitors

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 43

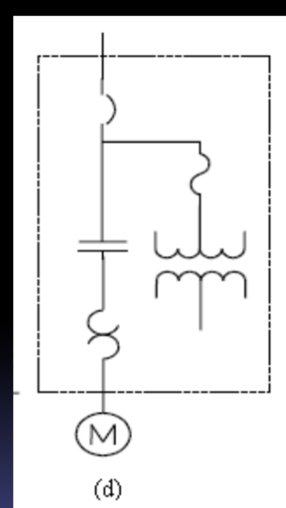
Fig. 15 Typical LV starter one-line diagrams for industrial applications using MCCs or combination starters



Motor size & load
Starter size & type

Motor nameplate FLC
Overload selection & settings

System Short-circuit kA
Fuse selection or Breaker selection & settings

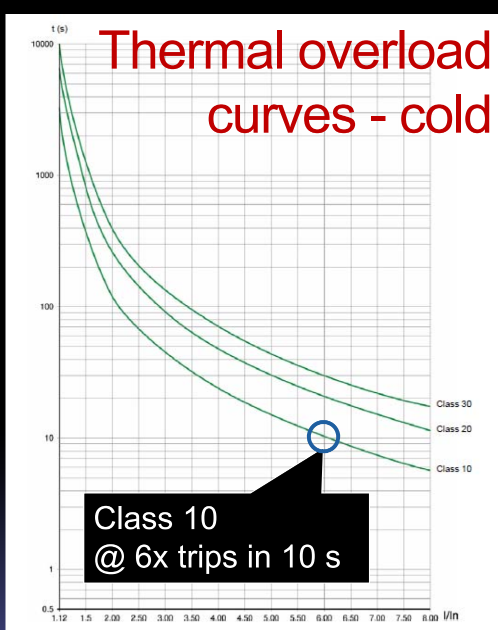


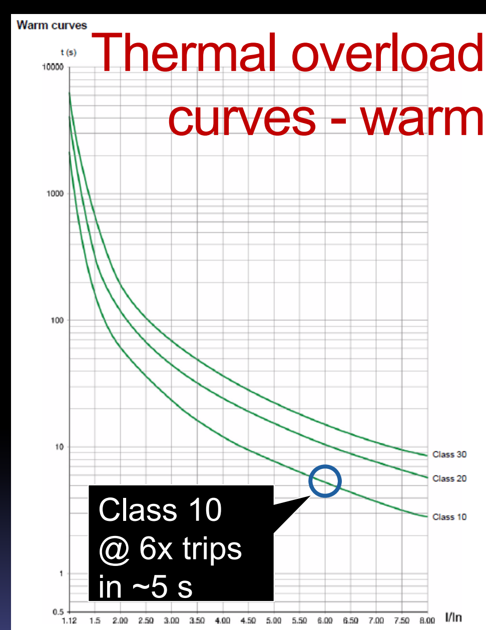
IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 44

High Available Short-Circuit

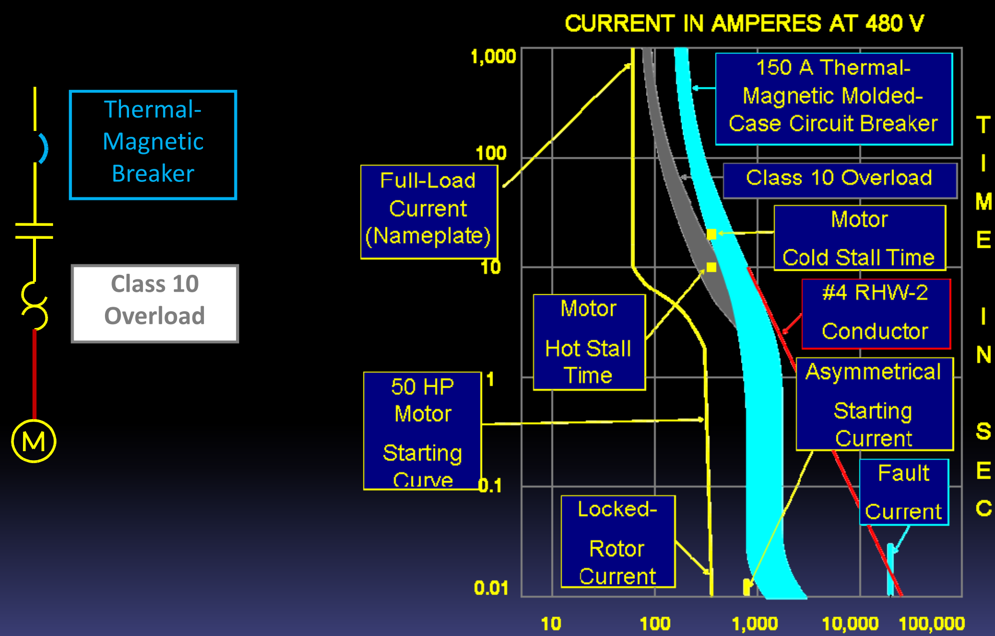
Correcting for X/R ratio

- 22 kA
- 25 kA
- 30 kA
- 35 kA
- 42 kA
- **50 kA**
- **65 kA**
- 100 kA



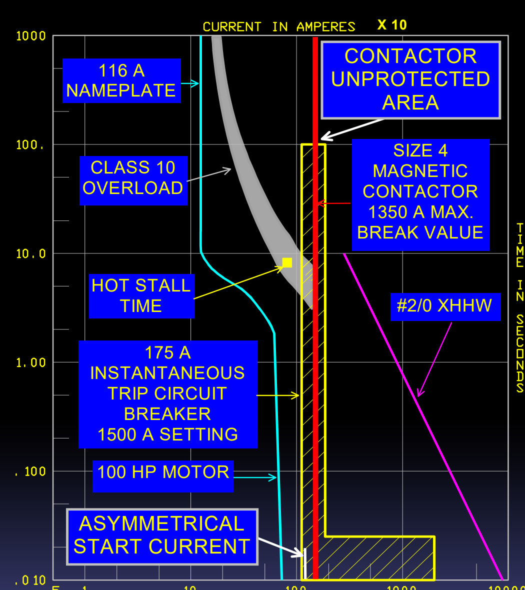


IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 46



STANDARD EFFICIENCY COORDINATION PLOT

- 100 hp, 460 V, NEMA B
  1276 A asymmetrical LRC
- 175 A Inst. trip breaker,
  1500 A setting (12xFLC)
- FALSE TRIPPING
- UNPROTECTED CONTACTOR



General overview

Low-voltage **Medium-voltage**

Multifunction motor protection relay, 11M

DESCRIPTION	INDUCTION MOTORS PROTECTION FUNCTIONS			SYNCHRONOUS MOTORS PROTECTION FUNCTIONS
	Minimum	Fused E2 Contactor Controlled	Critical Service Breaker Controlled	Critical Service Breaker Controlled
Distance Relay				21 (or 51V)
Volts (U/O)	27	27	27/59	27/59
Directional Power				32
Undercurrent			37	37
Bearing Temperature Protection		38	38	38
Vibration Protection			39	39
Loss of Field				40
Current Balance		46	46	46
Negative Sequence		47	47	47
Incomplete Sequence				48
Thermal overload relay Overload operated by motor current (replica),	49	49	49	49
Stator winding thermal overload (also embedded detectors)	49S	49S	49S	49S

DESCRIPTION	INDUCTION MOTORS PROTECTION FUNCTIONS			SYNCHRONOUS MOTORS PROTECTION FUNCTIONS
	Minimum	Fused E2 Contactor Controlled	Critical Service Breaker Controlled	Critical Service Breaker Controlled
Breaker Failure (breaker only)			50BF	50BF
IOC ground (zero sequence CT) (delayed on start) - Breaker Trip or - Vacuum Contactor within rating	50G	50G	50G	50G
TOC ground (residually connected) - Breaker Trip or - Vacuum Contactor within rating	51N	51N	51N	51N
IOC-Locked Rotor (delayed on start)		50LR	50LR	
TOC (V-voltage restrained)	51		51	51V (or 21)
Short-circuit	Fuse or Breaker, 50	Fuse	50	50
Current Inhibit (Blocks Contactor Opening) [1]	50B	50B		

Footnote

[1]*Current inhibit*: Instantaneous phase overcurrent (50B) function blocks opening of the motor contactor when the fault current exceeds the interrupting rating of the contactor.

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 53

DESCRIPTION	INDUCTION MOTORS PROTECTION FUNCTIONS			SYNCHRONOUS MOTORS PROTECTION FUNCTIONS
	Minimum	Fused E2 Contactor Controlled	Critical Service Breaker Controlled	Critical Service Breaker Controlled
Excitation check relay				53
Power Factor				55
Field application relay				56
Voltage Balance (Loss of Phase)			60	60
# of Starts	66	66	66	66
Directional Overcurrent				67
Trip CircuitMonitor, alarm			TCM	TCM
Out-of-step				78
Frequency			81U/O	81R, 81U/O
Lockout		86	86	86
Motor Differential			87M	87M

Footnote

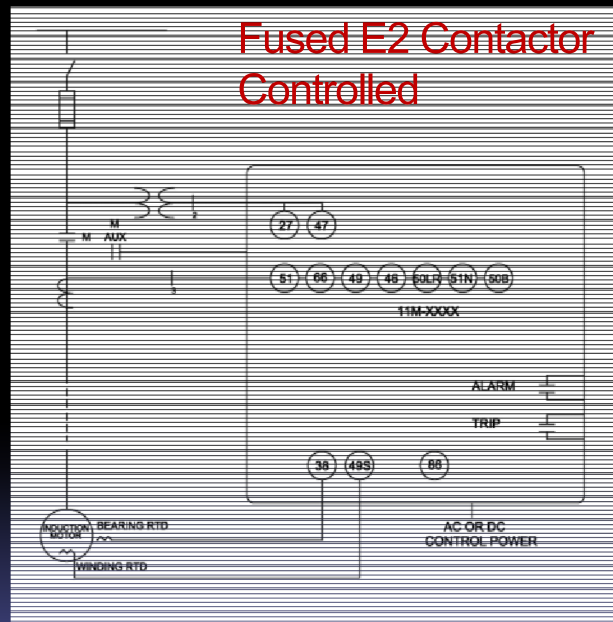
[2]See also Table B.3 Security, communication, and other protection functions

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 54

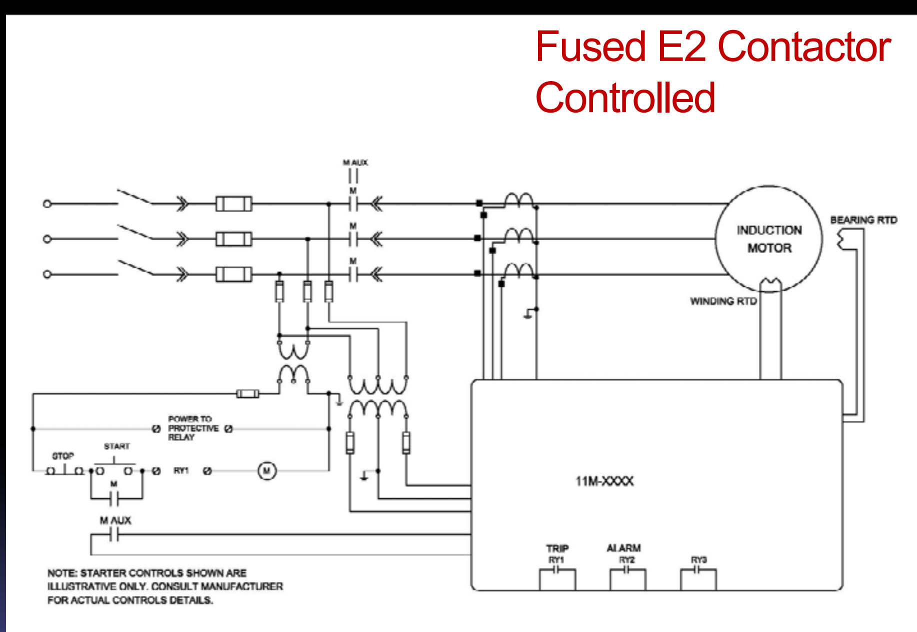
27 - Volts (U/O)
47 - Negative Sequence

51 - TOC
66 - # of Starts
49 - Thermal overload relay
Overload operated by motor current (replica)
46 - Current Balance
50LR - IOC-Locked Rotor
(delayed on start)
51N - TOC ground (residually connected)
– Contactor within rating
50B - Current Inhibit
(Blocks Contactor Opening)

