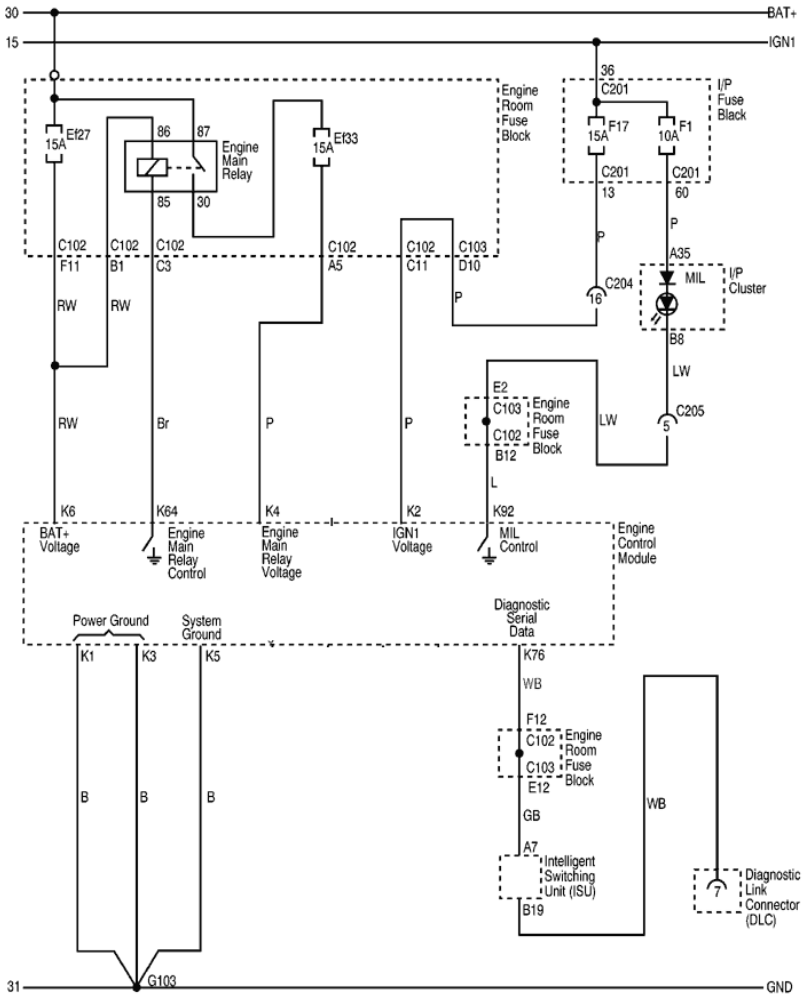
Control Systems and Protections

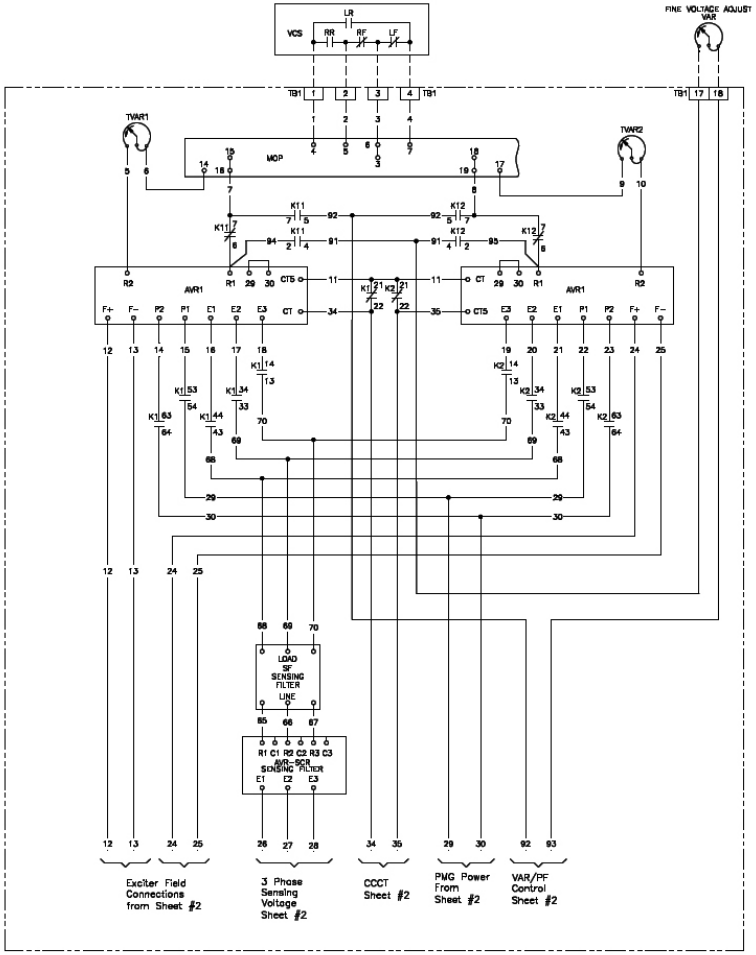
What Makes Up a Controls System?

- Engine/prime mover control systems
  - Speed control/governor
  - Load (kW) control (paralleled systems)
  - Protection systems (low oil pressure, high temperatures…)
- Generator control systems
  - Output voltage control
  - Load (VAR) control
  - Protection systems (excessive current, over voltage…)
- Distribution control/protection systems (300% S.C.)???

Engine-Generator Control Systems



Sample engine control systems



Sample generator control systems

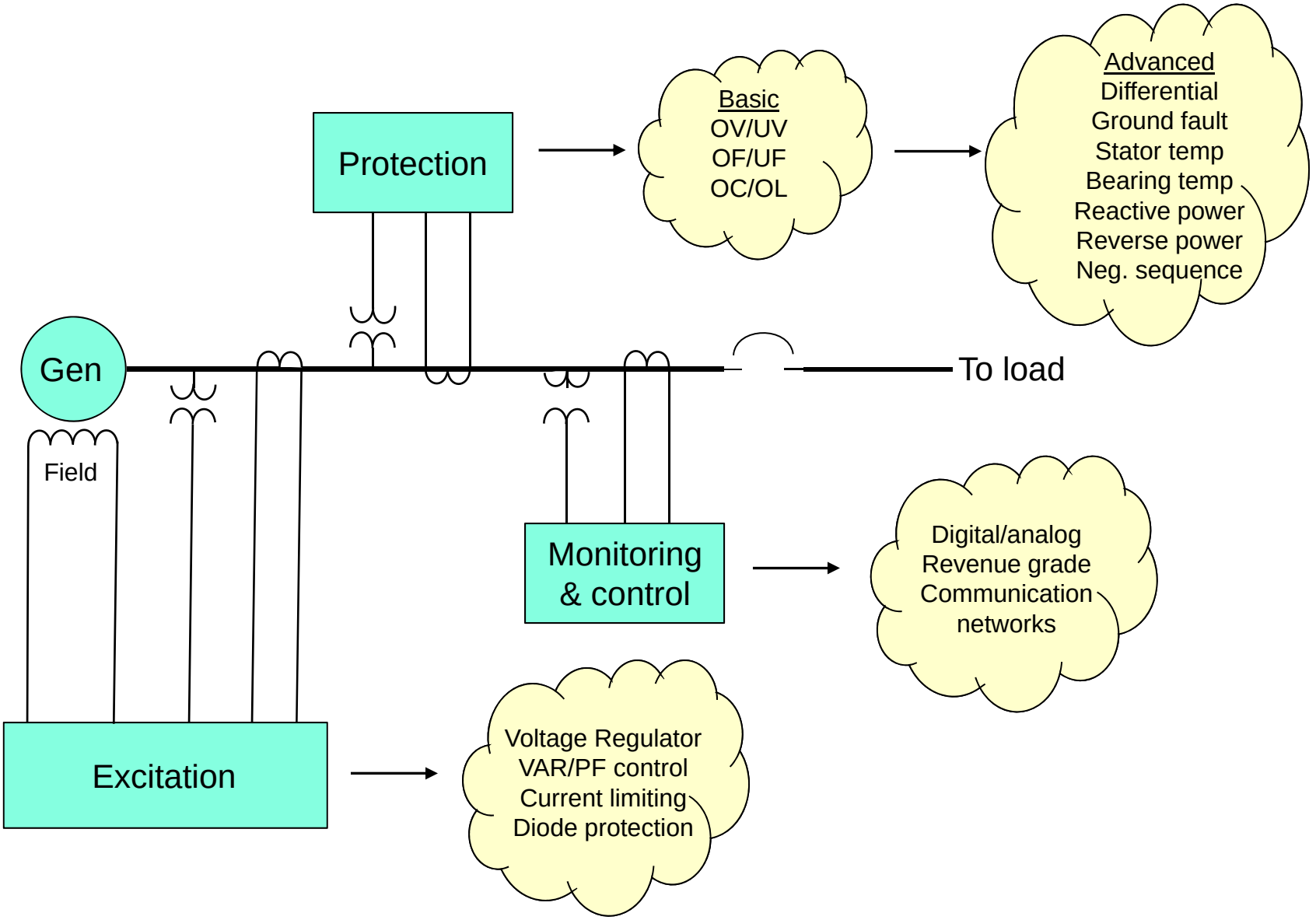
Control System Functions

- Control the production and distribution of power
- Improve safety of the generating system
- Protect the generator
- Protect loads connected to the generator system

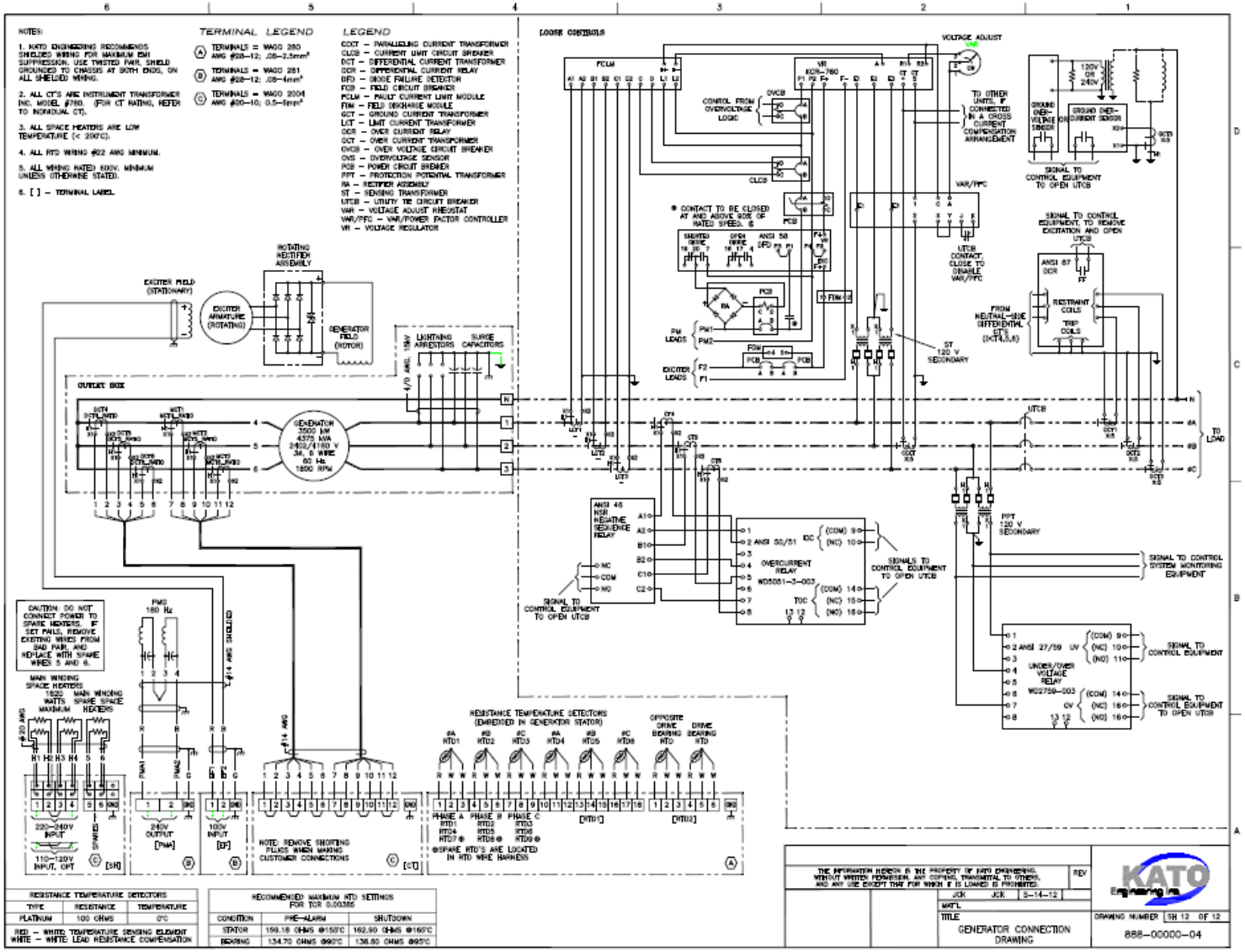
Generator Control Systems

- Voltage regulation/VAR control
  - Stand-alone operation (island mode)
  - Paralleled applications (similar sized units)
  - Co-gen applications (connected to grid)
- Monitoring and control
- Basic generator protection
  - Recommended minimum protection
  - Recommended additional protection

