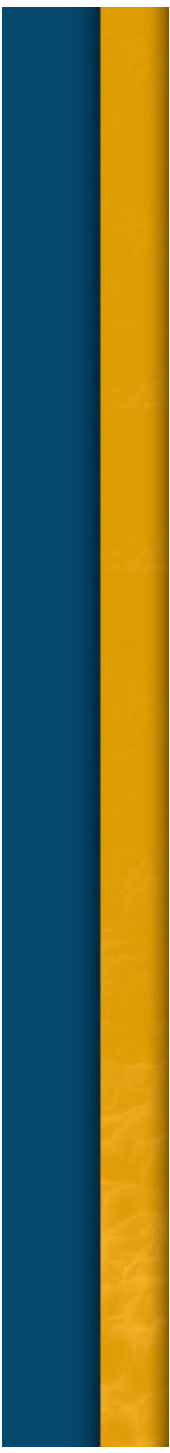


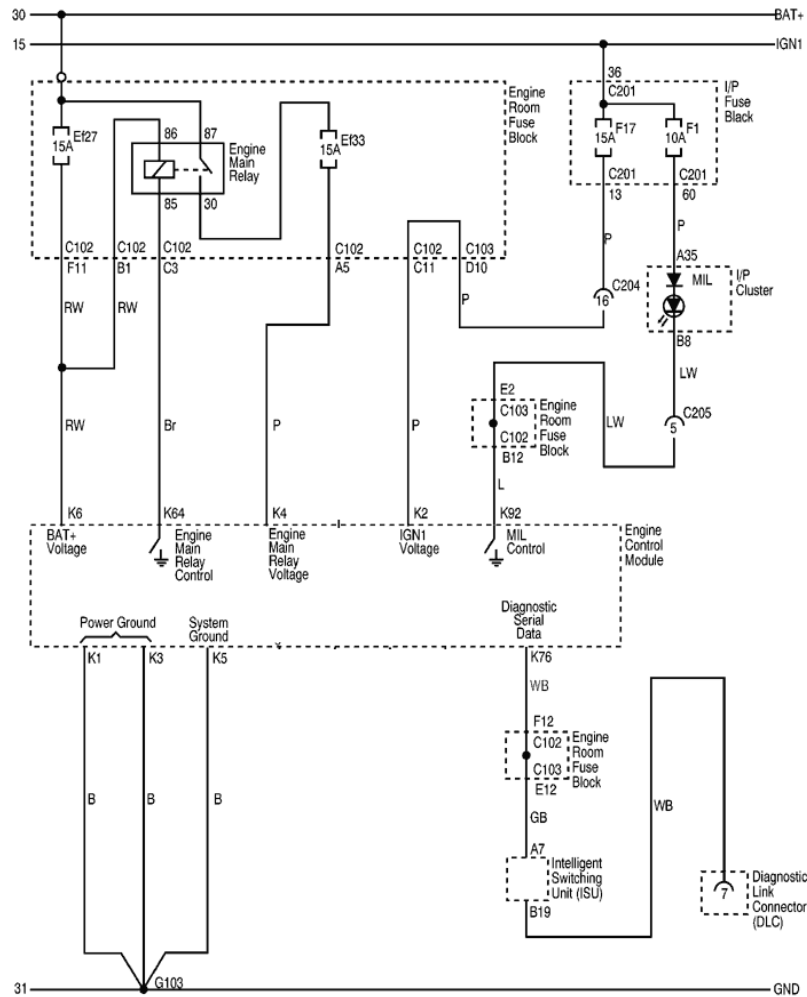
Control Systems and Protections