38 - Bearing Temperature Protection
49S - Stator winding thermal overload
(also embedded detectors)
86 - Lockout



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 55



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 56

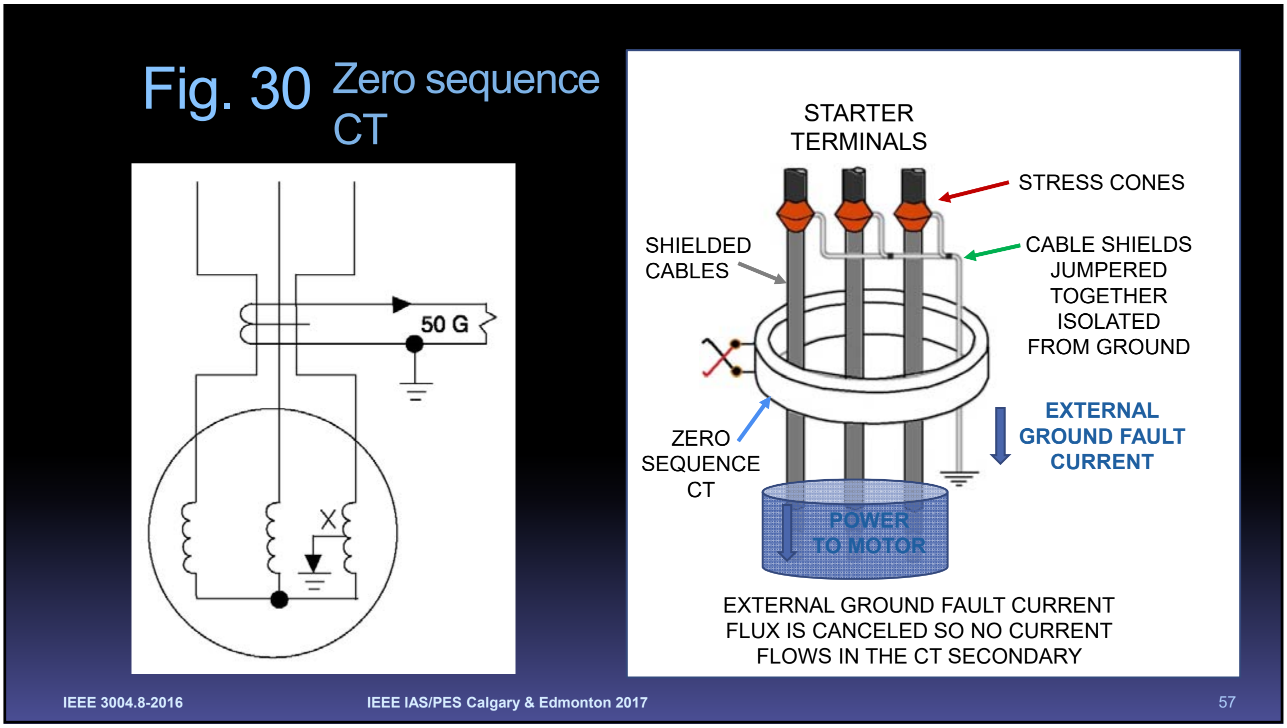


Fig. 30 Zero sequence CT
50 G
X
STARTER TERMINALS
STRESS CONES
SHIELDED CABLES
CABLE SHIELDS JUMPERED TOGETHER ISOLATED FROM GROUND
ZERO SEQUENCE CT
EXTERNAL GROUND FAULT CURRENT
POWER TO MOTOR
EXTERNAL GROUND FAULT CURRENT FLUX IS CANCELED SO NO CURRENT FLOWS IN THE CT SECONDARY
IEEE 3004.8-2016
IEEE IAS/PES Calgary & Edmonton 2017
57

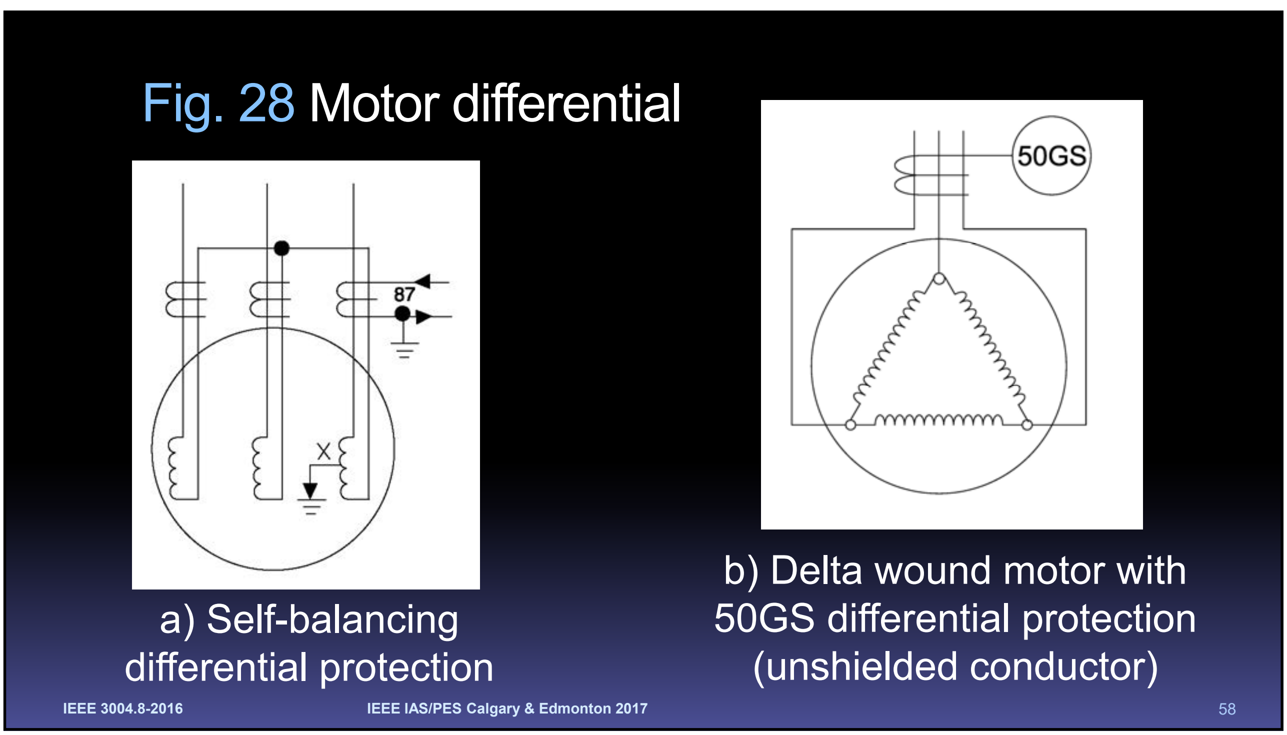


Fig. 28 Motor differential
87
X
50GS
a) Self-balancing differential protection
b) Delta wound motor with 50GS differential protection (unshielded conductor)
IEEE 3004.8-2016
IEEE IAS/PES Calgary & Edmonton 2017
58

Synchronous motor

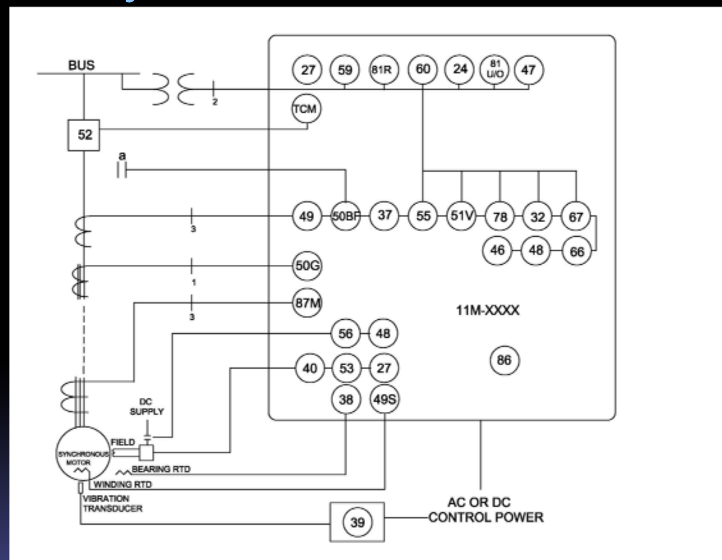
27/59 - Volts (U/O)
81R - Frequency, rate of change
81U/O – Frequency, under/over
60 - Voltage Balance (loss of phase)
24 – Overexcitation, V/Hz
47 - Negative Sequence

TCM – Trip Circuit Monitor

49 - Thermal overload relay
Overload operated by
motor current (replica)

50BF – Breaker failure
37 – Undercurrent

46 - Current Balance
48 - Incomplete Sequence
66 - # of Starts



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 59

Synchronous motor

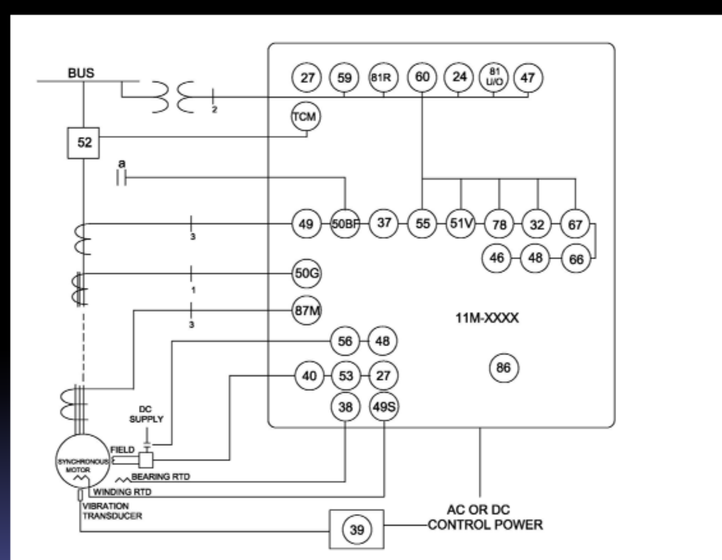
55 - Power Factor
51V - TOC (V-voltage restrained)
78 - Out-of-step
32 - Directional Power
67 - Directional Overcurrent

50G - IOC ground (zero sequence CT)
87M - Motor Differential

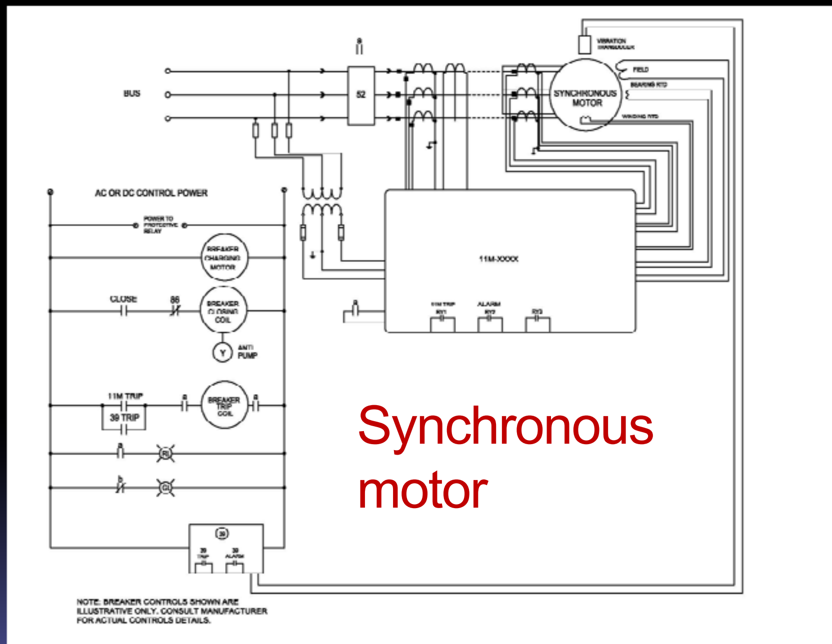
56 - Field application relay
48 - Incomplete Sequence
40 - Loss of Field
53 - Excitation check relay
27 - Volts (Under)

38 - Bearing Temperature Protection
49S - Stator winding thermal overload
(also embedded detectors)

86 - Lockout
39 - Vibration Protection



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 60



Synchronous motor

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 61

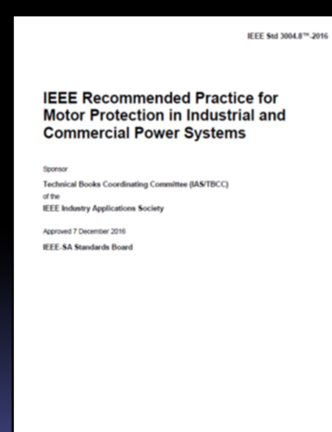
Questions ??