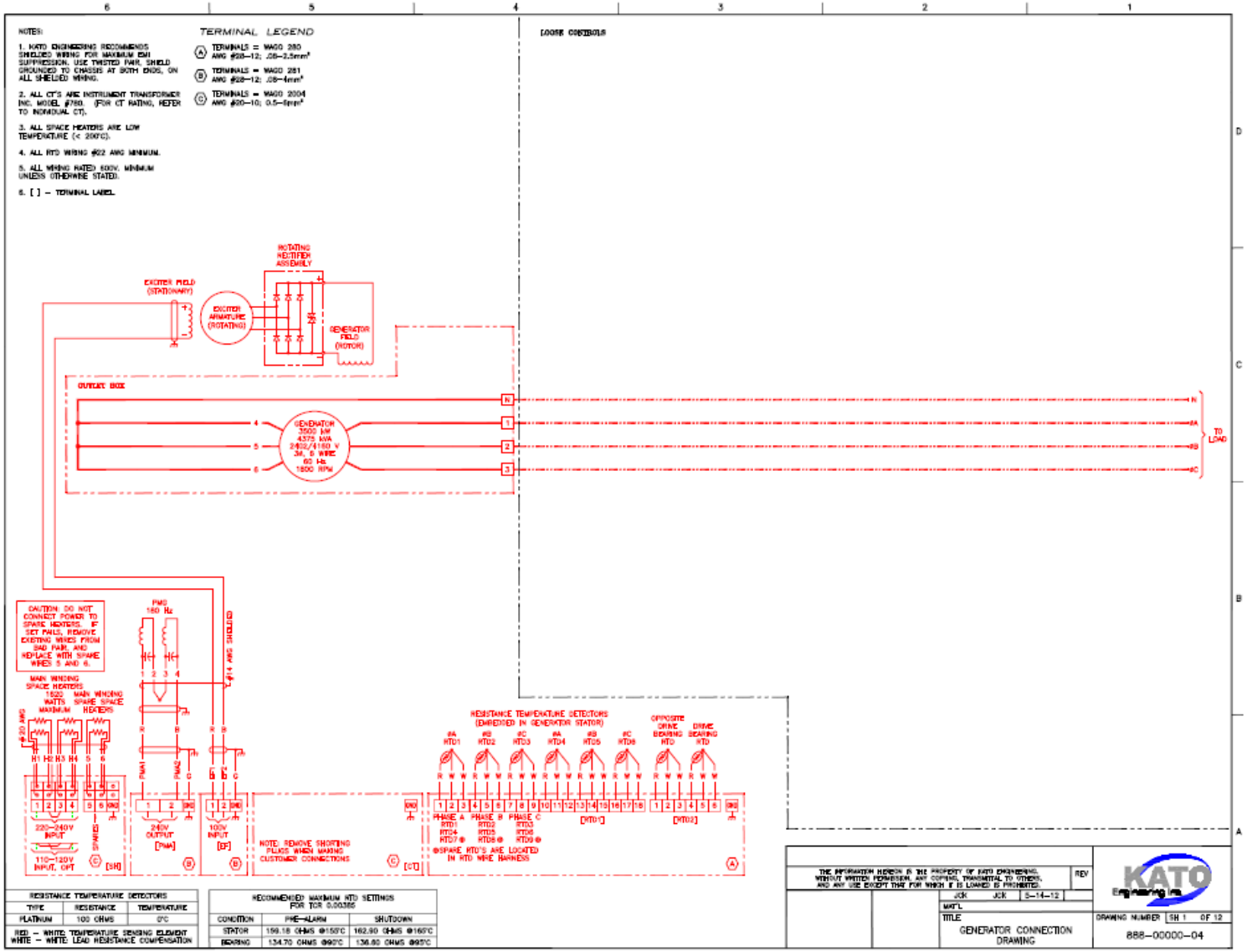
Generator Control Systems (cont.)



Typical Interconnection Drawing



Example: Synchronous Generator



Generator Excitation Control

- Basic excitation systems
  - Voltage regulators (field excitation/voltage regulation)
  - Redundant regulator systems
  - Analog vs. digital
- Parallel operation
  - More to consider

Voltage Regulators

Simple PS

Simple manual field excitation devices

Analog AVR

Automatic voltage regulators

Digital AVR

Redundant Voltage Regulators

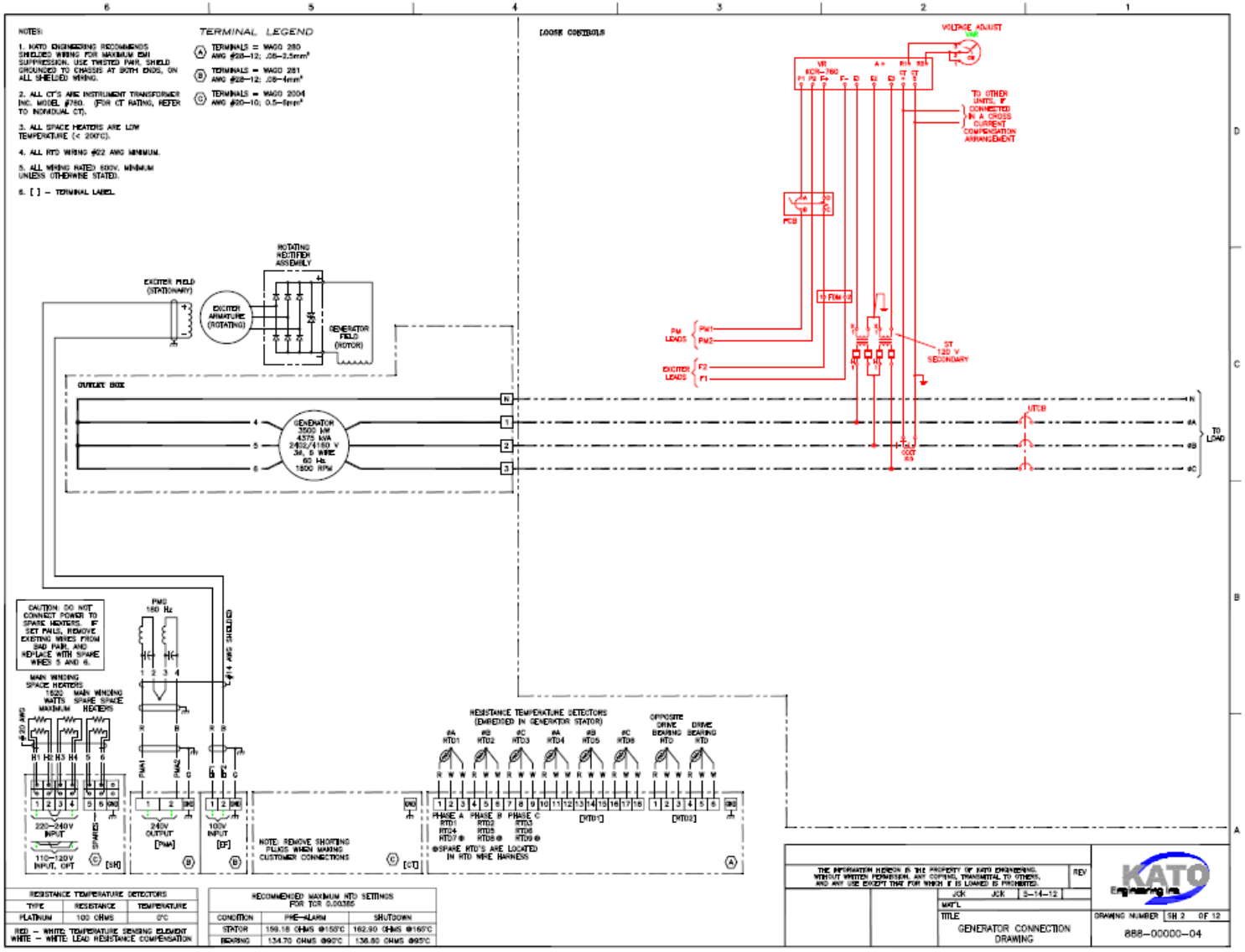
Analog and Digital Comparison

- Analog voltage regulators
  - Typically lower cost
  - Mature designs
  - Many OEM and customers are familiar with technology
  - Average sensing regulation (typically not RMS)
  - Limited versatility
  - Becoming more difficult to obtain and maintain……

Analog and Digital Comparison (cont.)

- Digital voltage regulators
  - Typically higher cost for basic functionality
  - Digital designs now becoming more widely used
  - RMS sensing regulation standard
  - Highly versatile
  - Many additional features enabled by digital technology (data monitoring, protective relaying, generator protection built in…)

Voltage Regulator and Load CB



Parallel Operation Control

- Stand alone operation (island mode)
  - No paralleling controls required
- Paralleled Applications (similar-sized units)
  - Micro-Grid
  - Can be run in droop or cross current compensation mode
- Co-gen applications (connected to grid)
  - Large utility grid
  - Must run in droop mode or in VAR / PF mode

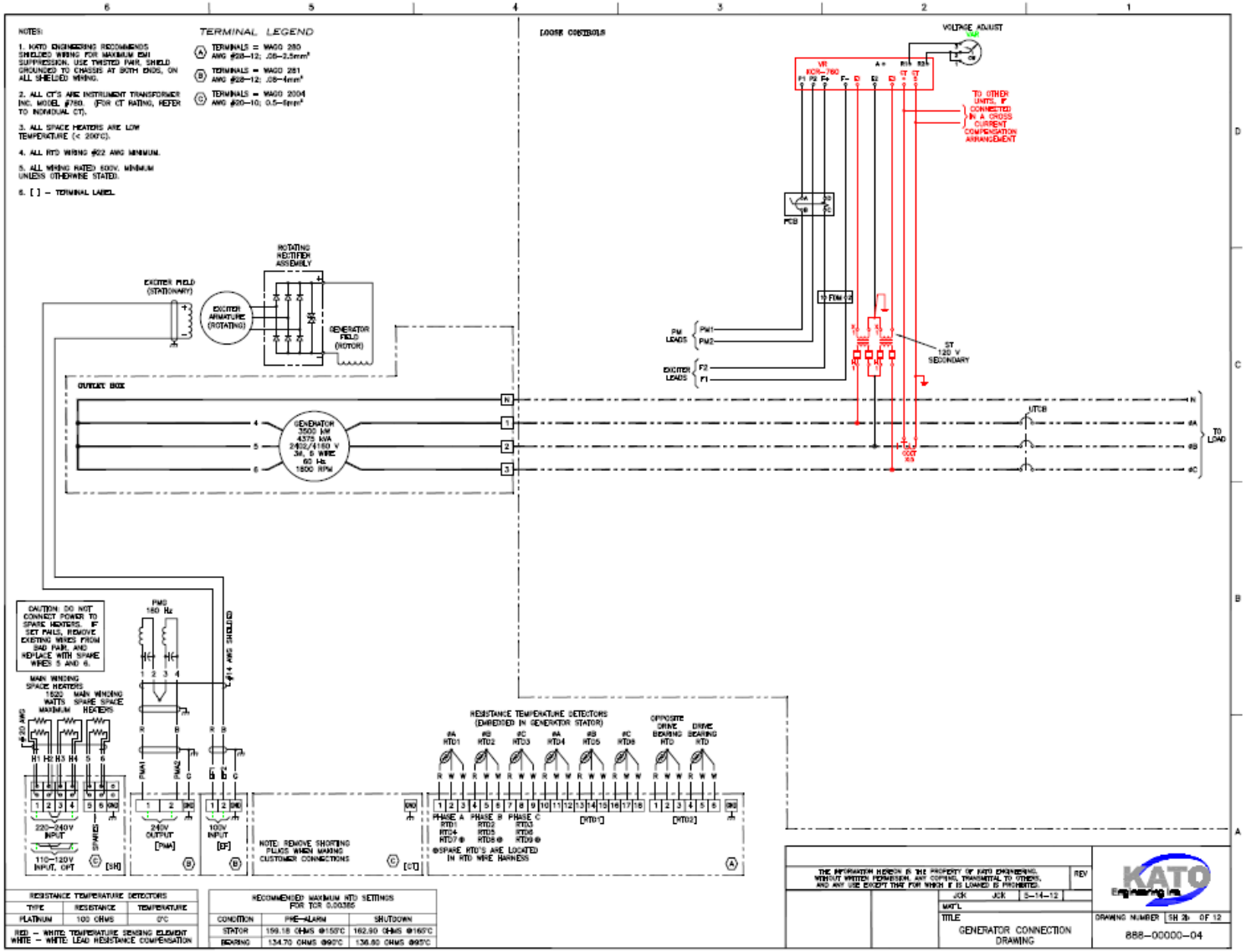
Stand Alone Operation (Island Mode)