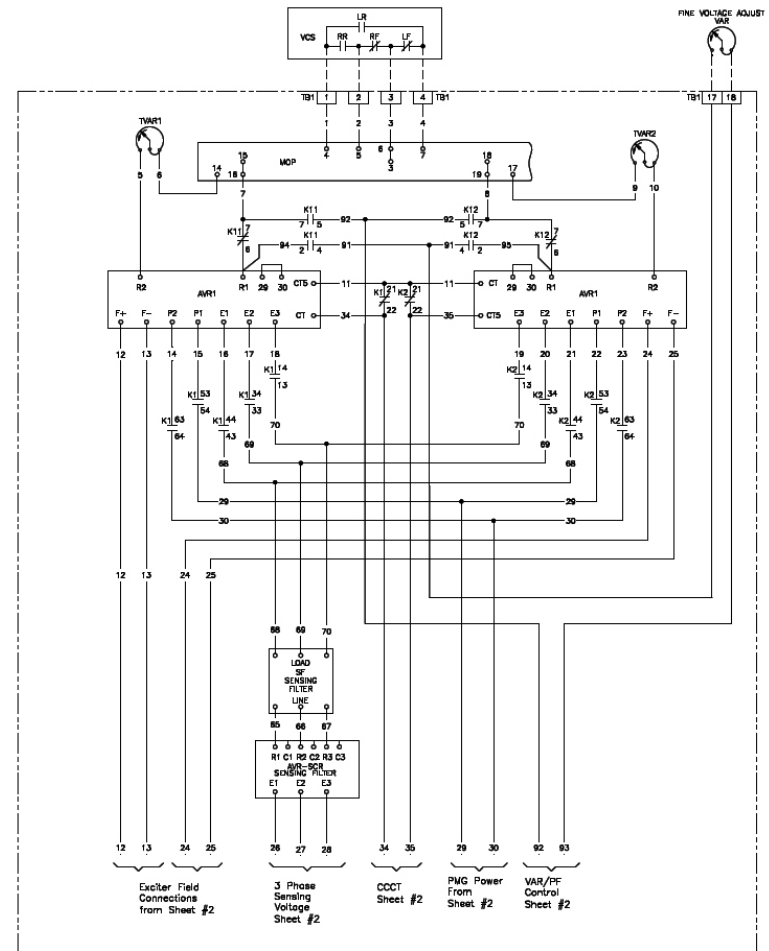
What Makes Up a Controls System?

- 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.)???