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 62

- LP
  - General overview
    - Low-voltage motor protection
    - Medium-voltage motor protection
- JK
  - Multifunction motor protection relays (11M)
    - MV Contactor controlled fused starters
    - MV Breaker controlled starters
- JK
  - Adjustable Speed Drives (ASD)
- LP
  - Motor monitoring - prefailure
    - Vibration, winding temperature
    - On-line partial discharge, others
- JK/LP
  - Information
    - Reduced voltage starting; Motor bus transfer
    - Hazardous locations; Arc flash hazards

IEEE Standard 3004.8™-2016

- Section 7 LV Motor Protection
- Section 8 MV Motor Protection
- Section 9 Protection for ac ASD applications
  - Device 11
    Microprocessor based multifunction device
  - Minimum of 3 protective features (numbers)


IEEE Std 3004.8™-2016

IEEE Recommended Practice for Motor Protection in Industrial and Commercial Power Systems

Sponsor
Technical Books Coordinating Committee (IAS/TBCC)
of the
IEEE Industry Applications Society

Approved 7 December 2016
IEEE-SA Standards Board

Bad things happen to good equipment…when assumptions are made

Why

What's affected…

How

When can we restart…

Who's responsible…!

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 65

Protection- Is it an art, a science or guess work?

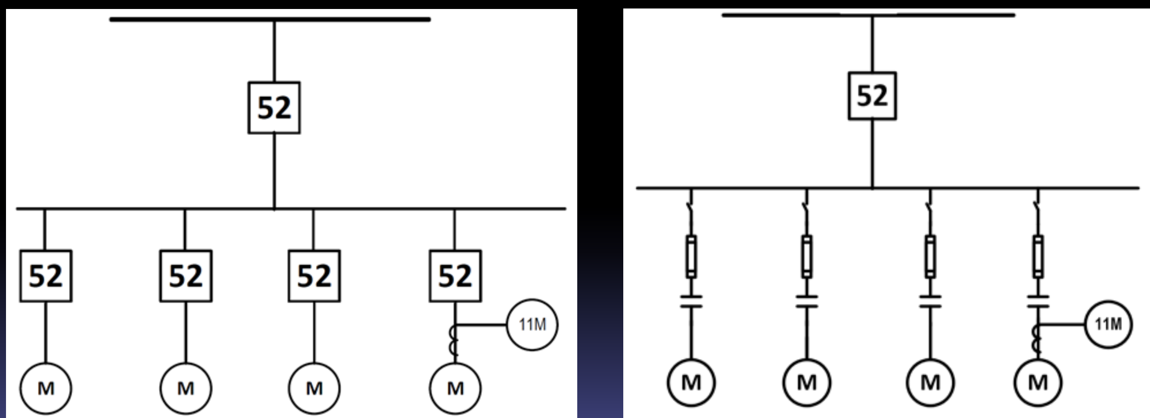
- Multifunction protection devices (MPR) are common place…
- Many vendors with many options… more everyday
- Most users only use between 20-30% of the these devices capabilities!
- Which protective elements are really important?

- Are there different protective setting based on switching devices?
- Are there setting differences based on control and application?

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 66

Proper Conventions

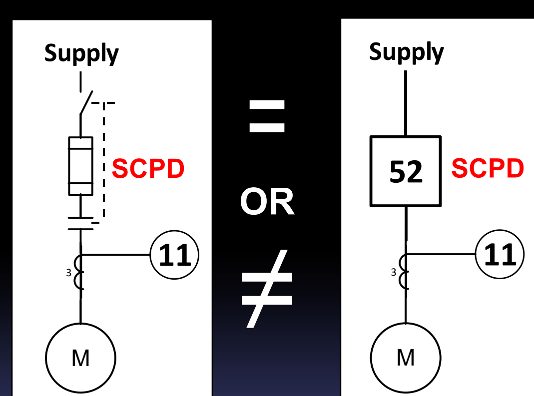
Does your perception of the protective methods and settings change... should it?



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 67

Protection- Is it an art, a science or guess work?

- Should Device 11 be programmed differently?
- Aren't the protective requirements the same?
  - Locked rotor
  - Jam or stall
  - Overcurrent
  - Overload
  - …



SCPD= Short Circuit Protective Device

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 68

Protection- Is it an art, a science or guess work?

- The SCPD and Device 11 must be coordinated so that each operates in its appropriate protection range
- Contactors are only rated for interrupting currents typically X10-15 their continuous rated current, e.g. 400A x 4000-6000A
- The SCPD must operate before the Device 11 opens the contactor
- The contactor will be damaged if it is forced to interrupt I > its interrupting rating

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 69

Contactors versus Breakers

- No protection element should trigger opening the contactor unless the fault current is less than contactors interrupting capabilities
- Same applies to differential protection relays used with contactors
- Fused contactor arrangements must be coordinated to support this condition

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 70

MV Contactors versus MV Breakers

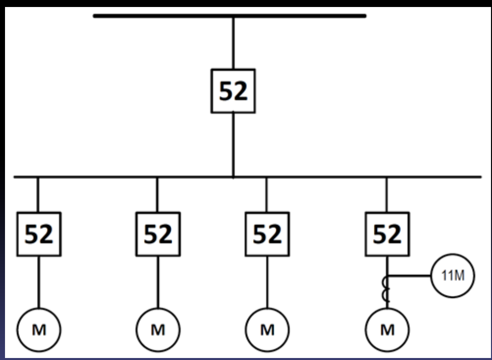
TYPICAL FAULT CLEARING TIME COMPARISON AT 20 X RATED CURRENT	
Vacuum Contactors (UL 347 Class E2 controller)	**Vacuum Circuit Breakers**
Current-limiting fuses clearing time is < ½ cycle	3 or 5 cycle interrupting time, **plus** the relay trip latency

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 71

Bad Habits…

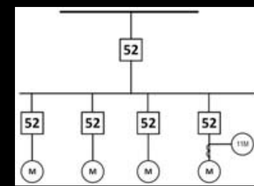
Generic use of the device number 52 does not distinguish the use of MV vacuum contactors versus circuit breakers

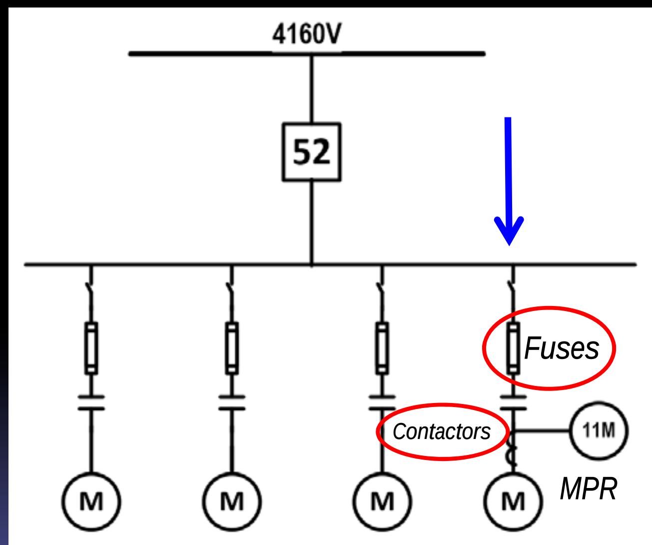
- How does one distinguish or determine the protective methods & settings?
- What if the actual hardware was this configuration…



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 72

Device Numbers & Definitions





Applications Best Suited for Switching Device

MV Circuit Breaker	MV Contactors
Disconnecting means for power bus	Motor control <800A
Substation switching	Controlling distribution transformers
Main-Tie-Main bus configurations	High duty switching requirements
Very large electric machines	Bypass for ASD or Soft Starters

Protection Functions

- So where are the issues?

	MV Circuit Breakers	MV Contactors
Can handle system S.C. current	Yes	**No**
Can handle overload currents	Yes	Yes
Can switch and carry rated current	Yes	Yes
Permitted to open under emergency high current conditions	Yes	**No**
Requires a supplemental S.C. protective device	**No**	Yes

Protection Functions

- So what settings are problematic?

	MV Contactors
50/51	**Contactors cannot open currents greater than 10-15 X their rated nominal current**
50/51N	
87**	

Protection Functions

- So what settings are problematic?

	MV Contactors
50/51	Contactors cannot open currents greater than 10-15 X their rated nominal current
50/51N	
87**	

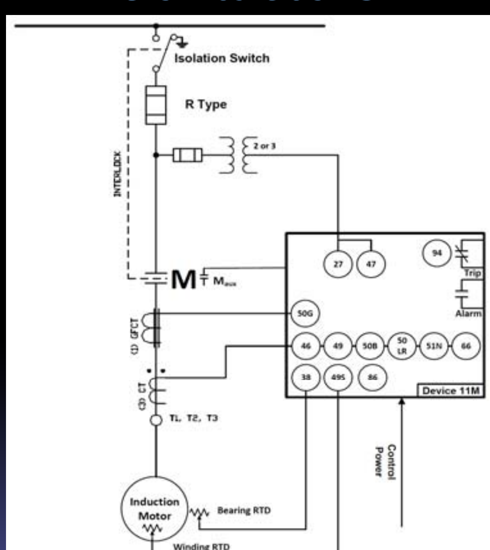
**Most manufacturers of MPRs, with Device 87 capabilities, finally now provide warnings in their user guides related to the use of the 87 function with fused contactors but ignore the 50/51

Problem is - FEW USERS READ THE MANUALS!

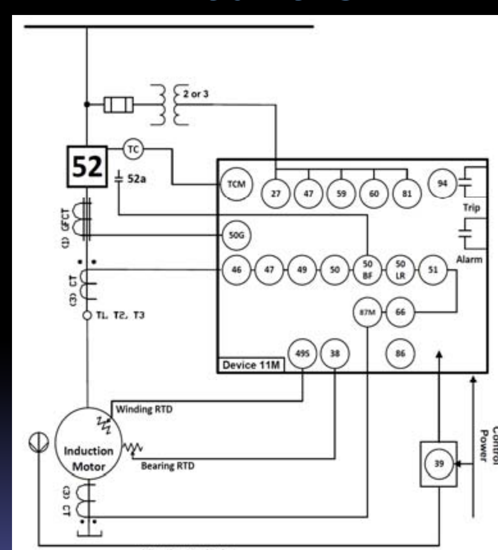
e.g. "…Care must be taken when enabling this feature. If the interrupting device (contactor or circuit breaker) is not rated to break potential faults, the feature should be disabled … A low level differential fault can develop into a short circuit in an instant…"

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 77

Contactors



Breakers



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 78

Conclusions & Recommendations

- Know the type of switching device being applied
- Use the proper symbology on drawings
- Know the interrupting rating of the switching devices
- Select proper protective elements for the switching device
- Insure protection settings are within rating of the switching device …

Assumptions in Protection Lead to Unsafe Conditions!

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 79

Conclusions & Recommendations

- One-line diagrams form the foundation for selecting the proper protective device settings
- One-line diagrams must clearly illustrate the difference between the two switching methods
- NEMA ICS 19-2002 uses "M" as the designation for the Main Contactor
- Do not use device 52 generically!

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 80

Questions ??