Paralleling controls are not required

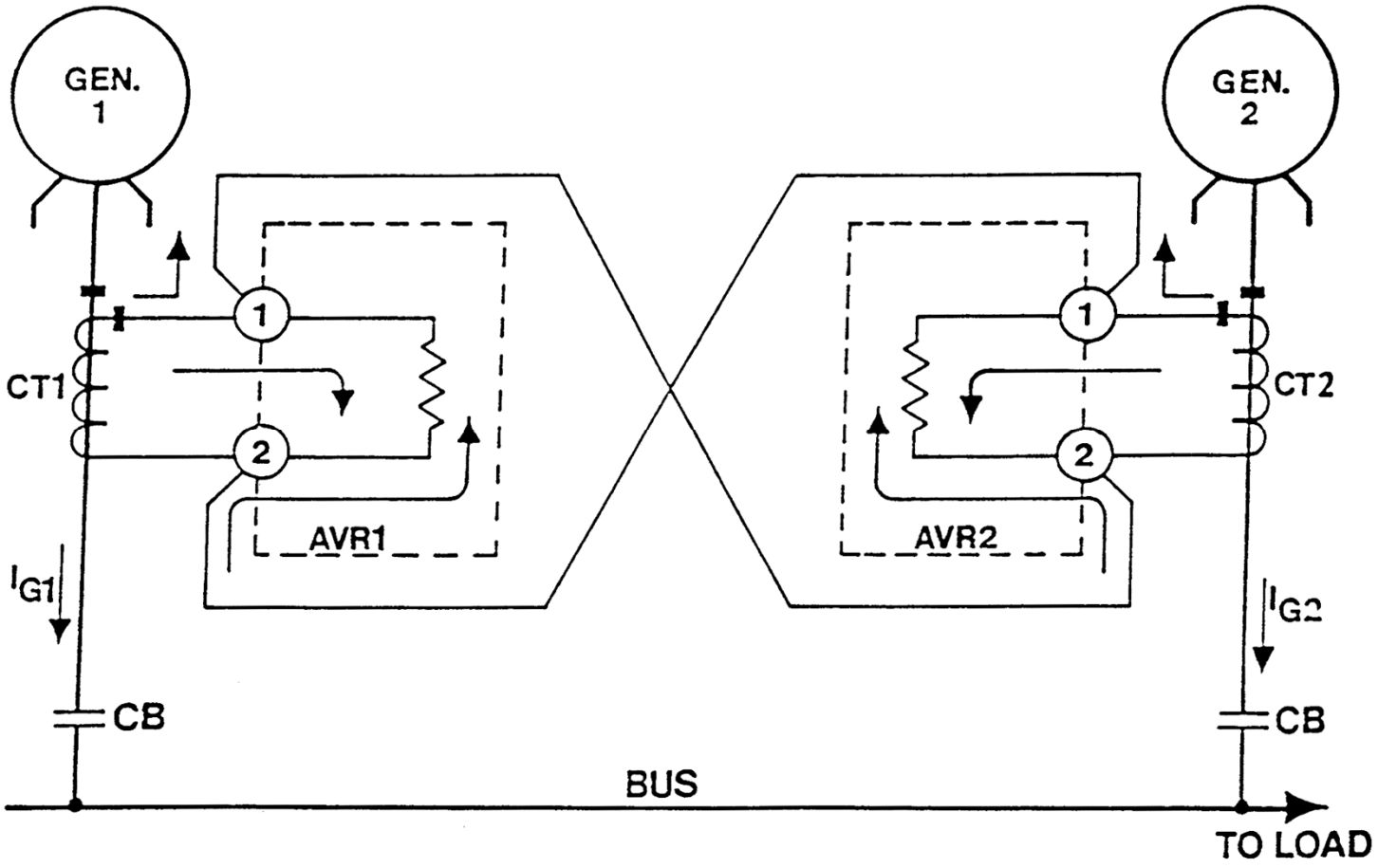
Paralleled Applications (Micro Grid)

- For operating in parallel with similar sized units (non utility or larger gen)
- “Cross current” paralleling controls typical

Voltage Regulator with CCCT

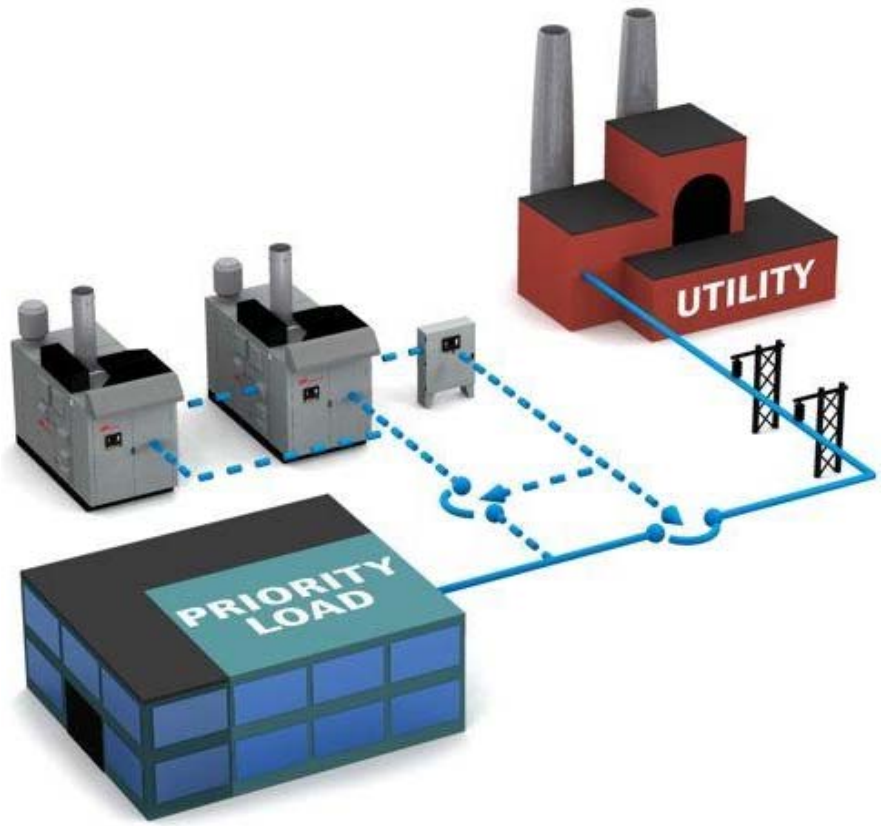


Cross-Current Compensation
Balanced kVAR Loading



Co-Gen Applications

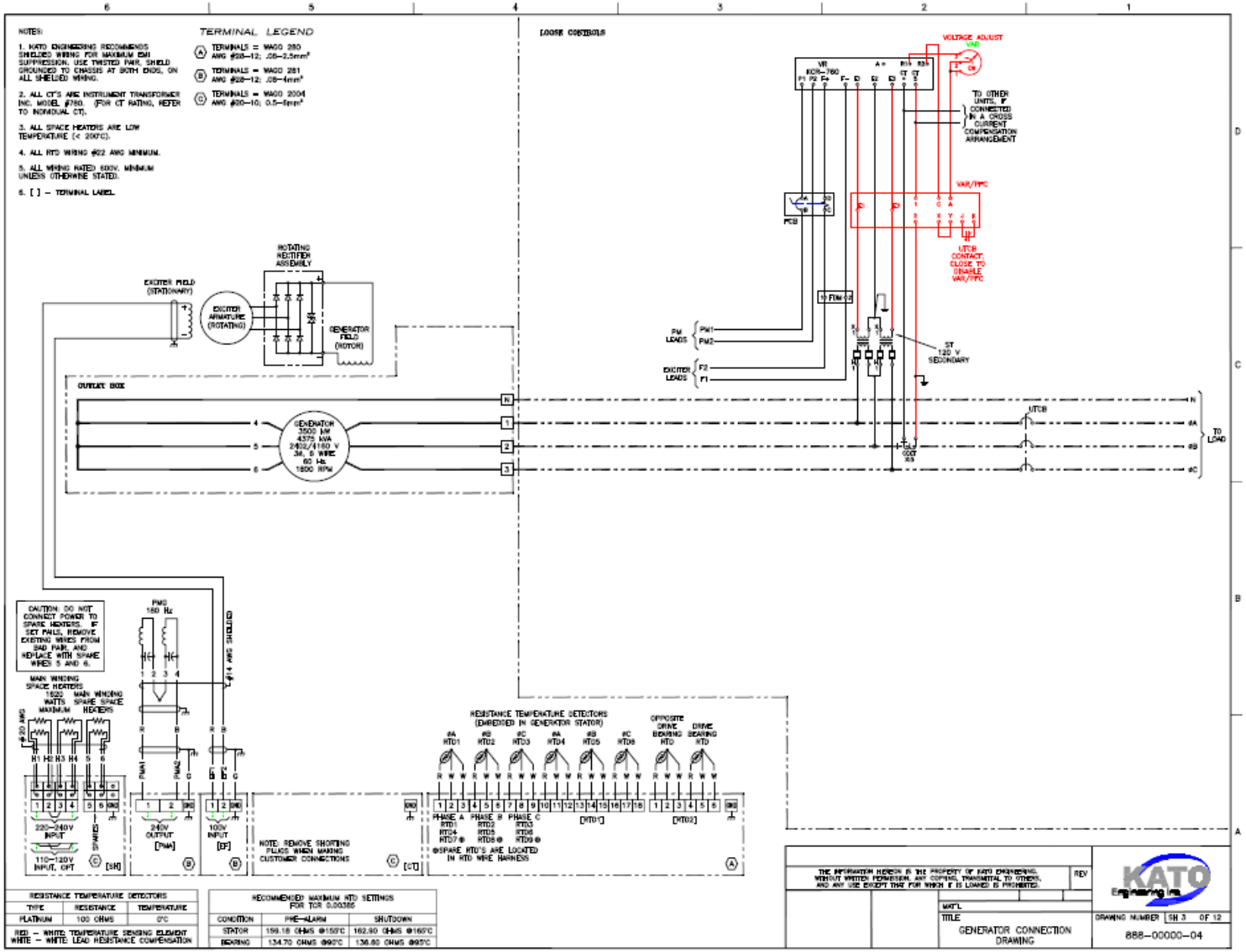
- For operating in parallel with utility or large generator set or turbine generator
- “Droop mode” paralleling controls needed
- VAR and Current limiting needed