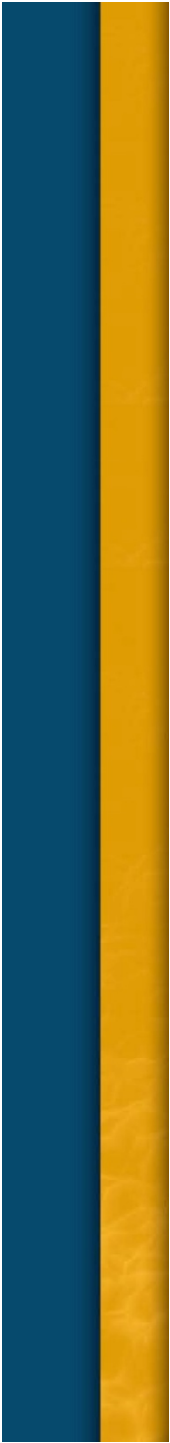
Engine-Generator Control Systems



Sample engine control systems

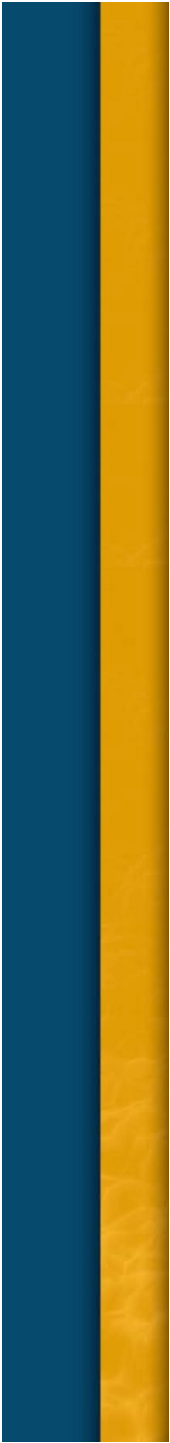


Sample generator control systems



Control System Functions

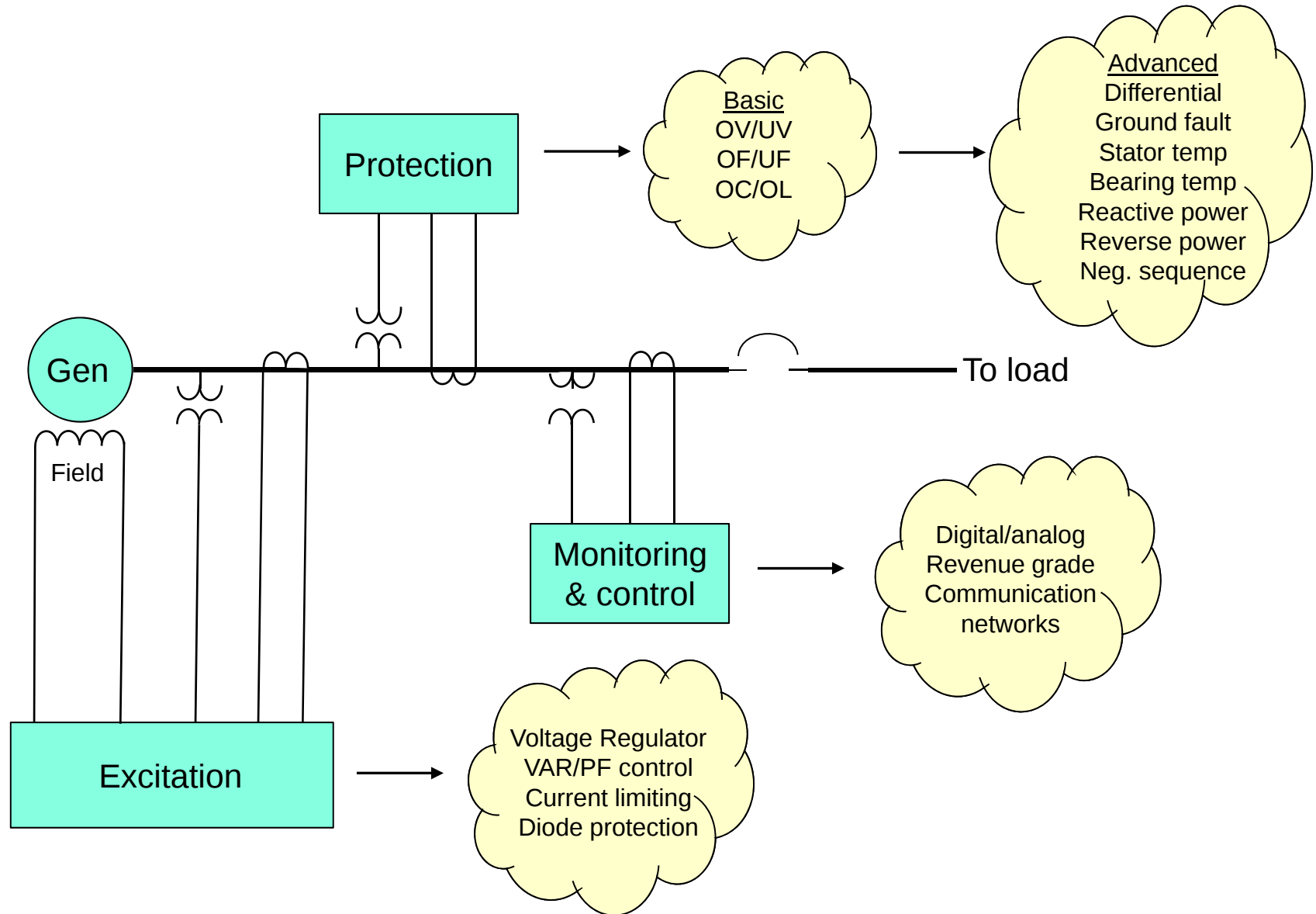
- Control the production and distribution of power
- Improve safety of the generating system
- Protect the generator
- Protect loads connected to the generator system



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.)