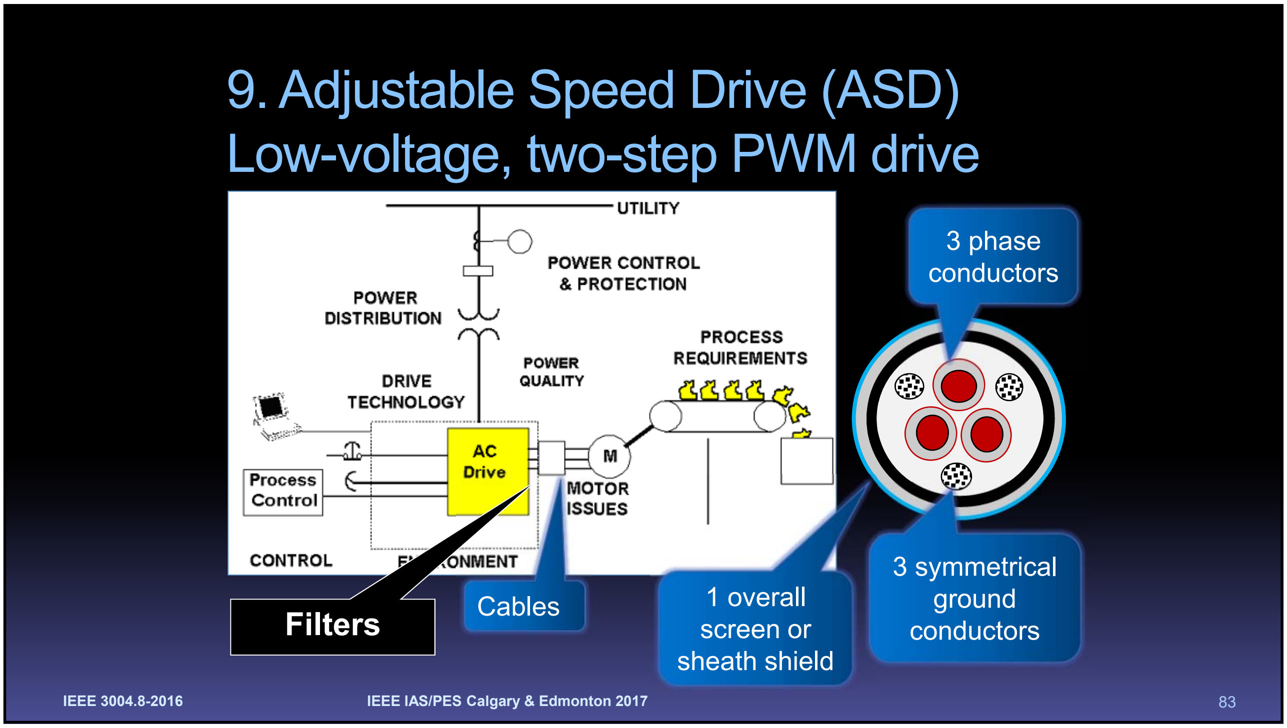
LP
- General overview
  - Low-voltage motor protection
  - Medium-voltage motor protection

JK
- Multifunction motor protection relays (11M)
  - MV Contactor controlled fused starters
  - MV Breaker controlled starters

JK
- Adjustable Speed Drives (ASD)

LP
- Motor monitoring - prefailure
  - Vibration, winding temperature
  - On-line partial discharge, others

JK/LP
- Information
  - Reduced voltage starting; Motor bus transfer
  - Hazardous locations; Arc flash hazards


9. Adjustable Speed Drive (ASD)
Low-voltage, two-step PWM drive
UTILITY
POWER CONTROL & PROTECTION
POWER DISTRIBUTION
PROCESS REQUIREMENTS
POWER QUALITY
DRIVE TECHNOLOGY
AC Drive
M
Process Control
MOTOR ISSUES
CONTROL
3 phase conductors
Filters
Cables
1 overall screen or sheath shield
3 symmetrical ground conductors
IEEE 3004.8-2016
IEEE IAS/PES Calgary & Edmonton 2017
83

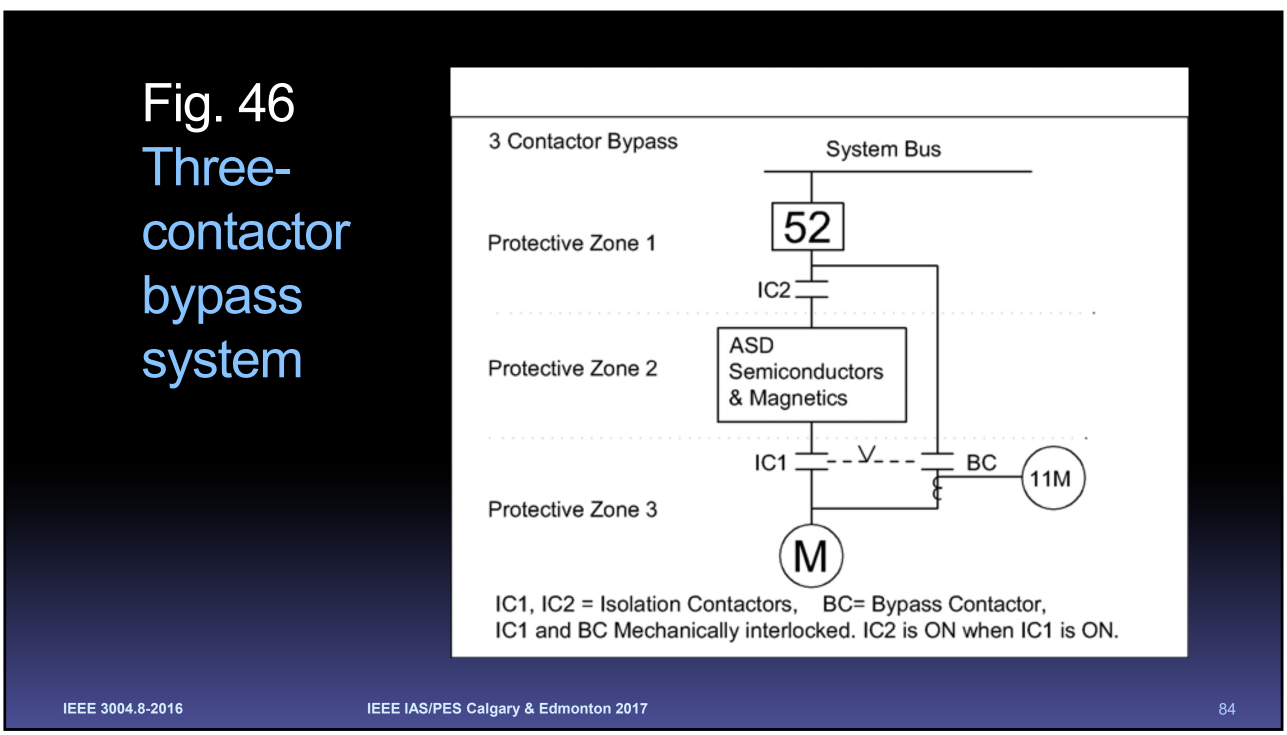


Fig. 46
Three-contactor bypass system
3 Contactor Bypass
System Bus
Protective Zone 1
52
IC2
Protective Zone 2
ASD Semiconductors & Magnetics
IC1
BC
11M
Protective Zone 3
M
IC1, IC2 = Isolation Contactors, BC= Bypass Contactor,
IC1 and BC Mechanically interlocked. IC2 is ON when IC1 is ON.
IEEE 3004.8-2016
IEEE IAS/PES Calgary & Edmonton 2017
84

The challenges of motor protection on ASD

- ASDs create additional challenges for external motor protection that are not present in direct, line connected, motors
- Some protection challenges are solved by "new" protection elements available in an electronic motor protection relay… but is it marketing hype?
- Fundamental frequency measurements are used in most protection elements in MPR
- ASD can rapidly change from the fundamental frequency

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 85

The challenges of motor protection on ASD

- The synthesized sine waves produced by some ASD topologies and vendor products can contain significant harmonic content
- True RMS measurements can properly account for the motor heating caused by harmonic currents
- Not all protection relays use true RMS (fundamental plus some of the harmonics) for protection
  - Can the relay measure the THD?

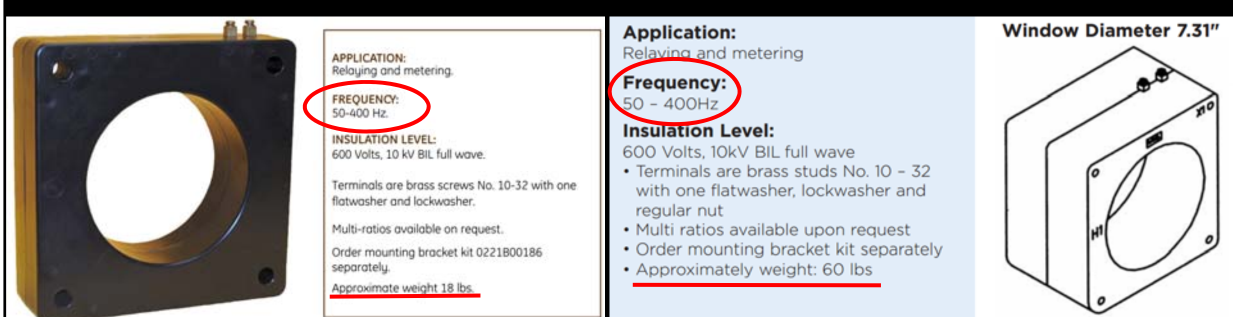
IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 86

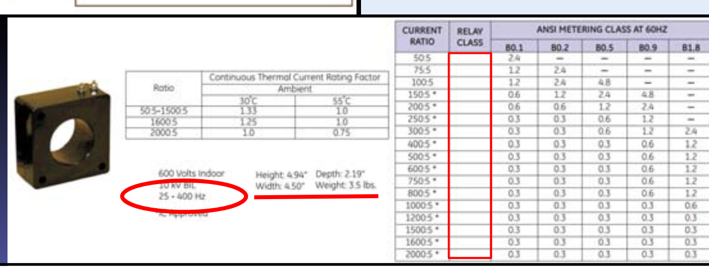
The challenges of motor protection on ASD

- The bigger challenge is not the MPR performance but having the measuring devices on the output, i.e. CTs & VT/PTs
- Poor data quality = poor protection
- Magnetic core based measurement devices are generally optimized to work based on a specific fundamental frequency
- CT designs optimized for use at 40 (50) – 400Hz
- PT/VT optimized for a specific fundamental frequency +/-%

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 87

The challenges of motor protection on ASD





Ratio	Continuous Thermal Current Rating Factor, Ambient 30°C	Continuous Thermal Current Rating Factor, Ambient 55°C
50:5-1500:5	1.33	1.0
1600:5	1.25	1.0
2000:5	1.0	0.75

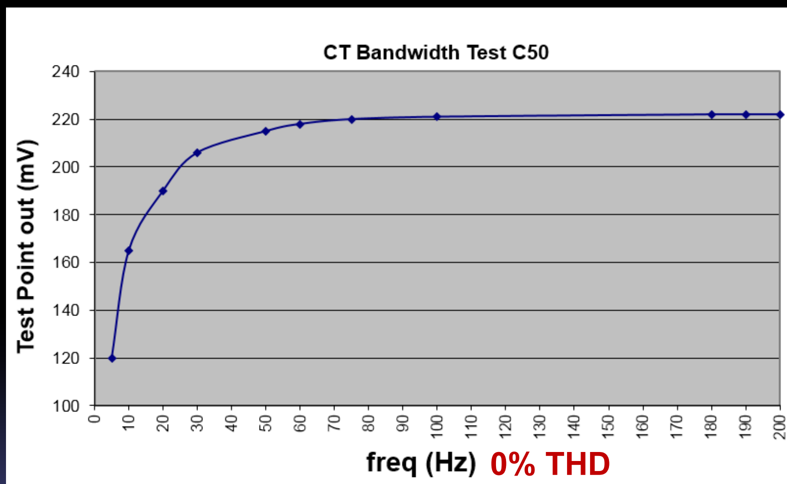
600 Volts Indoor
10 kV BIL
25 - 400 Hz

Height: 4.94" Depth: 2.19"
Width: 4.50" Weight: 3.5 lbs.