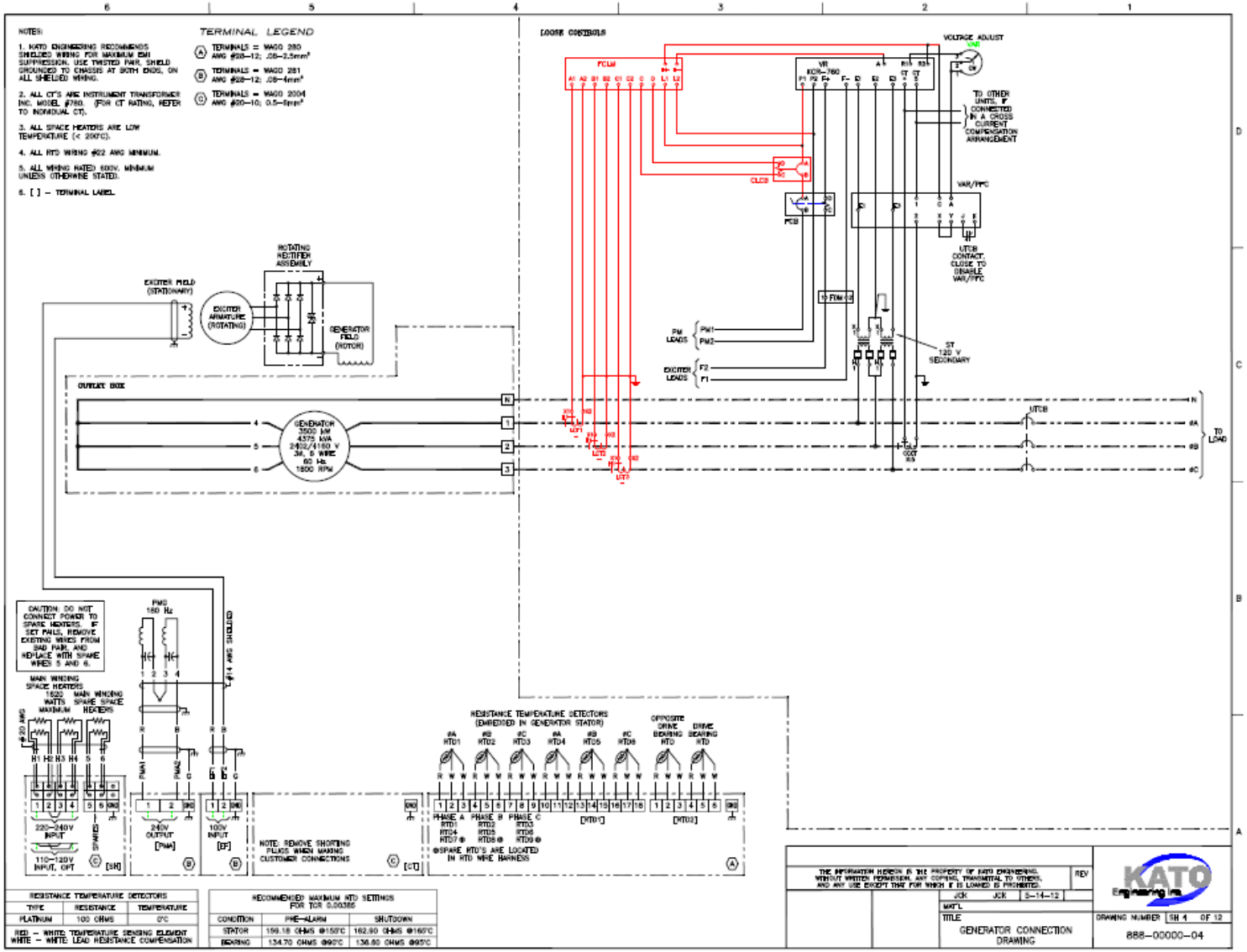
Reactive Load (VAR/PF) Control

- For operating in parallel with utility
- Don’t use pure VAR control on single, isolated generator.
  - Voltage control issues arise.
  - Must be disabled when generator is not paralleled.
  - Use voltage control mode (Standard mode)

VAR/PF Control



Current Limiting (300%)



Monitoring and Control

- Quality sensing devices
  - Current transformers (CTs)
  - Potential transformers (PTs)
- Data logging
- Remote control
- Revenue billing

Sensing CTs and PTs

- Sensing current transformers (CTs)
  - Size from miniature PCB to “bar type”
- Sensing potential transformers (PTs)
  - Miniature to medium voltage