NOTES:

1. IATD ENGINEERING RECOMMENDATIONS SHOULD BE USED FOR MAXIMUM EMI SUPPRESSION. USE TESTED PAIR, SHIELD GROUNDING TO CHASSIS AT BOTH ENDS ON ALL SHIELDED WIRING.
2. ALL CT'S AND INSTRUMENT TRANSFORMER INC. MODEL #750. (FOR CT RATING, REFER TO NOMINAL CT'S).
3. ALL SPACE HEATERS ARE LOW TEMPERATURE (< 200°C).
4. ALL IATD WIRING #22 AWG MINIMUM.
5. ALL WIRING RATED 600V MINIMUM UNLESS OTHERWISE STATED.

LEGEND:

TERM - TERMINAL LABEL

TERMINAL LEGEND:

TERMINALS - WAGO 280
ANG #20-12; 0.5-2.5mm²

TERMINALS - WAGO 281
ANG #20-12; 0.5-4mm²

TERMINALS - WAGO 2004
ANG #20-10; 0.5-1mm²

LEGEND:

CT - PARALLELING CURRENT TRANSFORMER
CLOS - CURRENT UNIT CIRCUIT BREAKER
ICT - DIFFERENTIAL CURRENT TRANSFORMER
CCR - SUPPLEMENTAL CURRENT RELAY
BFD - BLOW FAILURE DETECTOR
FCB - FUEL CIRCUIT BREAKER
FCM - FUEL CURRENT UNIT MODULE
FIM - FUEL INJECTION MODULE
GCT - GROUND CURRENT TRANSFORMER
LIT - LIMIT CURRENT TRANSFORMER
OCR - OVER CURRENT RELAY
OCT - OVER CURRENT TRANSFORMER
OVCB - OVER VOLTAGE CIRCUIT BREAKER
OVS - OVERVOLTAGE SENSOR
PGB - POWER CIRCUIT BREAKER
PPT - PROTECTION POTENTIAL TRANSFORMER
RA - RESTRAINT ASSEMBLY
ST - SENSING TRANSFORMER
UTCB - UTILITY TIE CIRCUIT BREAKER
VAR - VOLTAGE ADJUST INHIBITOR
VAR/PCS - VARIATION POTENTIAL CONTROLLER
VR - VOLTAGE REGULATOR

WIRING CONNECTIONS:

EXCITER FIELD (STATIONARY)
EXCITER ARMATURE (ROTATING)
GENERATOR FIELD (ROTARY)
GENERATOR 3000 KW
4375 KVA
2400/4160 V
36.5 MW
1800 RPM

CAUTION: DO NOT CONNECT POWER TO SPACE HEATERS. IF SET FAILS, REMOVE EXISTING WIRES FROM 240V PAIR AND REPLACE WITH SPARE WIRES 5 AND 6.

MAIN WIRING SPACE HEATERS:
120V SPACE HEATERS
WATER SPACE HEATERS
MAXIMUM HEATERS

RESISTANCE TEMPERATURE DETECTORS (INSTALLED IN GENERATOR STATOR):

RTD1 RTD2 RTD3 RTD4 RTD5 RTD6 RTD7 RTD8 RTD9 RTD10 RTD11 RTD12

OPPOSITE DRIVE BEARING RTD:

RTD13 RTD14 RTD15 RTD16 RTD17 RTD18 RTD19 RTD20 RTD21 RTD22 RTD23 RTD24

NOTE: REMOVE SHORTING PLUGS WHEN MAKING CUSTOMER CONNECTIONS

RECOMMENDED MAXIMUM RTD SETTINGS FOR TDS 5.030SE:

TYPE	RESISTANCE	TEMPERATURE
PLATINUM	100 OHMS	0°C

RECOMMENDED MAXIMUM RTD SETTINGS:

CONDITION	PHE-ALARM	SHUTDOWN
STATOR	159.18 OHMS @150°C	162.90 OHMS @160°C
BEARING	134.70 OHMS @90°C	136.80 OHMS @95°C

**RED - WHITE TEMPERATURE SENSING CABLE
WHITE - WHITE LEAD RESISTANCE COMPENSATION**

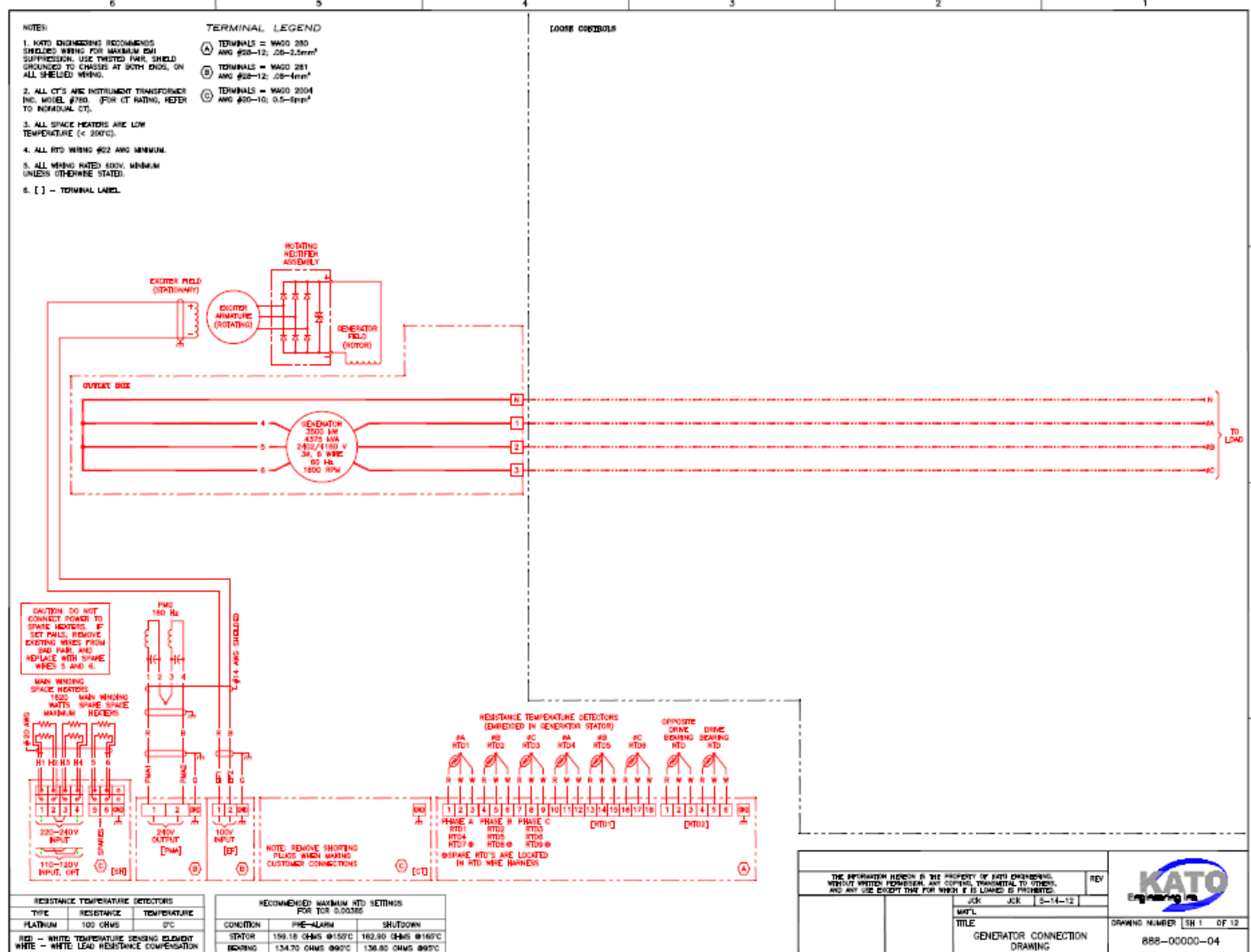
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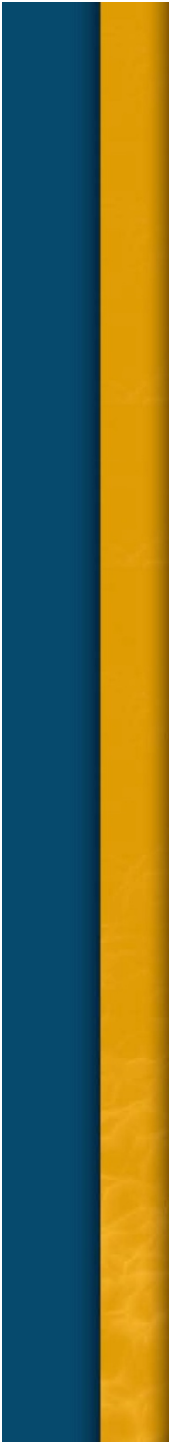
KATO Engineering Inc.