CURRENT RATIO	RELAY CLASS	ANSI METERING CLASS AT 60HZ B0.1	B0.2	B0.5	B0.9	B1.8
50:5		2.4	–	–	–	–
75:5		1.2	2.4	–	–	–
100:5		1.2	2.4	4.8	–	–
150:5 *		0.6	1.2	2.4	4.8	–
200:5 *		0.6	0.6	1.2	2.4	–
250:5 *		0.3	0.3	0.6	1.2	–
300:5 *		0.3	0.3	0.6	1.2	2.4
400:5 *		0.3	0.3	0.3	0.6	1.2
500:5 *		0.3	0.3	0.3	0.6	1.2
600:5 *		0.3	0.3	0.3	0.6	1.2
750:5 *		0.3	0.3	0.3	0.6	1.2
800:5 *		0.3	0.3	0.3	0.6	1.2
1000:5 *		0.3	0.3	0.3	0.3	0.6
1200:5 *		0.3	0.3	0.3	0.3	0.3
1500:5 *		0.3	0.3	0.3	0.3	0.3
1600:5 *		0.3	0.3	0.3	0.3	0.3
2000:5 *		0.3	0.3	0.3	0.3	0.3

IEEE 3004.8-2016 88

The challenges of motor protection on ASD



O/P Error	Frequency
-44.95%	5
-24.31%	10
-12.84%	20
-6.50%	30
-2.75%	40
-1.38%	50
0.89%	60
0.92%	75
1.38%	100
1.83%	183
1.83%	190
1.83%	200

Every CT has a difference performance characteristic at Var. Freq.!

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 89

The challenges of motor protection on ASD

- Lots of variability between CT core designs and materials
- At prolonged low frequency the saturated core actual has a significant temperature rise
- Rise varies significantly between materials and construction of the core

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 90

The challenges of motor protection on ASD

- Almost all motor protective algorithms in MPRs are based around a fixed frequency (non-VFD) protection
- Use positive and negative-sequence components as inputs to a first-order thermal model from which the rotor and stator heating are calculated
- ASD use hall effect style sensors which are accurate to very low frequency levels and high spec

- Certain MPR protective features must be disabled or set differently to work with the ASD
- Redundancy between the protection provided by MPR and the ASD leads to unnecessary added troubleshooting
- Having more devices to troubleshoot and potentially adding false positive indication for MPR’s that have not been properly set.

Motor Differential Protection

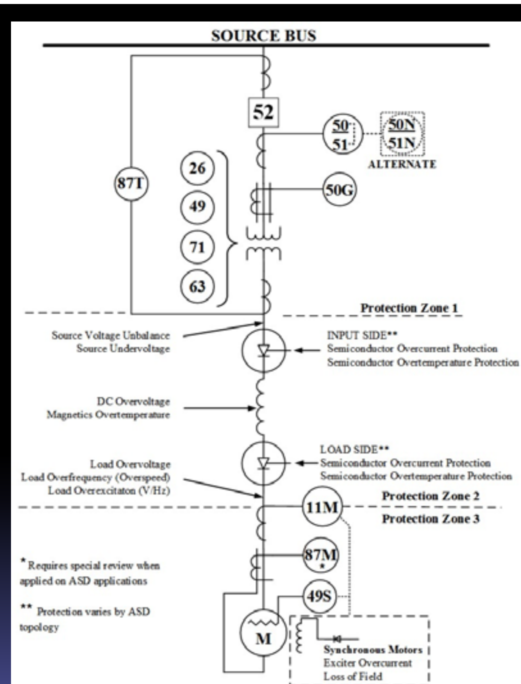
- There is a limitation in the ability to detect differential currents at lower frequencies
- The inherent characteristic of current transformers prevent accuracy
- Some ASDs have flux and DC unbalance protection schemes which may be used either on their own or in conjunction with the core balance approach since the accuracy particularly at lower speeds is superior
- These protective functions are embedded in the ASD control, do not require CTs in the motor terminal box or the associated conduit and wiring runs between the drive and motor which is particularly significant when the motor is at a significant distance away from the controller.

Load side protection on ASD using MPR

- Leads to many complications beyond those typically addressed for across-the-line applications
- Each protective function has to be evaluated independently
- Most standard MPRs are not equipped with the capability to analyze a power signal with these varying conditions
- The protective functions within the drives themselves eliminate complexity and avoid nuisance trip conditions
- If the functions are not available in the drive apply external protective relaying capable of analyzing the variable conditions present downstream of the drive, e.g.RTD

Recommendations

- Best motor protection provided by the drive's control!!!
- CT performance concerns at low frequency/high harmonic content
- Self-balancing differential protection (Device 87M) best but limitation on detecting at lower frequencies due to the inherent characteristics of current transformers



Questions ??

LP	• General overview • Low-voltage motor protection • Medium-voltage motor protection
JK	• Multifunction motor protection relays (11M) • MV Contactor controlled fused starters • MV Breaker controlled starters
JK	• Adjustable Speed Drives (ASD)
LP	• Motor monitoring - prefailure • Vibration, winding temperature • On-line partial discharge, others
JK/LP	• Information • Reduced voltage starting; Motor bus transfer • Hazardous locations; Arc flash hazards

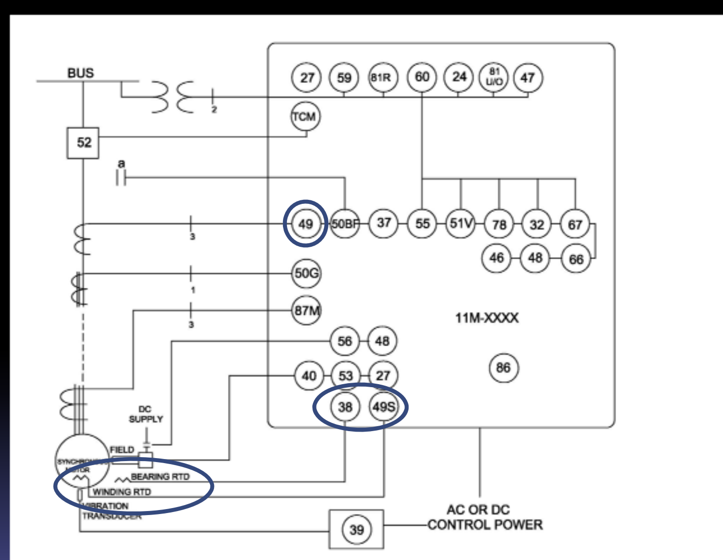
IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 97

Thermal Monitors

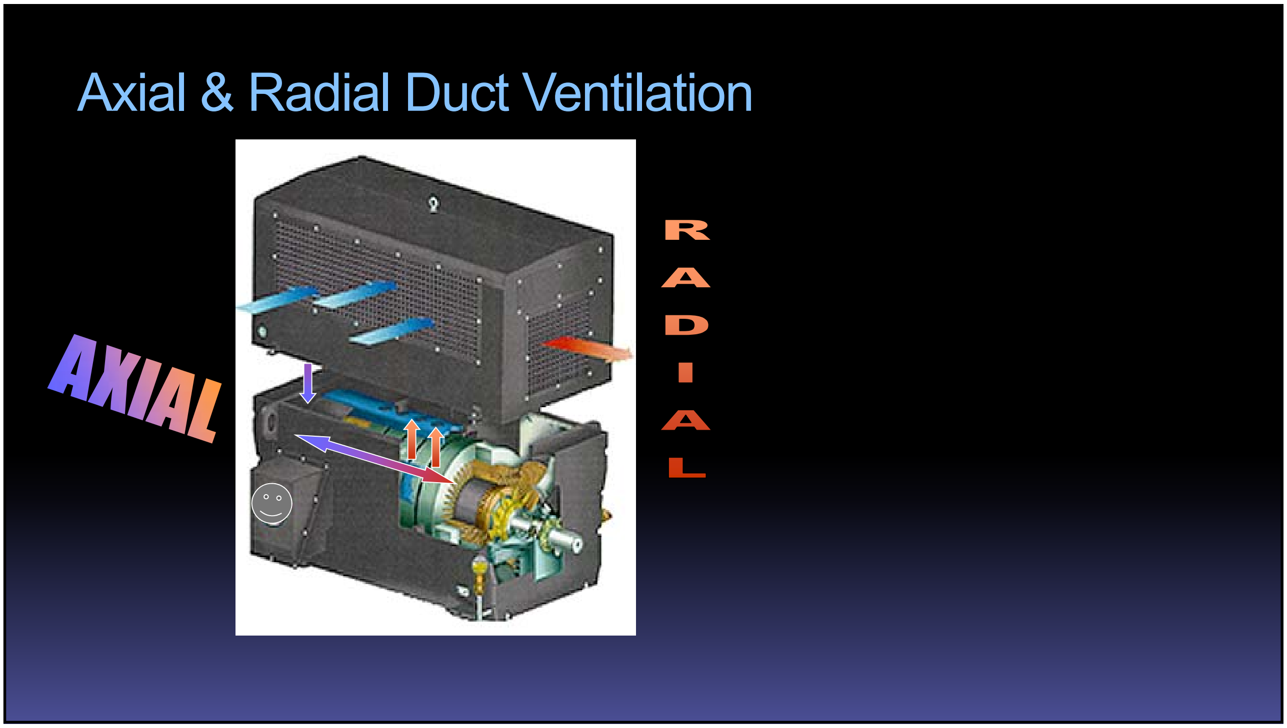
49 - Thermal overload relay
Overload operated by motor current (replica)

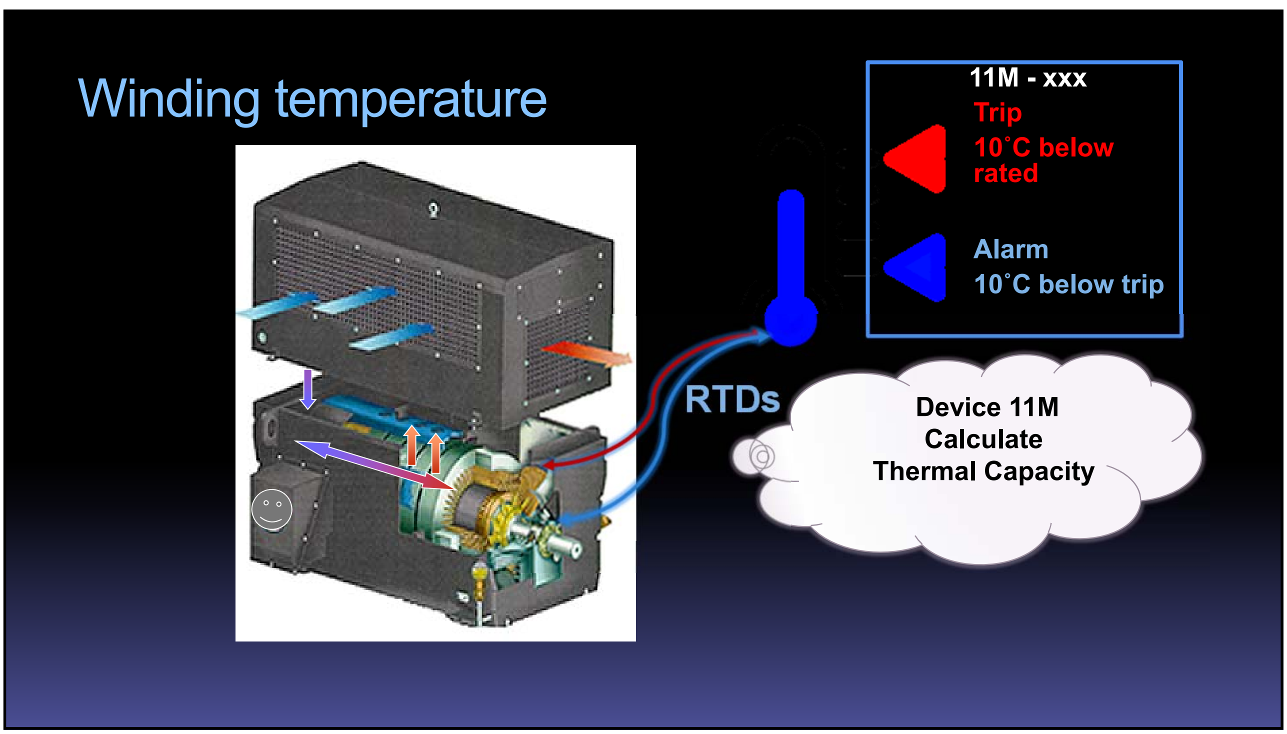
38 - Bearing Temperature Protection
49S - Stator winding thermal overload (also embedded detectors)