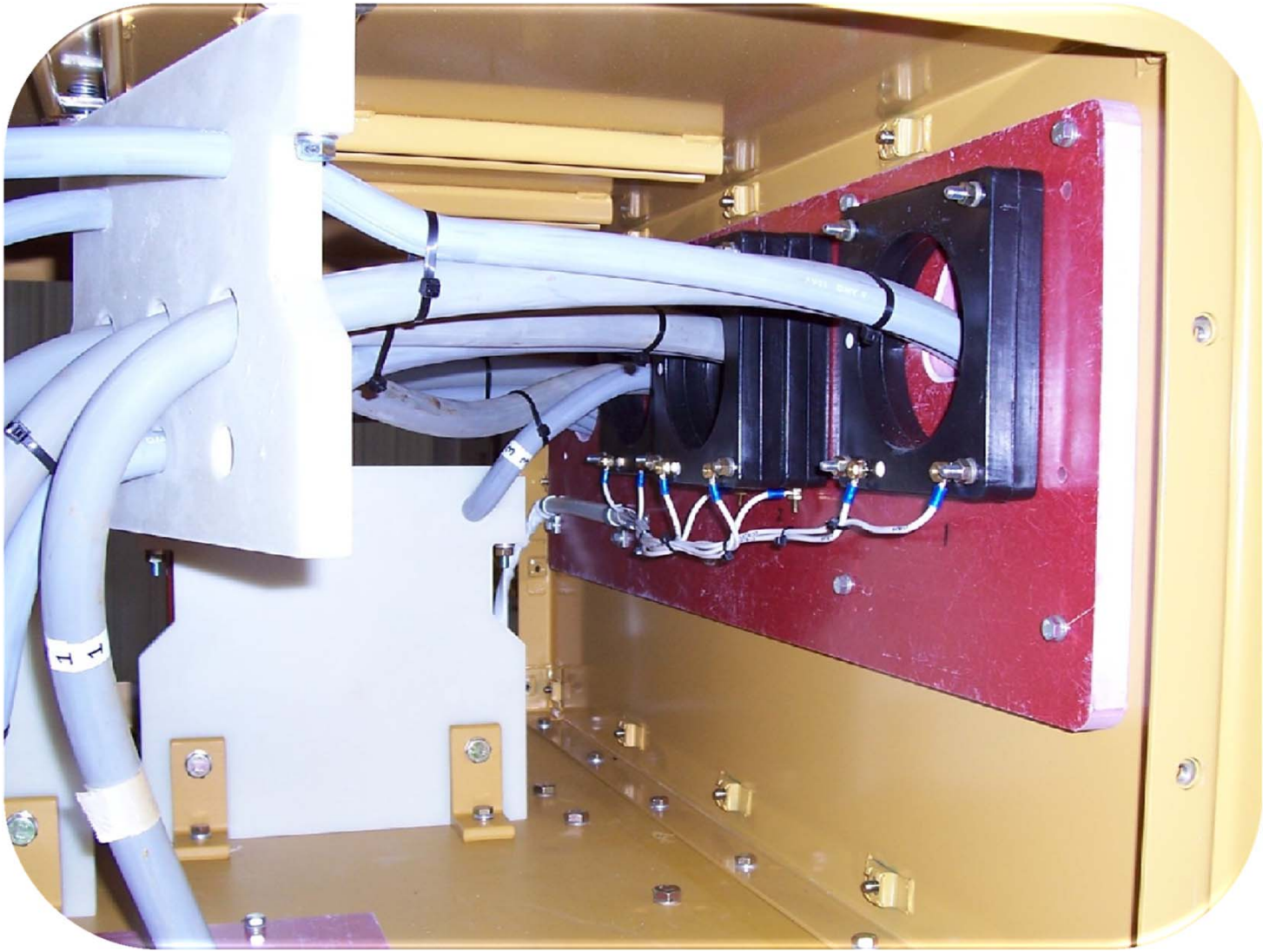
Current Transformers

Bar type

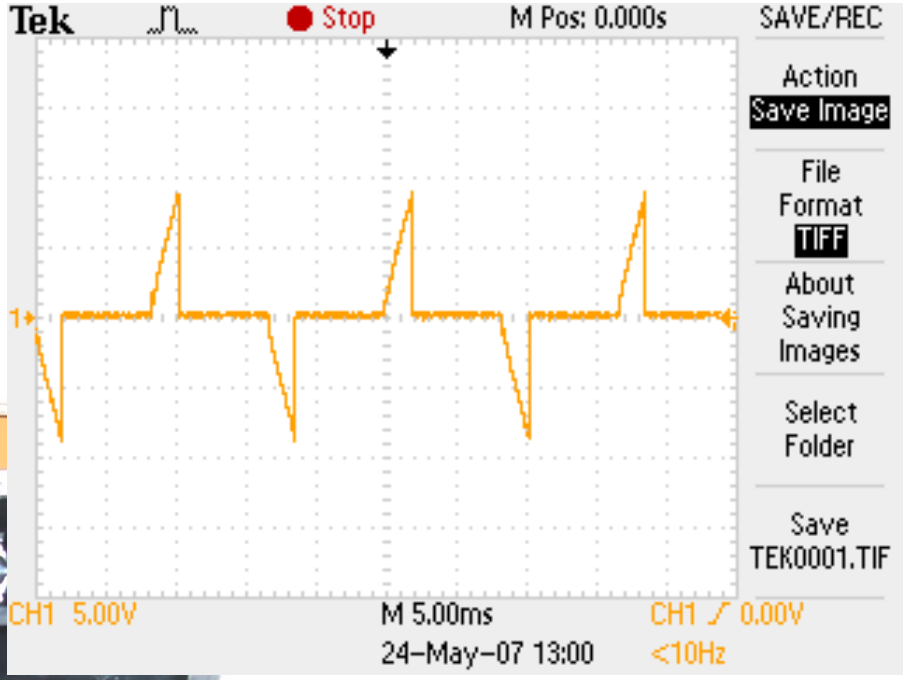
Donut type

Donut type with
lead support

Current Transformer Installation

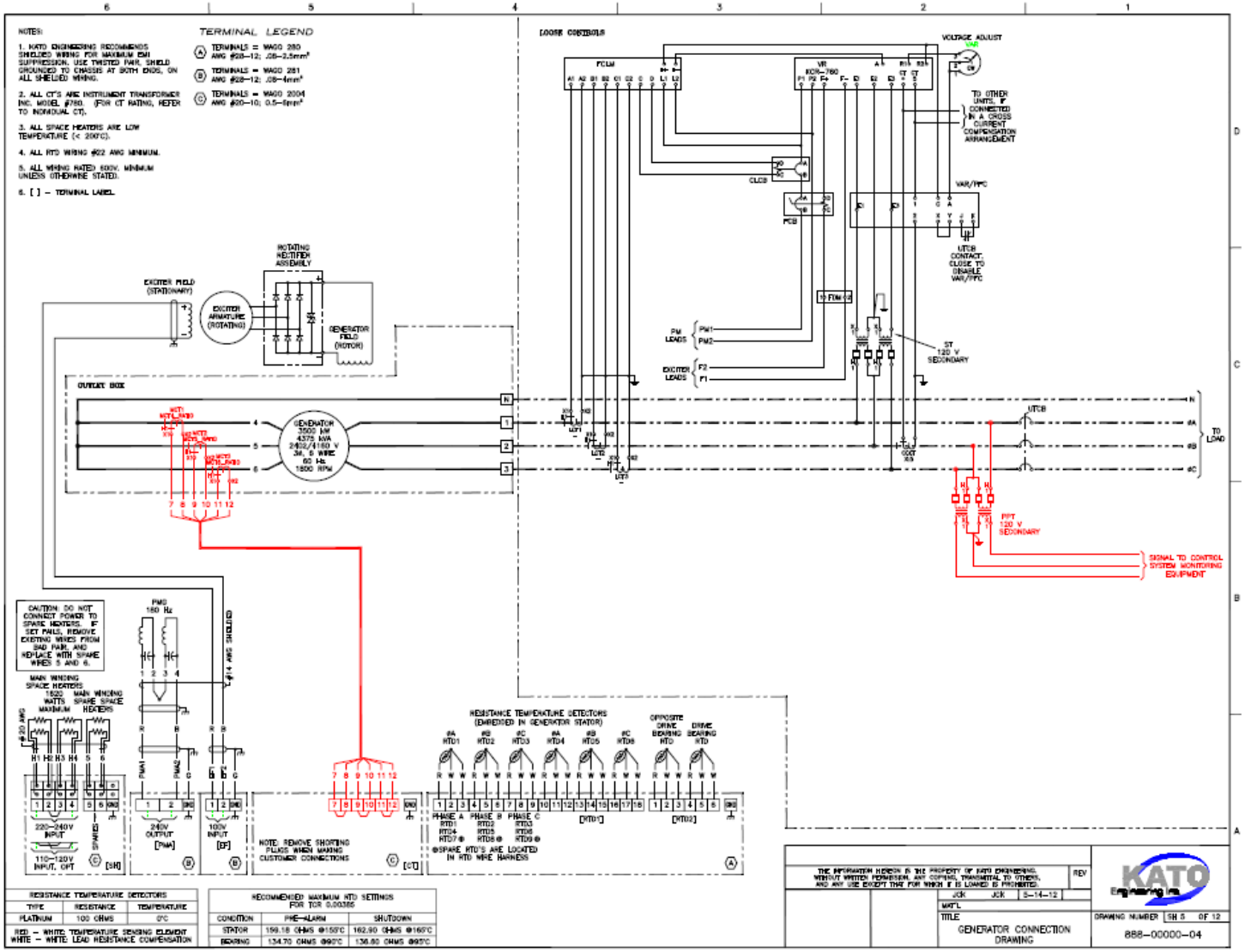


CT Clamping Circuit (ATEX)

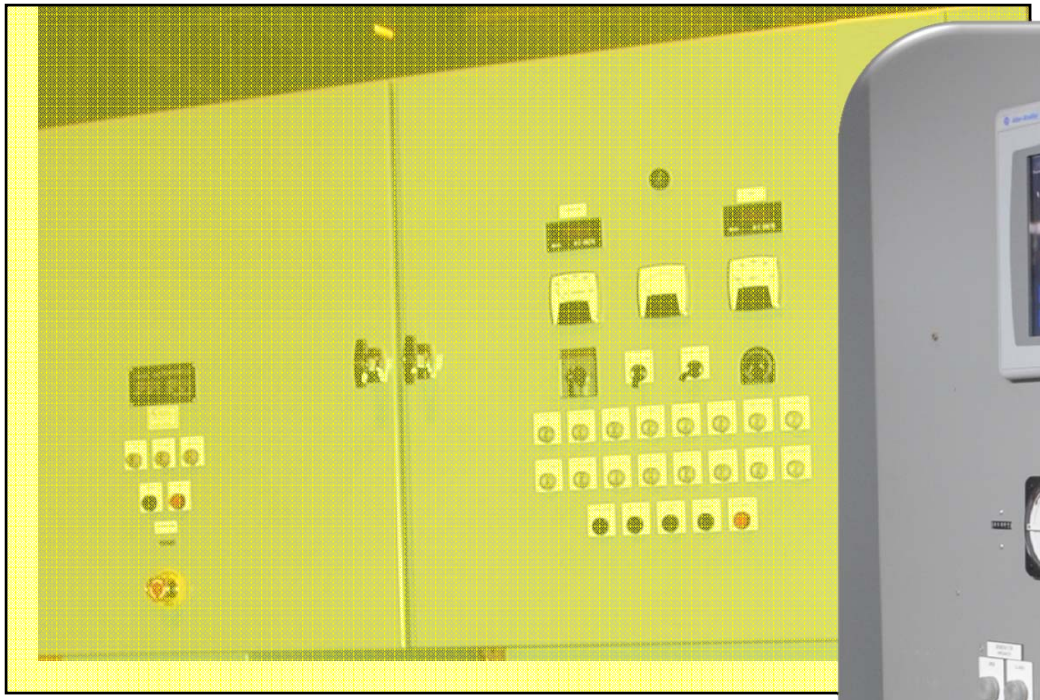


Potential Transformer Installation

Monitoring and Control



Advanced Monitoring and Control



Network enabled systems becoming the norm

Generator Protection

- Recommended minimum protection
  - Under-frequency (as a control: not true protection)
  - Over-voltage
  - Phase over-current

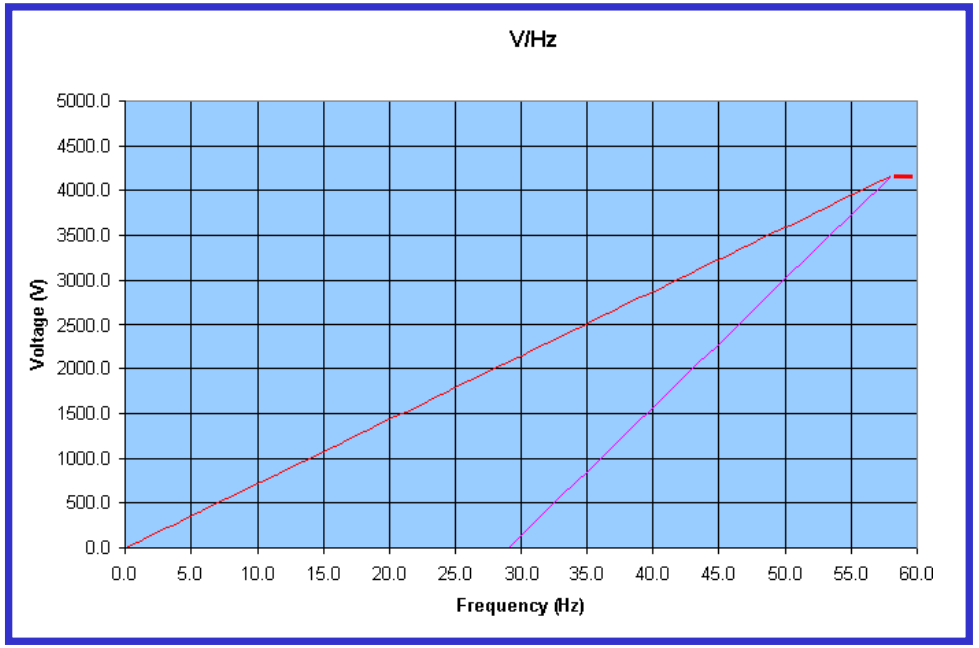
ANSI Device Numbers

List of ANSI/IEEE Device Numbers and Acronyms

1 – Master Element
2 – Time Delay Starting or Closing Relay
3 – Checking or Interlocking Relay
4 – Master Contactor
5 – Stopping Device
6 – Starting Circuit Breaker
7 – Rate of Change Relay
8 – Control Power Disconnecting Device
9 – Reversing Device
10 – Unit Sequence Switch
11 – Multi-function Device
12 – Overspeed Device
13 – Synchronous-speed Device
14 – Underspeed Device
15 – Speed – or Frequency, Matching Device
16 – Data Communications Device
17 – Shunting or Discharge Switch
18 – Accelerating or Decelerating Device
19 – Starting to Running Transition Contactor
20 – Electrically Operated Valve
21 – Distance Relay
22 – Equalizer Circuit Breaker
23 – Temperature Control Device
24 – Volts Per Hertz Relay
25 – Synchronizing or Synchronism-Check Device
26 – Apparatus Thermal Device
27 – Undervoltage Relay
28 – Flame detector
29 – Isolating Contactor or Switch
30 – Annunciator Relay
31 – Separate Excitation Device
32 – Directional Power Relay
33 – Position Switch
34 – Master Sequence Device
35 – Brush-Operating or Slip-Ring Short-Circuiting Device
36 – Polarity or Polarizing Voltage Devices
37 – Undercurrent or Under Power Relay
38 – Bearing Protective Device
39 – Mechanical Condition Monitor
40 – Field (over/under excitation) Relay
41 – Field Circuit Breaker
42 – Running Circuit Breaker
43 – Manual Transfer or Selector Device
44 – Unit Sequence Starting Relay
45 – Abnormal Atmospheric Condition Monitor
46 – Reverse-phase or Phase-Balance Current Relay
47 – Phase-Sequence or Phase-Balance Voltage Relay
48 – Incomplete Sequence Relay
49 – Machine or Transformer, Thermal Relay
50 – Instantaneous Over Current Relay
51 – AC Inverse Time Over Current Relay
52 – AC Circuit Breaker
53 – Exciter or DC Generator Relay
54 – Turning Gear Engaging Device
55 – Power Factor Relay
56 – Field Application Relay
57 – Short-Circuiting or Grounding Device
58 – Rectification Failure Relay
59 – Overvoltage Relay
60 – Voltage or Current Balance Relay
61 – Density Switch or Sensor
62 – Time-Delay Stopping or Opening Relay
63 – Pressure Switch
64 – Ground Detector Relay
65 – Governor
66 – Notching or Jogging Device
67 – AC Directional Overcurrent Relay
68 – Blocking or "Out-of-Step" Relay
69 – Permissive Control Device
70 – Rheostat
71 – Liquid Level Switch
72 – DC Circuit Breaker
73 – Load-Resistor Contactor
74 – Alarm Relay
75 – Position Changing Mechanism
76 – DC Overcurrent Relay
77 – Telemetering Device
78 – Phase-Angle Measuring Relay
79 – AC Reclosing Relay
80 – Flow Switch
81 – Frequency Relay
82 – DC Reclosing Relay
83 – Automatic Selective Control or Transfer Relay
84 – Operating Mechanism
85 – Communications, Carrier or Pilot-Wire Relay
86 – Lockout Relay
87 – Differential Protective Relay
88 – Auxiliary Motor or Motor Generator
89 – Line Switch
90 – Regulating Device
91 – Voltage Directional Relay
92 – Voltage and Power Directional Relay
93 – Field Changing Contactor
94 – Tripping or Trip-Free Relay