GENERATOR CONNECTION DRAWING

888-00000-04

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 manual field excitation devices

Simple PS



Analog AVR

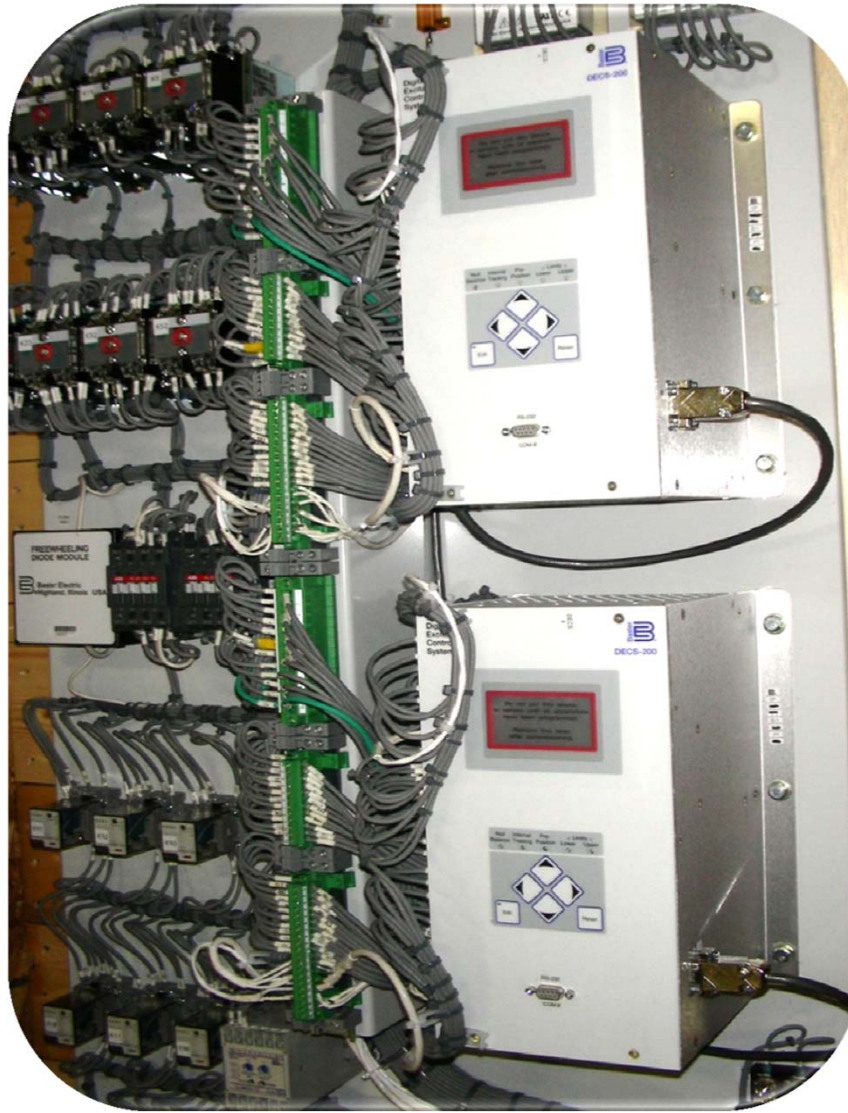


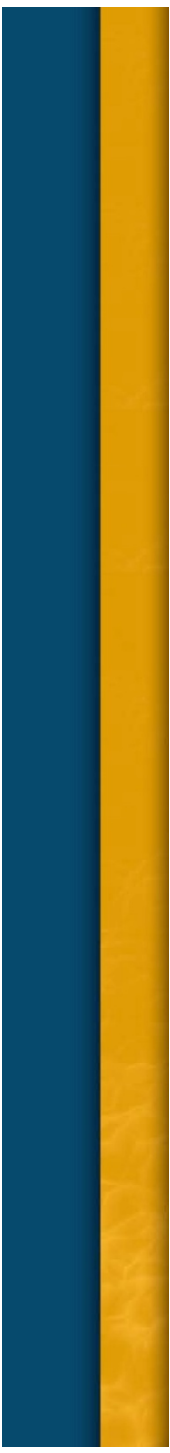
Automatic voltage regulators