Synchronous motor

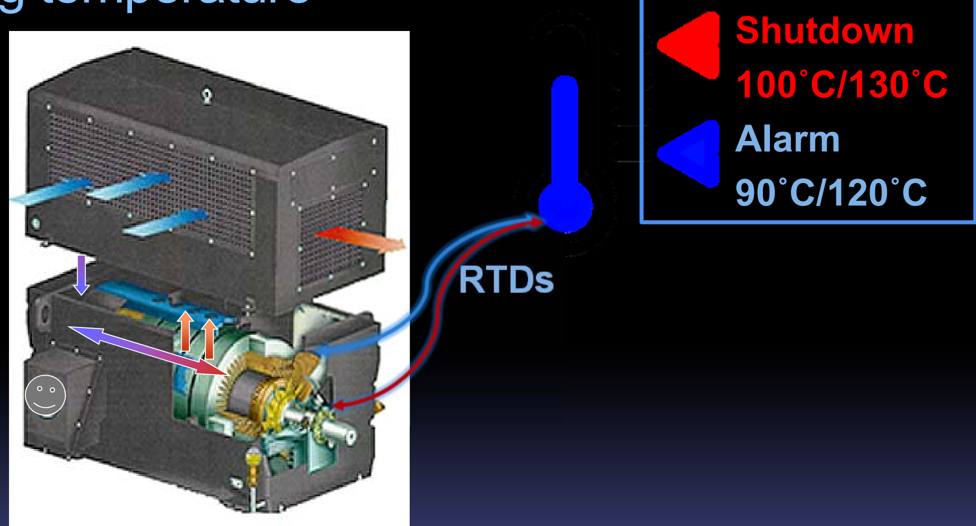


IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 98


Axial & Radial Duct Ventilation
AXIAL
RADIAL


Winding temperature
11M - xxx
Trip
10˚C below rated
Alarm
10˚C below trip
RTDs
Device 11M
Calculate
Thermal Capacity

Bearing temperature



Condition monitoring, periodic (trending)

Winding insulation resistance test	➢ IEEE Std 112 ➢ IEEE Std 115
Polarization index	➢ IEEE Std 43
Partial discharge (PD)	➢ ASTM D 1868, [B9] and [B61]
Power factor/tip up test for MV motors	➢ IEEE Std 286 [B25]

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 102

Condition monitoring, on-line (trending)

- ✓Vibration analysis (8.5.5)
- ✓On-line partial discharge (OLPD) (8.5.4.6 and C.1) [8 bibliography references]
- ✓Monitoring motor insulation on-line (C.2)

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 103

8.5.5 Vibration

Bearing fail

Shaft break

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 104

Synchronous motor

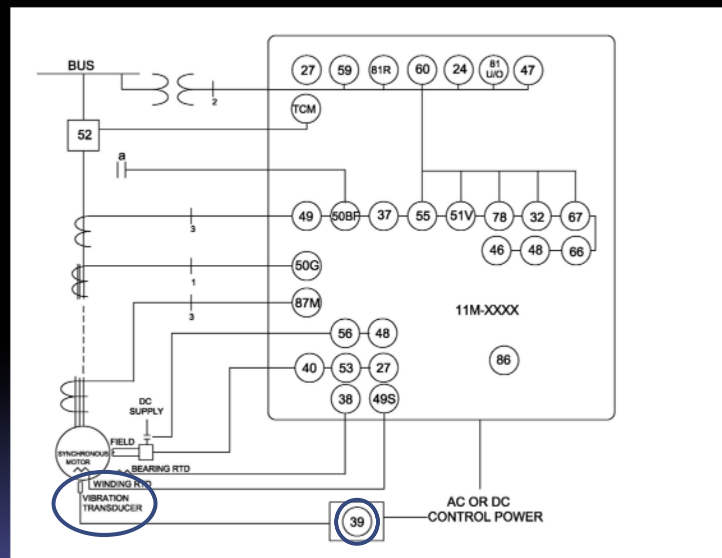
39 - Vibration Protection

Vibration Limits

- Manufacture
- Field monitoring

Standards

- NEMA MG 1
- IEEE 841
- API 541
- API 546
- API 547

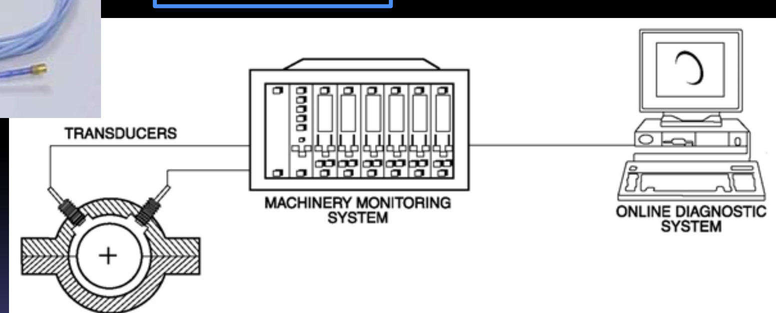


IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 105

Vibration

Device 39

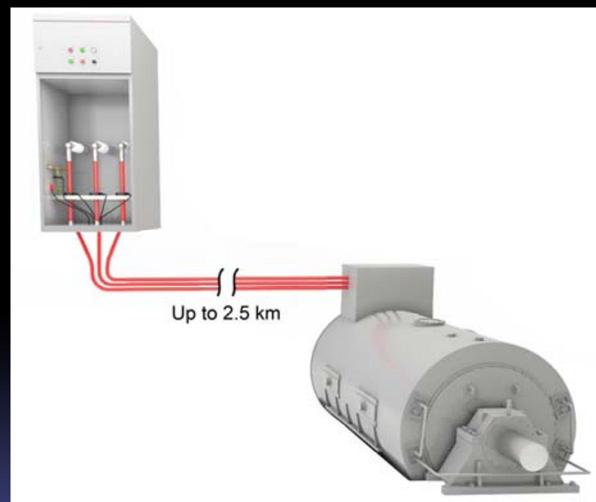
Vibration monitoring system panels



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 106

On-line partial discharge (OLPD)

High frequency CT HFCT



		
High Voltage Coupling Capacitor (HVCC)	High Frequency Current Transformers (HFCT)	Rogowski Coil Sensors (RC)
- 80 pF / 500 pF / 1 nF rating - High sensitivity (if installed in the machine's terminal box) - 'Ex/Atex' certified (for use in hazardous gas zones) - The higher the capacitance the better lower frequency response (to sub-10 MHz) - Relative sensitivity to an HVCC at 10 MHz = 100%	- Available in a range of sizes to fit most confined spaces - 'Ex/Atex' certified, saturation currents of up to 1000 A - High sensitivity **at low frequencies** and capable of detecting PD in the machine **remotely at the switchgear** - Relative sensitivity to an HVCC at 10 MHz = 30%	- Does not saturate with high currents (>5000 A) - 'Ex/Atex' certified (for use in hazardous gas zones) - Very low sensitivity and thus does not detect low levels of PD i.e. only significant activity - Relative sensitivity to an HVCC at 10 MHz = 1%

Table C.1 OLPD guideline levels for MV motors in the 10 kV to 15 kV class

Condition Assessment	Peak PD Level (nC)	OLPD Activity (nC/cycle)
Excellent	< 2	< 50
Good	2 – 4	50 – 99
Average	4 – 10	100 – 249
Still Acceptable	10 – 15	250 – 499
Inspection Recommended	15 – 25	500 – 999
Unreliable	> 25	> 1000

Questions ??

- LP
  - General overview
    - Low-voltage motor protection
    - Medium-voltage motor protection
- JK
  - Multifunction motor protection relays (11M)
    - MV Contactor controlled fused starters
    - MV Breaker controlled starters
- JK
  - Adjustable Speed Drives (ASD)
- LP
  - Motor monitoring - prefailure
    - Vibration, winding temperature
    - On-line partial discharge, others
- JK/LP
  - Information
    - Reduced voltage starting; Motor bus transfer
    - Hazardous locations; Arc flash hazards

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 111

Reduced-voltage starters

- 5.2.1 Solid-state reduced-voltage motor start
- 5.2.2 ASD start

- Table 4
  Comparison of electro-mechanical reduced-voltage starters

- Reduce starting current (6 x FLC)
- Reduce torque/impact to load/system
  - Soft power system
  - Need softer torque

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 112

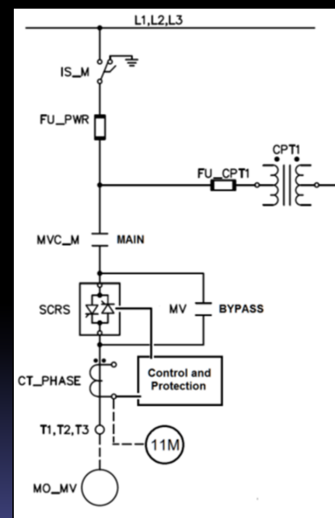
	Autotransformer*			Primary resistor or reactor		Part winding†	Wye start-delta run
	50% Tap	65% Tap	**80% Tap**	65% Tap	80% Tap	2-step	
Starting **current** drawn from line as percentage of that which would be drawn upon full-voltage starting‡	28%	45%	**67%**	65%	80%	60%‡	**33 $^1/_3$ %**
Starting **torque** developed as percentage of that which would be developed on full-voltage starting	25%	42%	**64%**	42%	64%	50%	**33 $^1/_3$ %**
	Increases slightly with speed			Increases greatly with speed			
Smoothness of acceleration	Second in order of smoothness			Smoothest of reduced-voltage types in Table 4. As motor gains speed, current decreases. Voltage drop across resistor decreases and motor terminal voltage increases		Fourth in order of smoothness	Third in order of smoothness
Starting current and torque adjustment	Adjustable within limits of various taps			Adjustable within limits of various taps			Fixed

Solid-State Reduced-Voltage Starting

- ASD are the premium solution for reduced voltage starting
  - Very large
  - Very costly
  - Generally way more machine than is needed
- Internal ASD protection elements adequate for motor protection except usually additional 49S/38/39 protection required

Solid-State Reduced-Voltage Starting

- Fundamental motor protection elements on board in control and protection modules
- A device 11 (or others) may provide additional protection such additional stator, bearing or vibration protection
- Use caution when there are duplicate protection elements between the multiple protection devices…



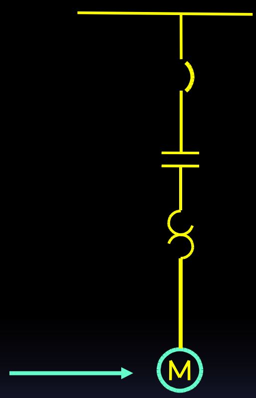
IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 115

Other protection considerations

- Transition timing (incomplete sequence) for autotransformer and reactor starters
- Controllers where two or more sets of CTs are used – special consideration required for protection
  - Multispeed motors
  - Some Wye Delta configurations
- PF Capacitors

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 116

6.11 Motor bus automatic transfer & reclosing

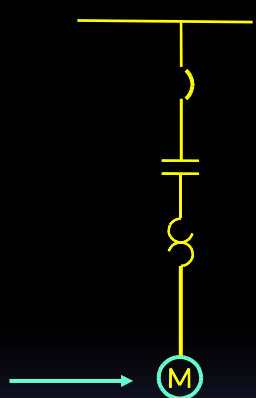


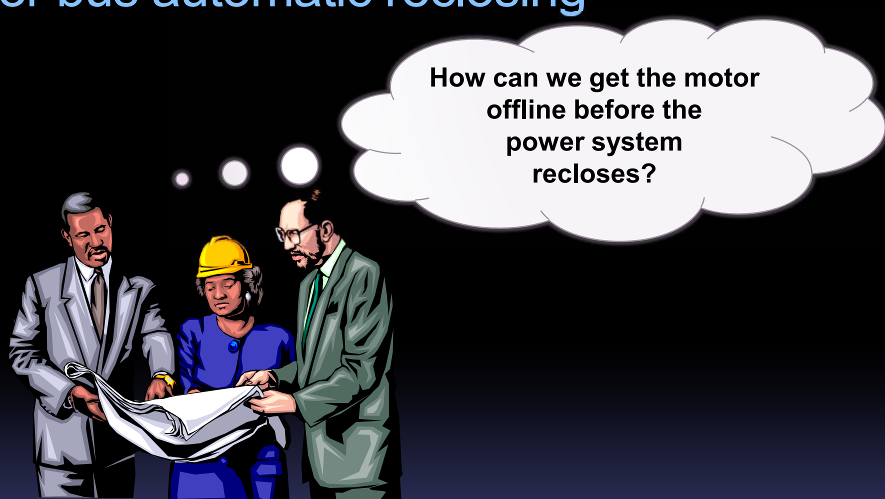
Why worry?