Under Frequency

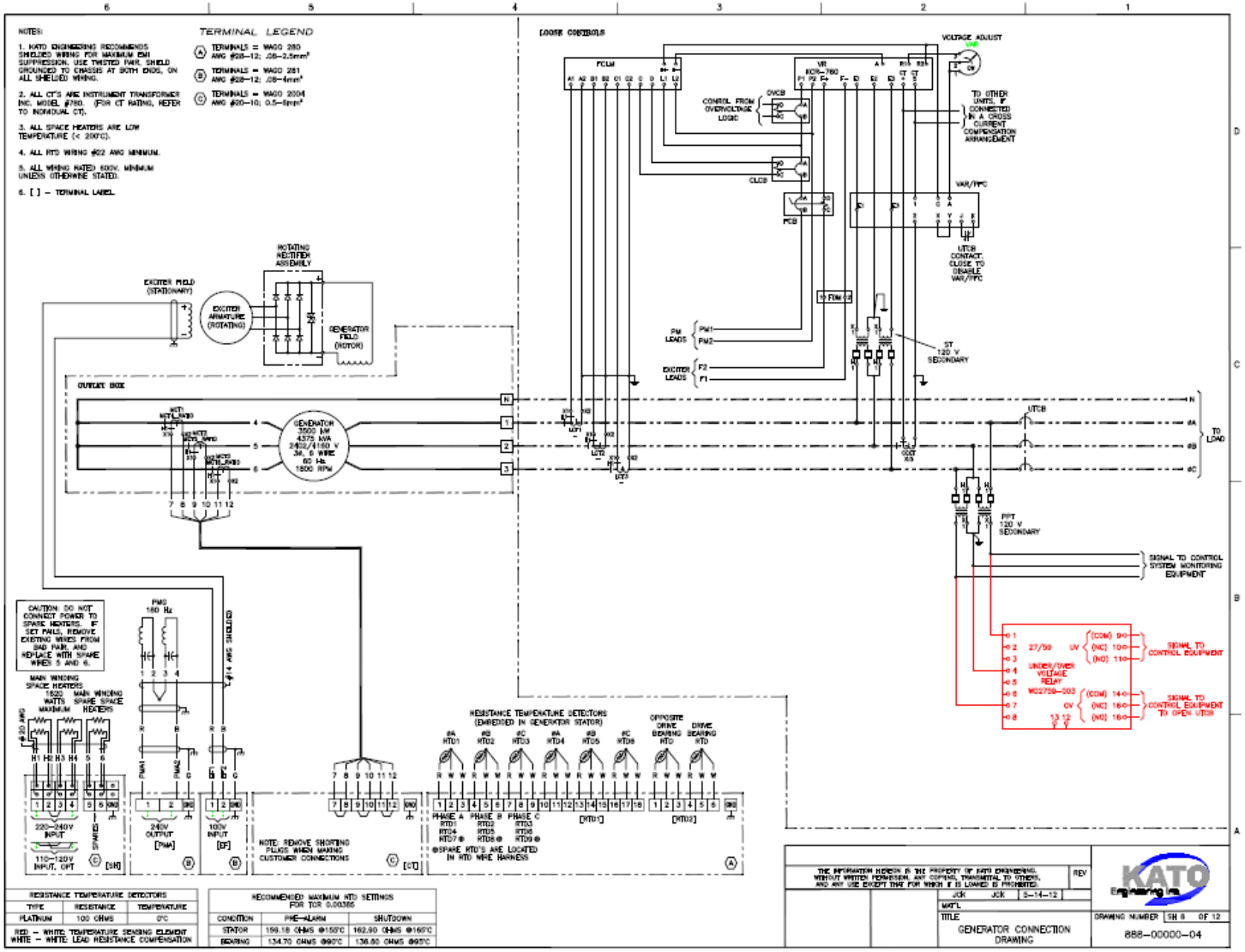
- Control-type operates through voltage regulator
  - Controls generator voltage proportional to frequency
- Protection-type may be needed to protect other equipment
  - Required to trip generator offline upon under frequency detection



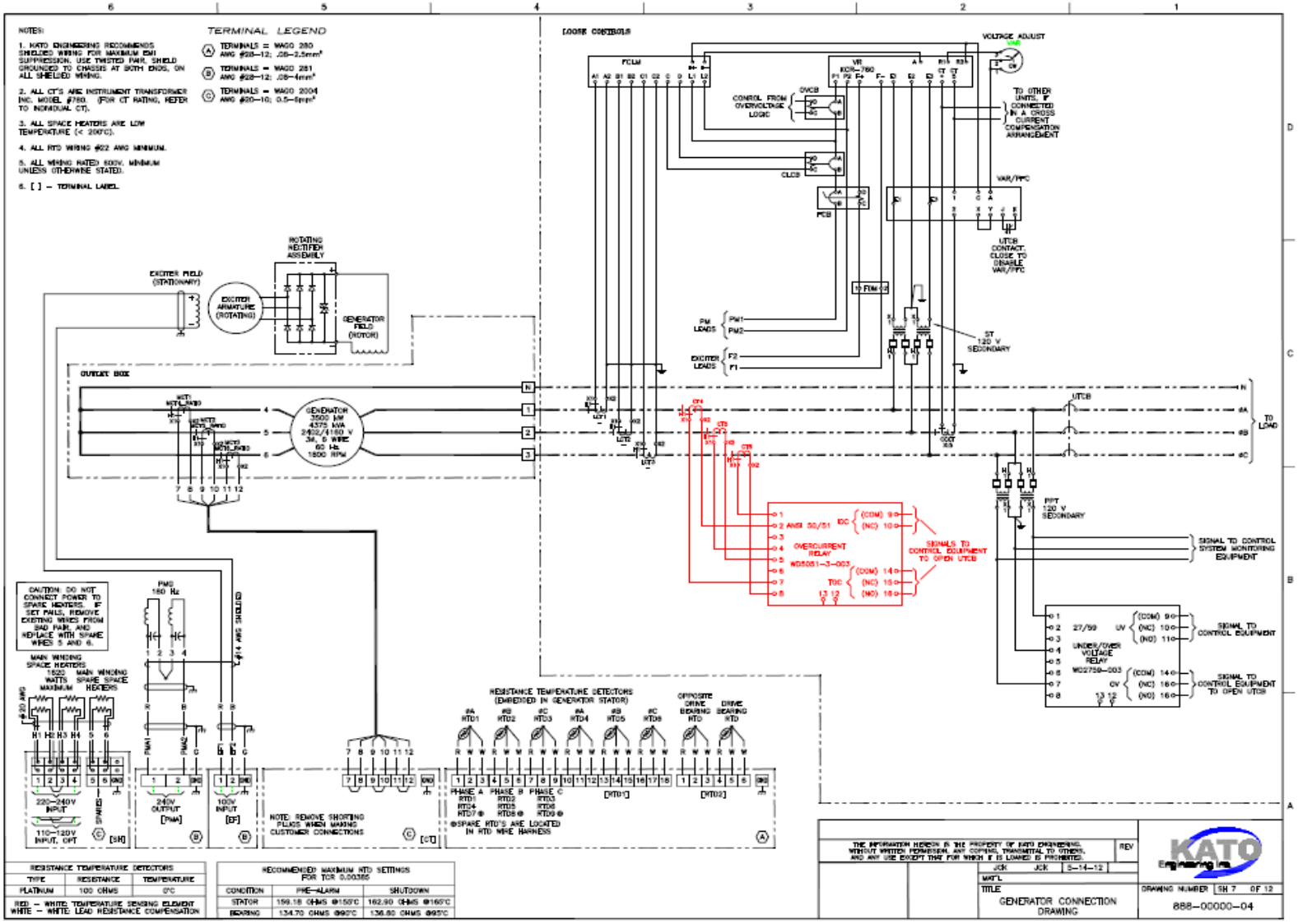
Over-Voltage Protection

- Should be used with every generator
- Protects loads as well as generator and exciter
- Must remove excitation from generator

Over Voltage Protection (cont.)



Over-Current Protection



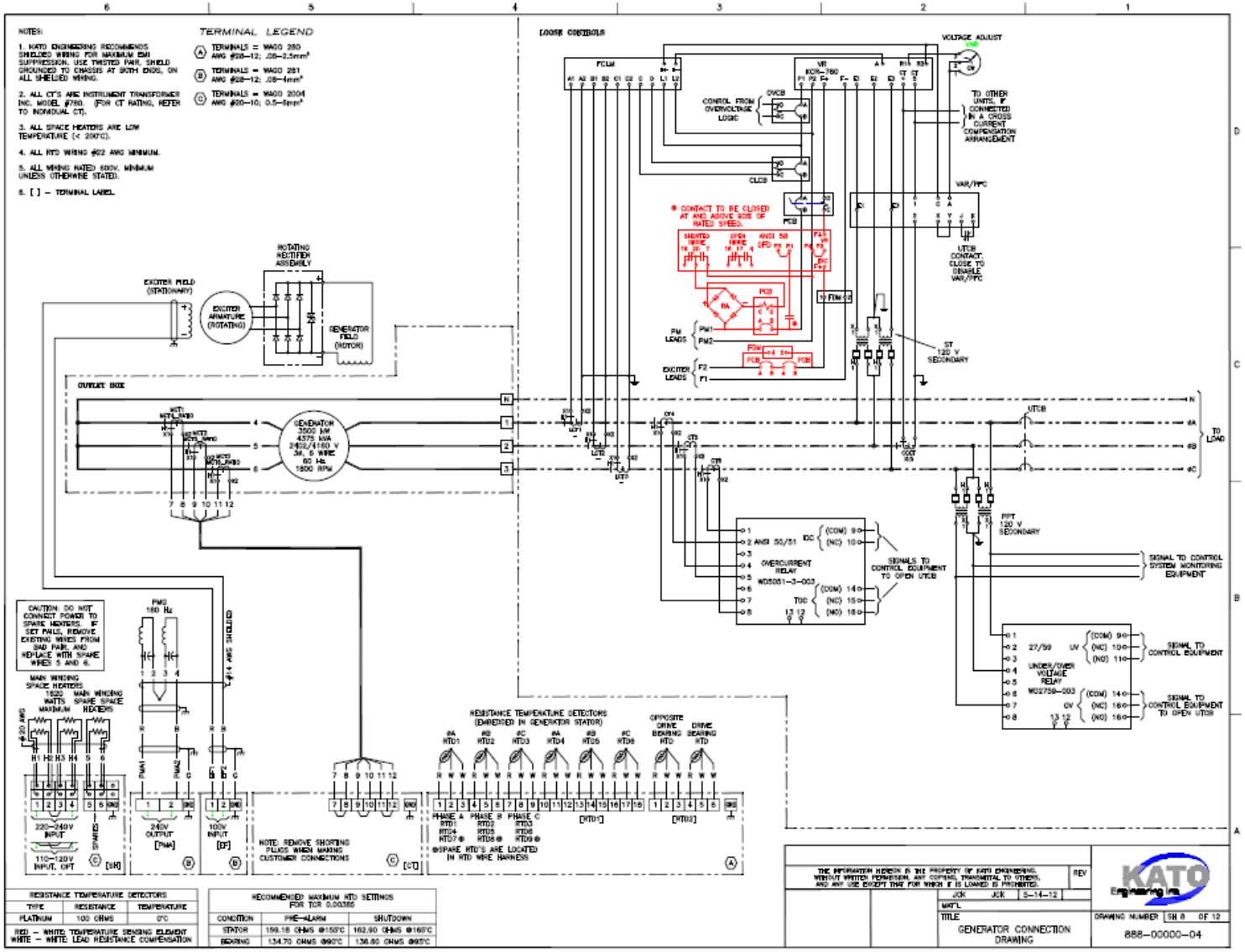
Additional Generator Protection

- Required for some but not every installation (specification driven.
  - Exciter diode fault protection
  - Negative sequence over current
  - Differential over current
  - Lightning arrestors and surge capacitors

Exciter Diode Failure Protection

- Indirect-type monitors ripple current in exciter field winding
- Protects against generator field overheating

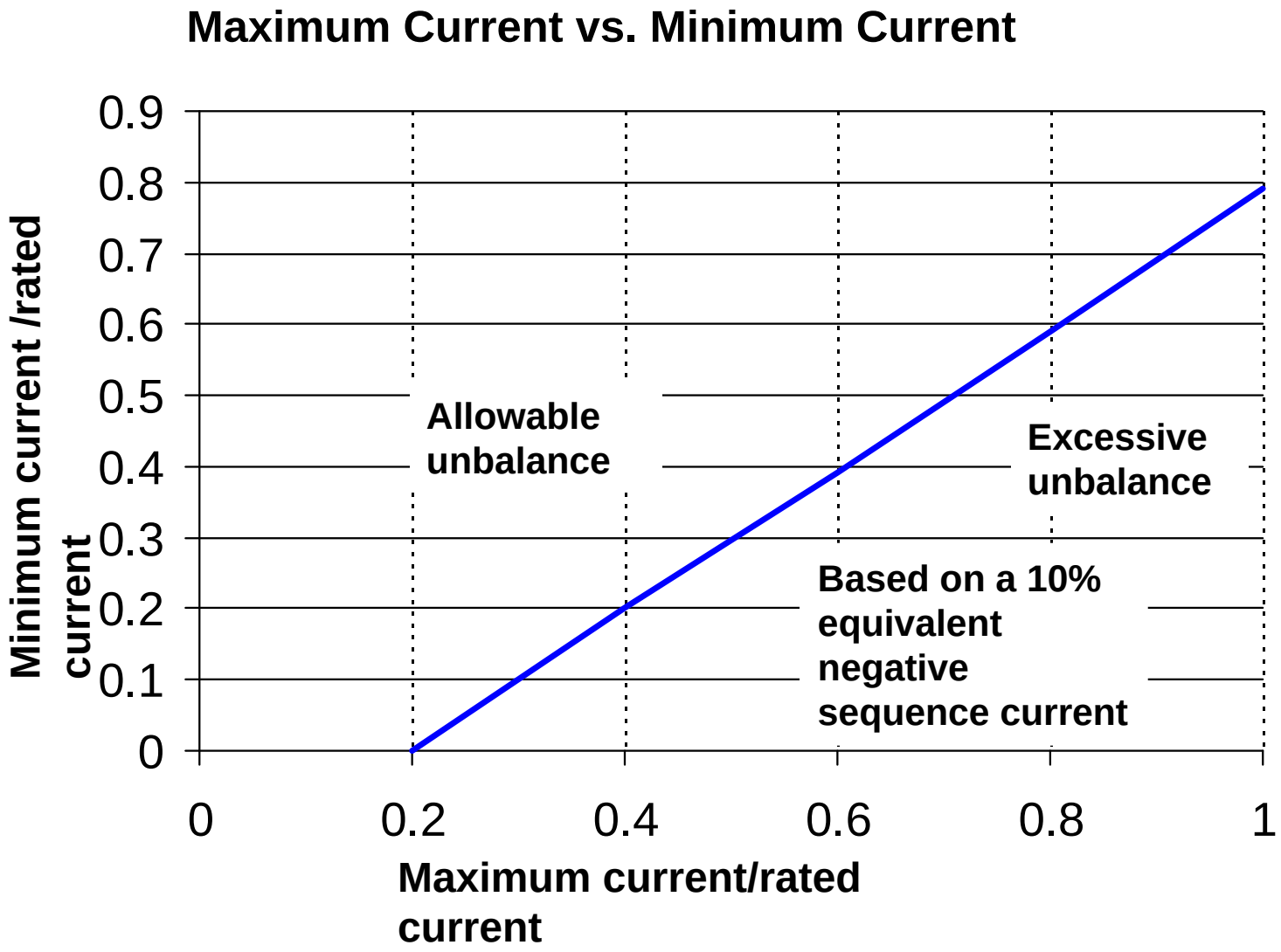
Diode Fault Protection



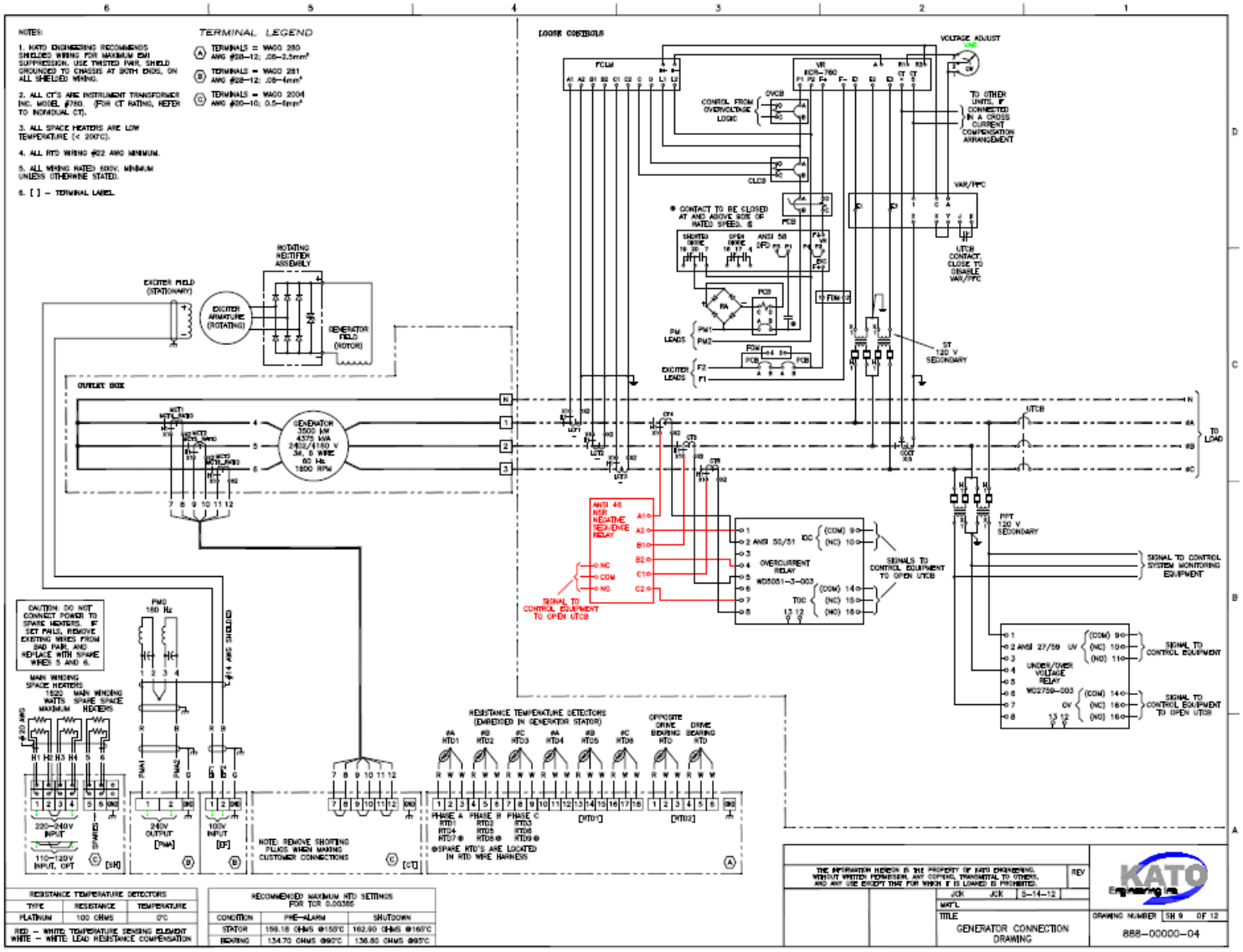
Negative Sequence Protection

- Also known as unbalanced current protection.
- Needed when there is any chance of unbalanced load.
- For Kato™ generators, k factor is 40
  (k factor = $(I_2)^2$ t)

Negative Sequence

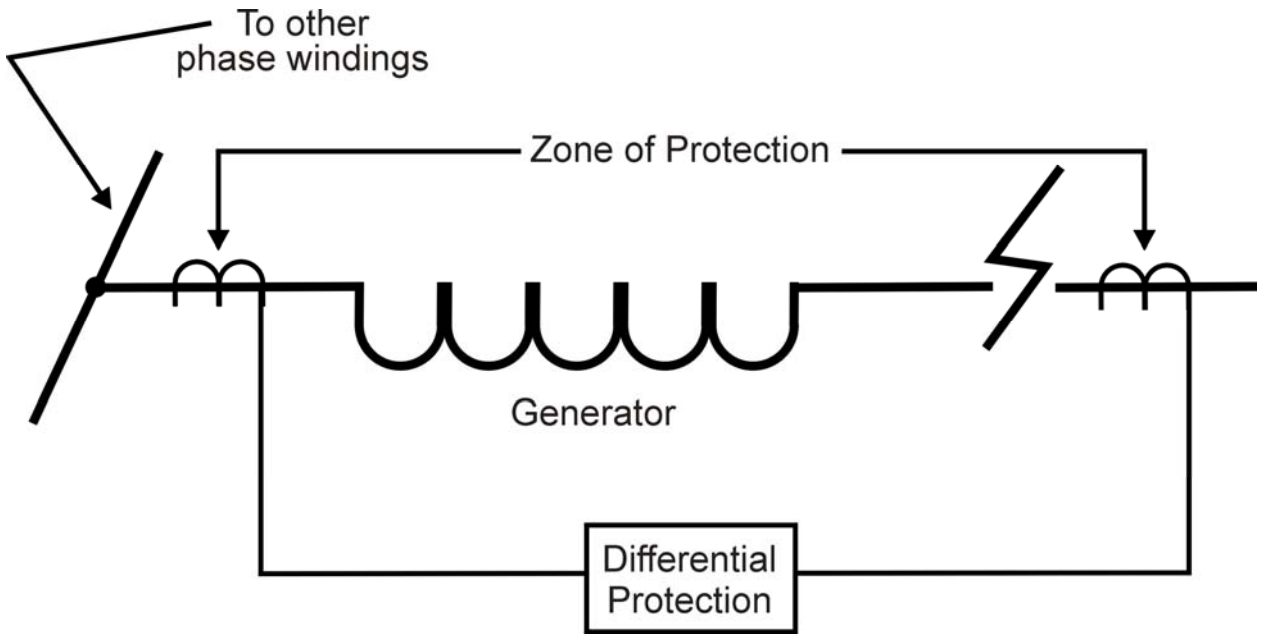


Negative Sequence Protection

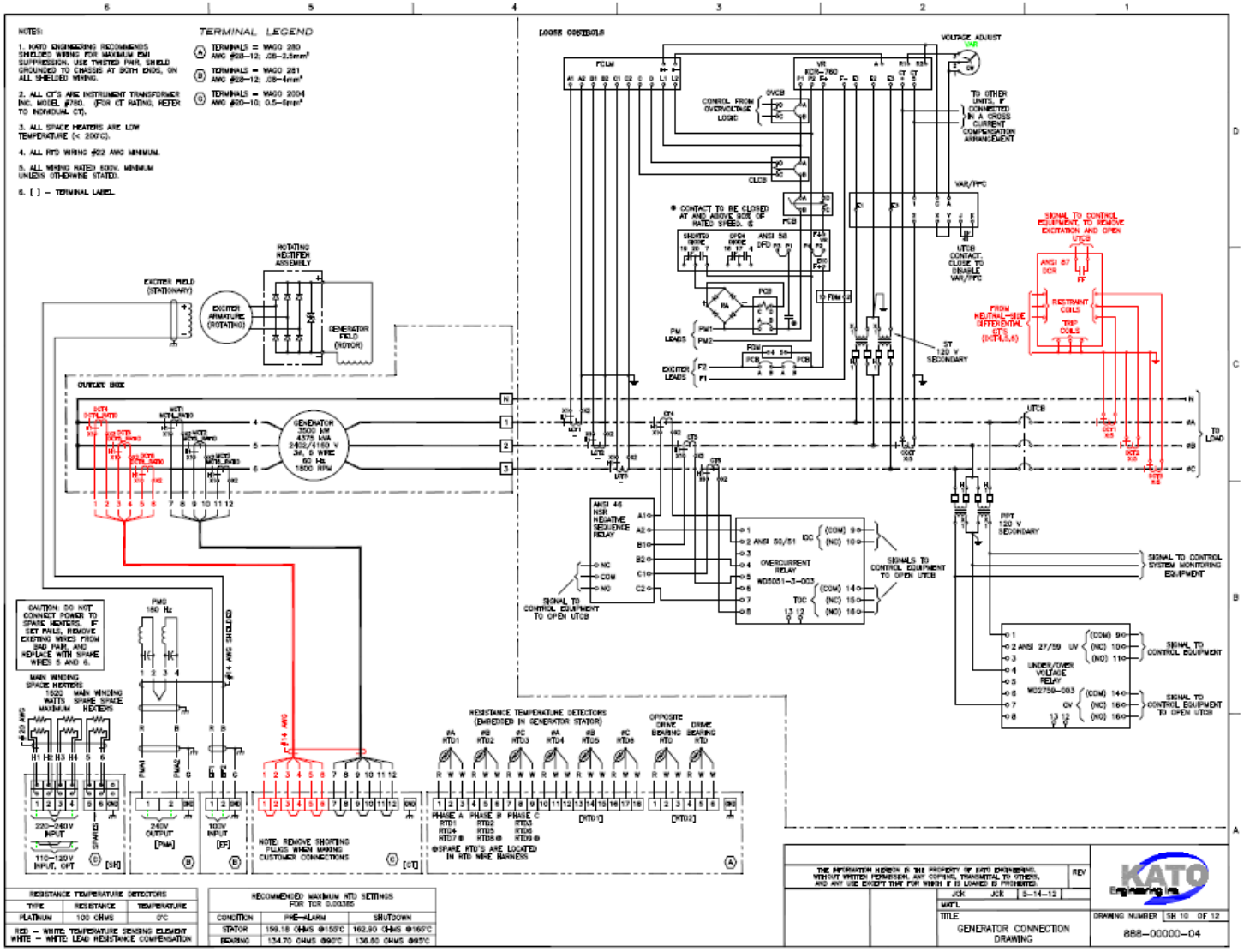


Differential Current Protection

- Compares currents of corresponding phase & neutral windings.
- Does not prevent damage, but limits damage.
- CTs must be identical at both ends of windings.
- Watch for applications energizing large transformers.