- ✓ Very high **inrush current**
  - ➢ Trip breaker
  - ➢ Open fuse
  - ➢ Damage motor system components
- ✓ Mechanical damage – **excessive torque**
  - ➢ Motor
  - ➢ Coupling
  - ➢ Load

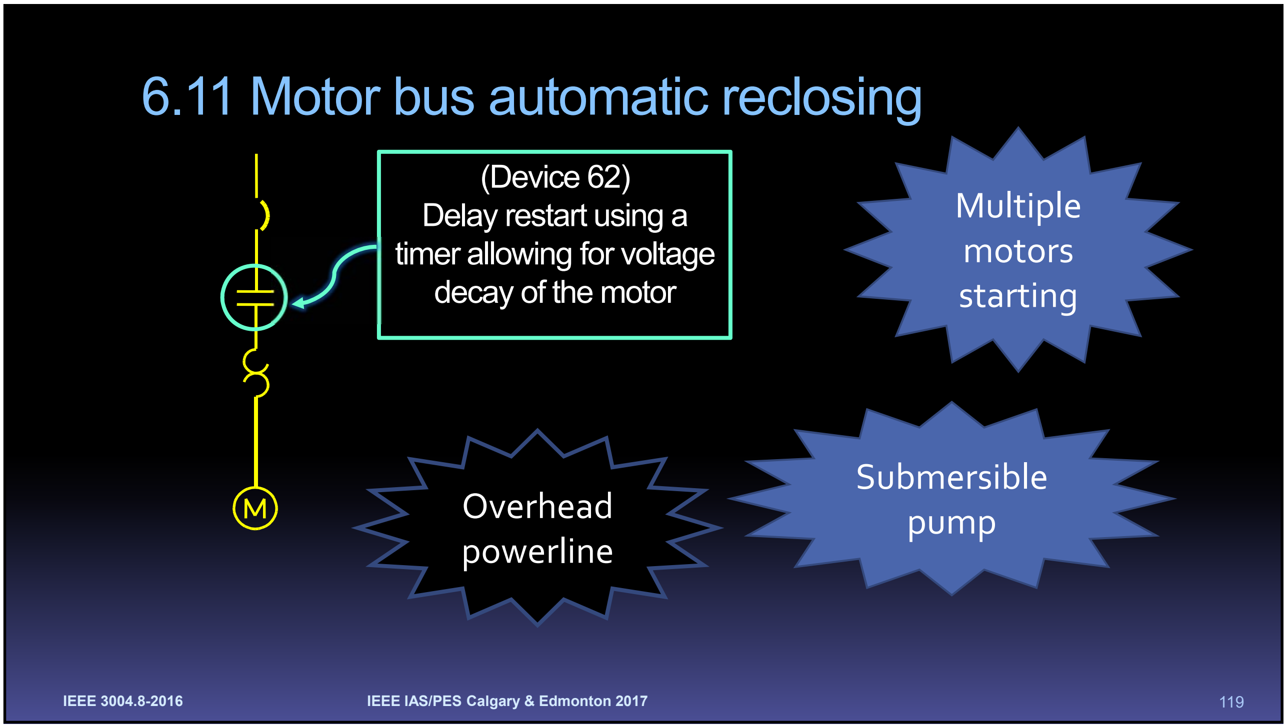
IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 117

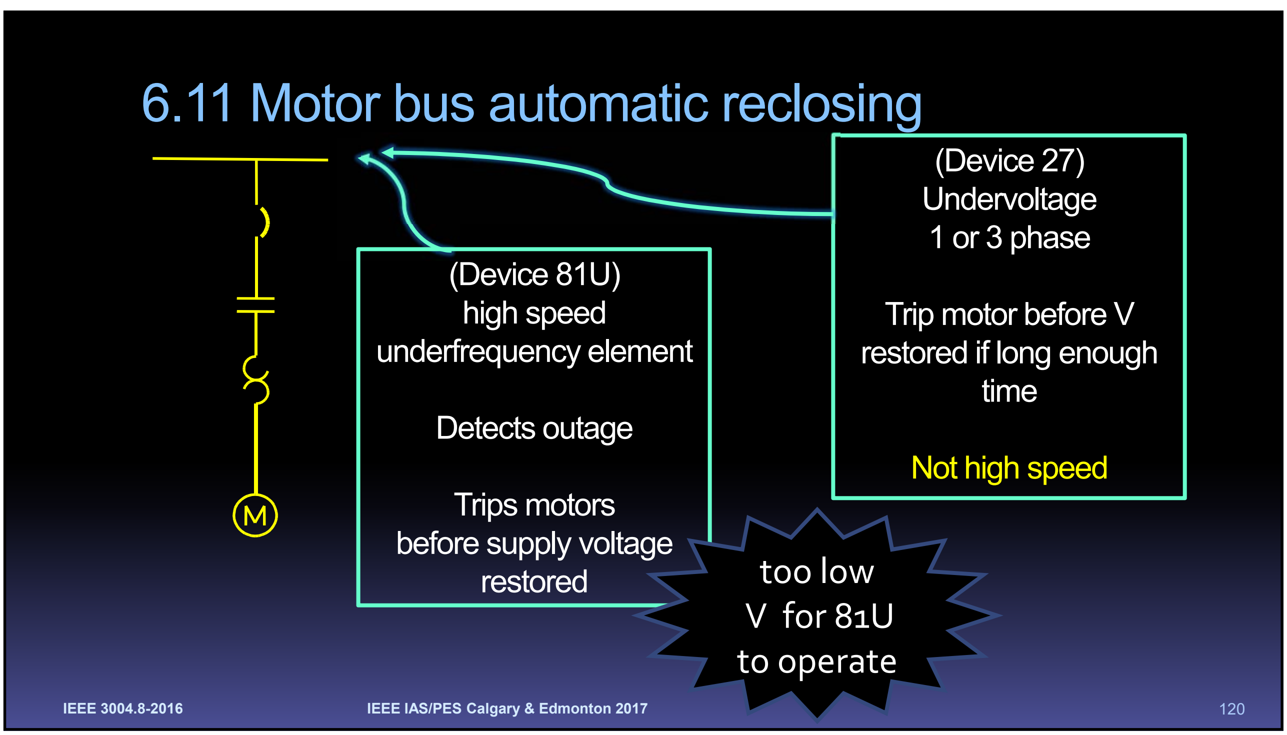
6.11 Motor bus automatic reclosing



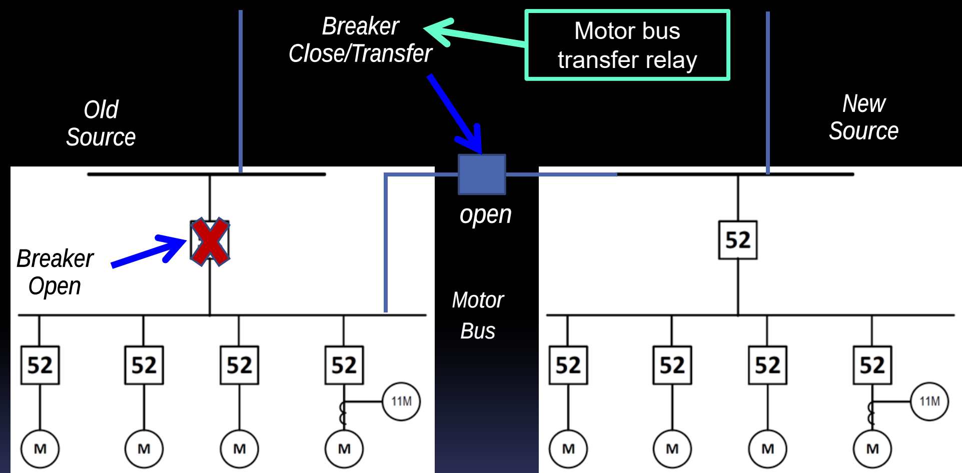


IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 118


6.11 Motor bus automatic reclosing
(Device 62)
Delay restart using a timer allowing for voltage decay of the motor
Multiple motors starting
M
Overhead powerline
Submersible pump
IEEE 3004.8-2016
IEEE IAS/PES Calgary & Edmonton 2017
119

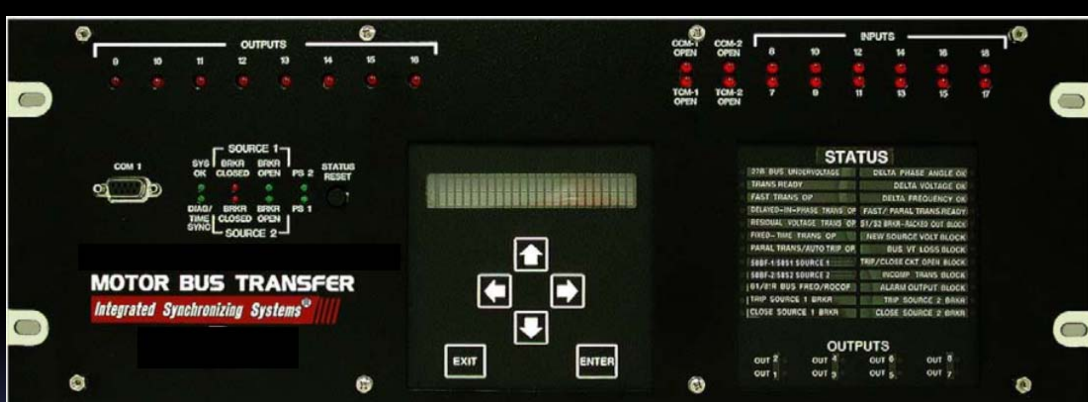

6.11 Motor bus automatic reclosing
(Device 27)
Undervoltage
1 or 3 phase
Trip motor before V restored if long enough time
Not high speed
(Device 81U)
high speed
underfrequency element
Detects outage
Trips motors
before supply voltage restored
M
too low
V for 81U
to operate
IEEE 3004.8-2016
IEEE IAS/PES Calgary & Edmonton 2017
120

Motor bus automatic transfer



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 121

Motor bus transfer relay

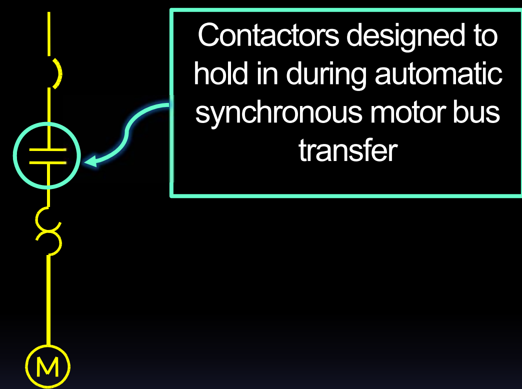


IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 122

MBT	Old Source Breaker	New Source Breaker	Supervised	Unsupervised
Open-transition transfer	**Open**	**Open**		
Fast transfer – supervised	Open	Open	Voltage phase angle (synch-check)	
Fast transfer – unsupervised	Open	Open		No synch-check or slow synch-check
In-phase transfer	Open	Open	Close command compensates for breaker close time	
Residual voltage transfer	**Open**	**Open**	**New Breaker close command after voltage on Old Source is low enough**	**No sych-check**
Sequential transfer (fast, in-phase, & sequential)	Open	Open	Close command supervised by open signal from Old Source Breaker	

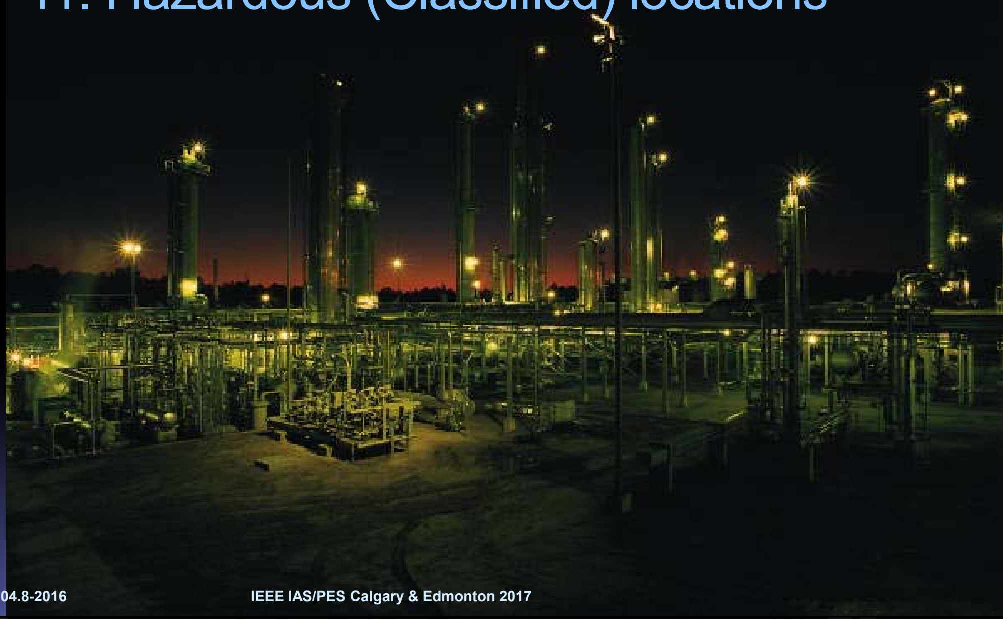
MBT	Old Source Breaker	New Source Breaker	Supervised	Unsupervised
Simultaneous transfer (fast, in-phase, & sequential)	Open	Open		No verification the Old Source Breaker is open
Slow transfer	Open	Open	Verified Old Source Breaker open for >20 cycles; then close New Breaker	No synch-check No Voltage monitor
Synchronous bus transfer (fast transfer-supervised or in-phase)	**Open**	**Open**	**Breaker close is supervised, voltage decay and frequency decay monitored to close New Breaker at or near zero phase coincidence**	
Closed-transition transfer (parallel transfer)	Closed	Closed	(sych-check)	

6.11 Motor bus automatic transfer



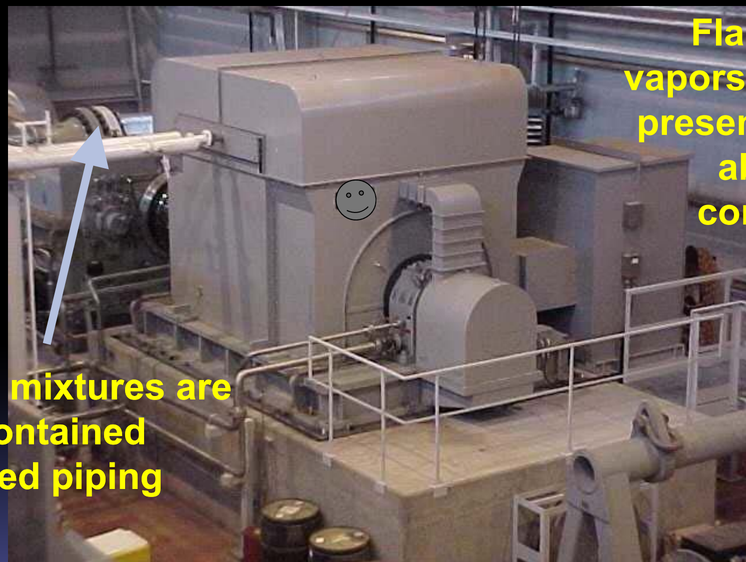
IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 125

11. Hazardous (Classified) locations



IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 126

Class I, Division 2 or Zone 2 Location



Flammable vapors may be present under abnormal conditions

Flammable mixtures are normally contained within closed piping systems

Abnormal condition

Precautions

Excessive surface temperature

Uncontrolled/uncontained sparking

IEEE 1349 – Provides guidance

Selecting

Operating

Maintaining motors

Class I, Division 2 & Zone 2; Class II

CAUTION
"For hazardous (Classified) locations, additional caution should be used when selecting and setting motor protection.
Refer to the NEC."

Class I, Division 1, Class I, Zone 1, Class I, Zone 0, and Class III locations are beyond the scope of this document

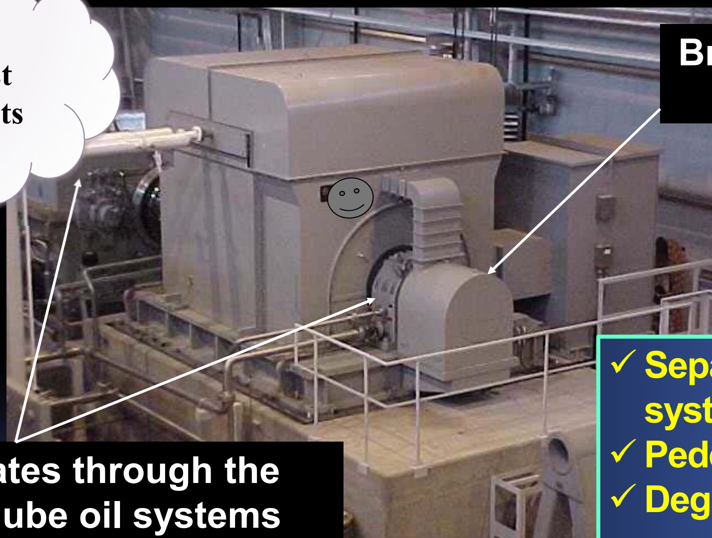
IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 131

Overload

Select motor size to avoid overload condition

- Reference 2017 NEC
  - *430.32 - continuous-duty motors*
  - *430.124 - ASD overload protection*
  - *430.225(B) – motors over 1000 V nominal*
- Overload device settings
  - 115% or less of motor rated current
- ASD operating current limit
  - 100% of motor nameplate rated current

Motors over 1000 V



- ✓ Separate lube oil systems
- ✓ Pedestal bearings
- ✓ Degassing

Auxiliary devices

- IEEE Std. 303TM-2004 (R 2011)
- 2017 *NEC* 501.35(B)
  - Non-sparking surge arresters
  - Metal oxide varistor (MOV) Sealed type
  - Specific duty surge protective capacitor
- 2017 NEC 505.20(C)

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 134

Surge capacitors

NEW!
"NOTE- For a motor application, using three single-phase specific duty surge capacitors avoids phase-phase short-circuit faults within the capacitor."

8.9.3 Surge protection

- **MV motors >375 kW (500 hp)**
- **Motors 150 kW (200 hp) or larger on open overhead powerlines**
- **Some starters (restrike; spike)**
  - **Starters are vacuum or SF_6 breakers**
  - **Starters are vacuum contactors**


Arc Flash Hazards
857
Allen-Bradley
ARC RESISTANT EQUIPMENT
ACCESSIBILITY : TYPE 2B, PER IEEE C37.20.7 ARC SHORT CIRCUIT CURRENT : 50 kA ARC DURATION : 0.5 seconds
CAUTION
MV DOOR(S) MUST BE BOLTED AND LATCHED. ALL COVERS MUST BE FULLY SECURED.
EQUIPMENT MUST BE INSTALLED PER MANUFACTURER'S INSTRUCTIONS (REFER TO USER MANUAL)
EQUIPMENT WILL NOT FUNCTION AS ARC RESISTANT IF ABOVE GUIDELINES ARE NOT FOLLOWED
Mitigate arc flash hazard
Arc Resistant – Enclosures
Arc Fault Detector – 11M, AFD
IEEE 3004.8-2016
IEEE IAS/PES Calgary & Edmonton 2017
137


Arc flash hazard - motors
NEW!
"NOTE- To direct hot gases from an arc flash that may occur in the motor terminal box, rupture panels can be installed to direct the hot gases away from the front of the motor and away from personnel.
See Murfield et al. [B39]
CC BY-NC-ND
IEEE 3004.8-2016
IEEE IAS/PES Calgary & Edmonton 2017
138

Questions ??

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 139

- **LP**
  - General overview
    - Low-voltage motor protection
    - Medium-voltage motor protection
- **JK**
  - Multifunction motor protection relays (11M)
    - MV Contactor controlled fused starters
    - MV Breaker controlled starters
- **JK**
  - Adjustable Speed Drives (ASD)
- **LP**
  - Motor monitoring - prefailure
    - Vibration, winding temperature
    - On-line partial discharge, others
- **JK/LP**
  - Information
    - Reduced voltage starting; Motor bus transfer
    - Hazardous locations; Arc flash hazards

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 140

Copyrights and permissions

Every effort has been made to secure permission to reprint borrowed material contained in this document. If omissions have been made, please bring them to our attention.

Portions of this standard reprinted with permission from…

IEEE Std 1349™, © 2011 IEEE.
IEEE Std C37.2™, © 2008 IEEE.
IEEE Std C37.96™, © 2012 IEEE.
NEMA MG-1, © 2011.
NEMA MG-10, © 2013.

Portions of this standard reprinted with permission…
Figures 2, 3, 4, 5, 11, 17, 18, 43, 44, 45, 46, 47, and 54 courtesy of Schneider Electric.
Figures 7, 8, 19, 20, 38, and 39 courtesy of C&I Engineering.
Figures 9, 13, and 21 courtesy of Basler Electric.
Figure 10 courtesy of EASA.
Figure 12 courtesy of Beckwith Electric.
Figures 14, 15, and 16 and Table 5 courtesy of Padden Engineering, LLC.
Figures 31, 32, 33, and 34 courtesy of GE Bentley-Nevada.
Figures 48, 49, 50, 51, 52, 53, and D.1 courtesy of Rockwell Automation.
Figures C.1, C.2, and C.3 and Table C.1 courtesy of HVPD.
Figures D.2, D.3, and D.4 courtesy of DC Water.

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 141

Acknowledgements

IAS/TBCC
Carey Cook, *past Chair*
Daleep Mohla, *Chair*

(> 100 Formal Balloters)

I&CPS
Protection & Coordination Working Group

Rasheek Rifaat, *Chair*
Donald McCullough II, *Vice Chair*

Carey Cook
Thomas Domitrovich
Robert Hoerauf
Ed Larsen
Claudio Mardegan
Chuck Mozina
Dan Neeser
Lorraine Padden
Louie Powell
Daniel Ransom
Marcelo Valdes

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 142

Acknowledgements

IEEE 3004.8 Project Working Group
Rasheek Rifaat, *Working Group Committee Chair*
Lorraine K. Padden, *Project Working Group Chair*

Partha Basu
Thomas Beckwith
Sirak Belayneh
Robert David Bredhold
James Bryan
Jim Crook
Randall Groves
Jeffrey Hensley
Chris Heron
Byron Hohrein
Umar Khan
John Kay
Daniel Leland Ransom
Bill Stewart

Contributers, but were not working group members
Paul Cardinal
Jerry Franklin
David Hinchliffe
Mayank Jain
Ed Larsen
Duane Leschert
Daniel Neeser
Timothy O'Hearn
Pero Ostojic
David C. Rains*
Malcolm Seltzer-Grant
Manish Singh
Louis Spence
Mike Thomasson
Marcelo E. Valdes
Sunil Verma

*Postumously

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 143

IEEE 3004.8-2016 IEEE IAS/PES Calgary & Edmonton 2017 144

IEEE STD. 3004.8-2016
IEEE RP FOR MOTOR PROTECTION IN INDUSTRIAL & COMMERCIAL POWER SYSTEMS
OVERVIEW & WHAT'S NEW!

Lorraine K. Padden
Senior Member, IEEE
Padden Engineering, LLC
paddeneng@aol.com

John A. Kay
Fellow, IEEE
Rockwell Automation
jakay@ra.rockwell.com

2017 IEEE/IAS/PES Calgary & Edmonton, Canada