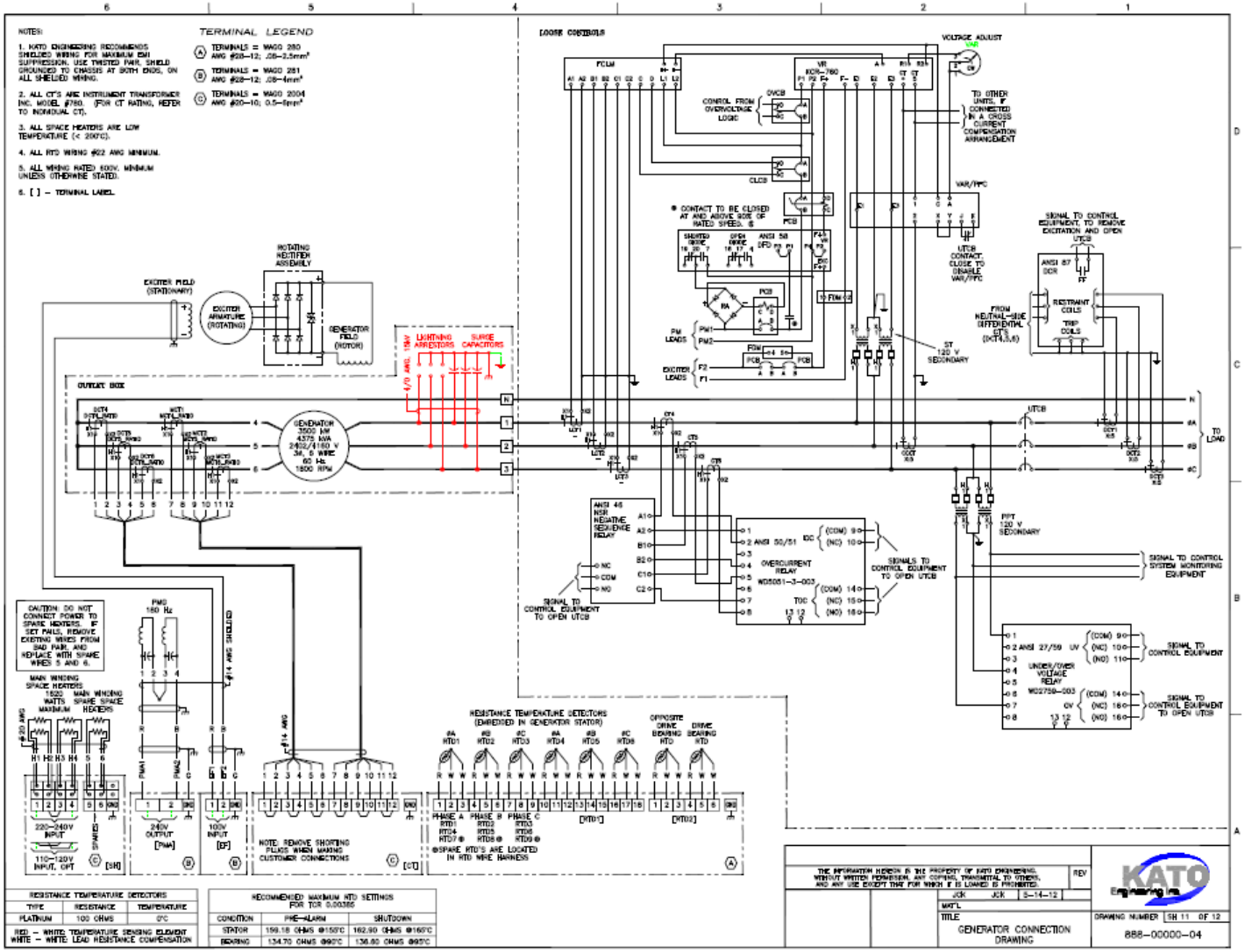
Differential Current Protection



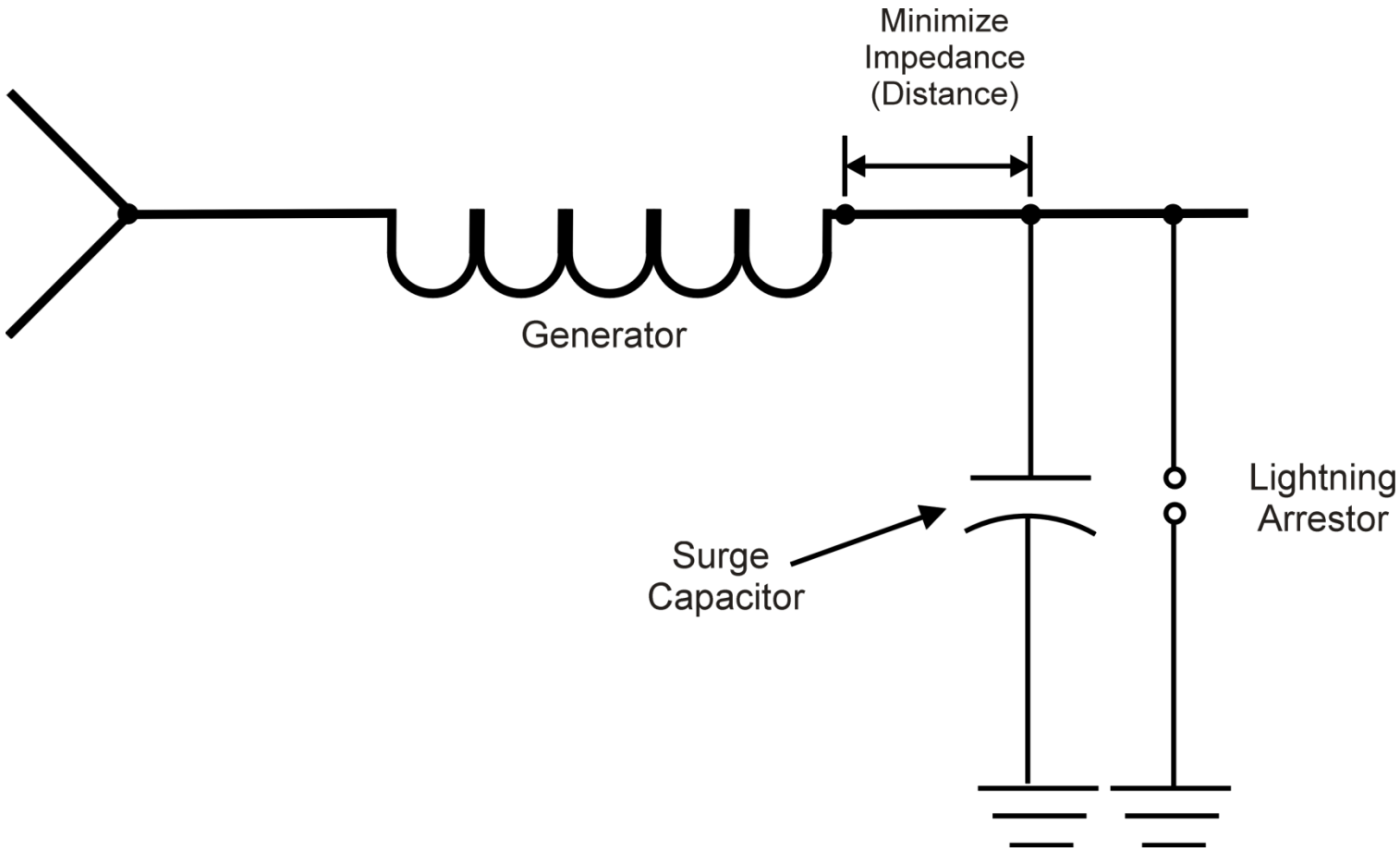
Lightning Arrestors, Surge Capacitors

- Protect generator windings against lightning and switching. (What happens if not protected? Why?)
- Should be used on all medium and high-voltage generators.
- As close to generator as possible.
- Use high-quality, low impedance, arrestors.

Lightning Protection



Capacitor/Arrestor Location



Lightning/Surge Protection

Lightning/Surge Protection (cont.)

Typical installation

General Recommended Protection

Generator Capability Limits; Protections Required.

IMPORTANT–these values are for the generator only where sychronism is maintained. System Engineers MUST evaluate these limits for each application. For specific system requirements, custom designs can be developed.

Protection Type	Protection Limits	Source
Phase Overcurrent	110% for 2 hrs out of 24 hrs 150% for 30 sec I^2t = 270 max at 3 pu short circuit max.	NEMA MG1 32.8 NEMA MG1 32.9 NEMA MG1 32.13
Negative Sequence Current	I_2 = 0.10 pu max. continuous $(I_2)^2t$ = 40 for I_2 above 0.10 pu unbalanced current (I max. – I min.) = 20% rated amps max. continuous	NEMA MG1 32.14 / ANSI C50.12 6.2 NEMA MG1 32.13 / ANSI C50.12 6.1
Phase Differential Overcurrent	2–5% (low as possible without experiencing false trips) of rated phase current, 10% max. no delay	Kato Engineering recommended to minimize generator damage
Over–voltage	continuous 105% rated transient 115% rated	NEMA MG1 32.17.2/ IEC 60034–1 Fig.11 This is acceptable operation for Kato generators. However, protection of loads connected to the generator is the responsibility of the user
Under–voltage	continuous 95% rated transient not significant to generator	NEMA MG1 32.17.2/ IEC 60034–1 Fig.11 protection of loads connected to the generator is the responsibilty of the user
Over–fluxing (excess V/Hz)	not significant to generator if over–voltage and under–frequency protection is applied correctly. brushless rotating exciters also add protection against this	recommended operation per IEC 60034–1 Figure 11
Over–frequency	102% at rated voltage continuous 125% overspeed for 2 minutes max.	IEC 60034–1 Figure 11 NEMA MG1 32.16
Under–frequency	98% at rated voltage continuous	IEC 60034–1 Figure 11
Under/Loss of Excitation	determined by generator reactive capability curve	Kato Engineering standard design practice
Over–excitation	120% rated excitation field current max. at least 1 minute	Kato Engineering standard design practice
Reverse Power	100% rated max. continuous (without loss of synchronism)	Kato Engineering standard design practice. If synchronism is lost the generator must be removed from operation.

Protection Type	Protection Limits	Source
Excess Winding Temp	by RTDs in slots, 155°C max. continuous 165°C max. immediate trip point (Class F insulation system) by RTDs in slots, 175°C max. continuous 185°C max. immediate trip point (Class H insulation system)	NEMA MG1 32.6 Table 32–3
High Bearing Temp	by RTD, 85°C max. continuous, 95°C max. immediate point	determined by bearing design
Insulation Stress	stator windings must be effectively grounded X0/X1=+0 to +3, R0/X1=+0 to +1	IEEE Std 142 (2007) 1.2 Definition (1.2.1 effectively Grounded) Greenbook Chapter 1
Ground (Earth) Fault	not significant to generator, however is a consideration of system design	NEMA MG–1 33.4.4.2
Voltage Unbalance	not significant to generator if unbalanced current (negative–sequence) is within limits	protection of loads connected to the generator is the responsibilty of the user
Neutral Current	same as Phase Overcurrent above but measured as the vectorial sum of fundamental and all harmonics	Unbalance Current and Negative Sequence protection is required
Voltage Surges on Windings	Kato Engineering recommended surge protection (consult factory)	Transient Voltage Suppression and Surge Protection offer a limited type of protection for the generator windings. Protection of the generator windings from surges originating from outside of the generator as well as lightning strikes are the responsibility of the user.
Insulation Resistance	periodic preventive maintenace insulation resistance test and/or addition of insulation resistance monitor	IEEE 43–2000 12.3

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KATO Engineering Inc.

TITLE

GENERATOR PROTECTION REQUIREMENTS

DRAWING NUMBER SH 1 OF 1

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