Digital AVR



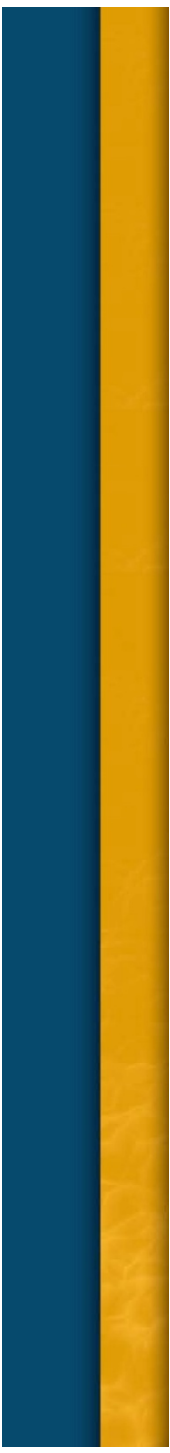
Redundant Voltage Regulators





Analog and Digital Comparison

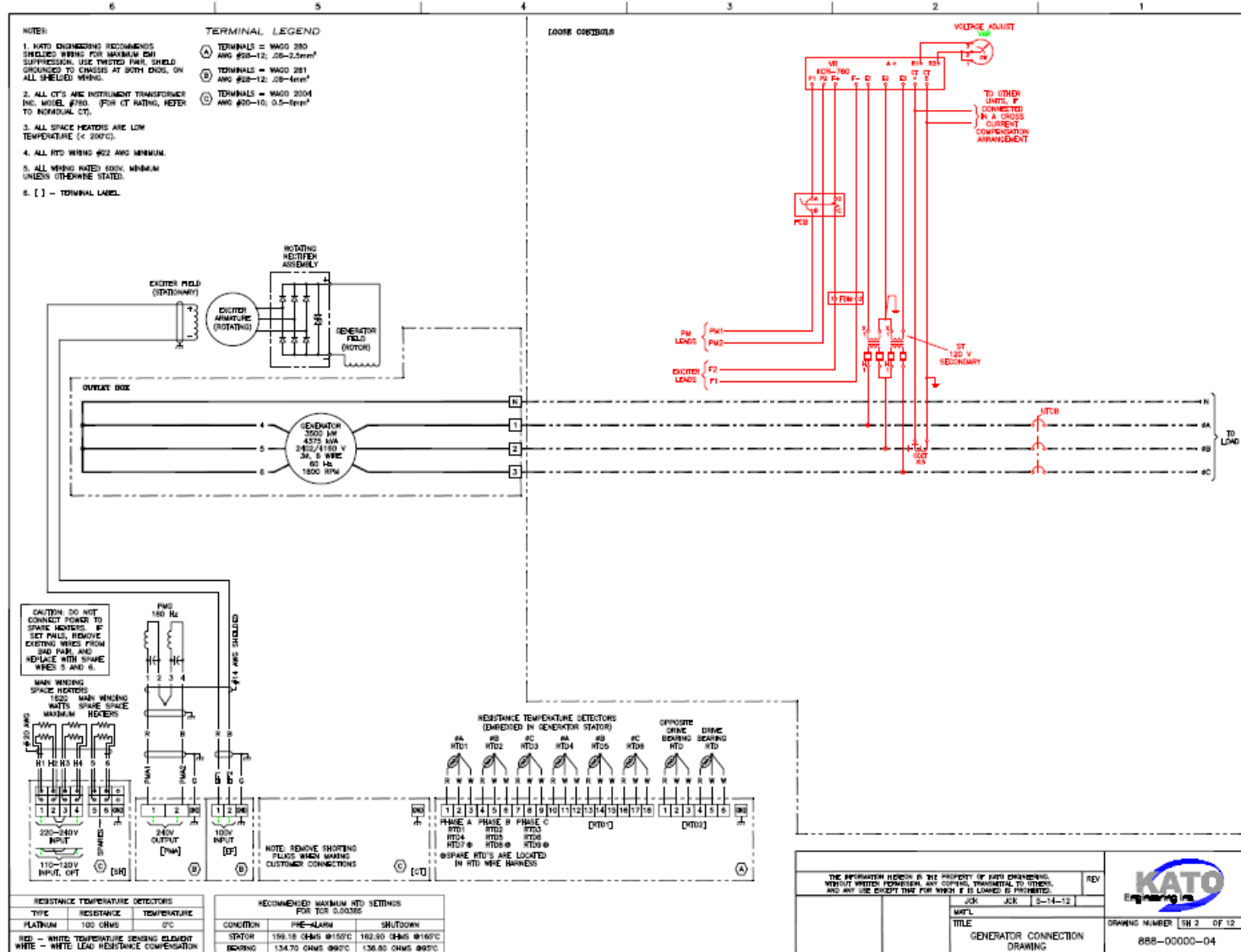
- Analog voltage regulators
 - Typically lower cost
 - Mature designs
 - Many OEM and customers are familiar with technology
 - Average sensing regulation (typically not RMS)
 - Limited versatility
 - Becoming more difficult to obtain and maintain.....

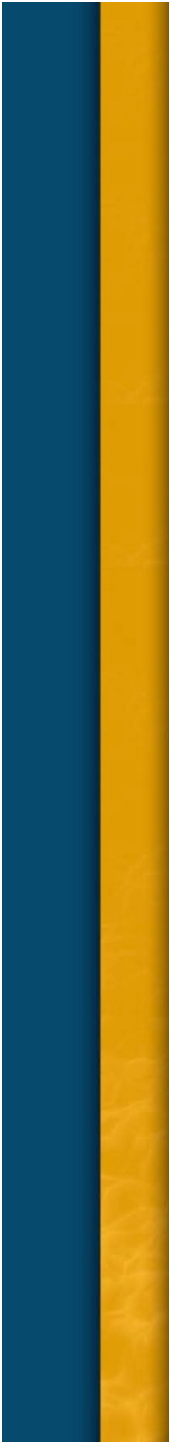


Analog and Digital Comparison (cont.)

- 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)



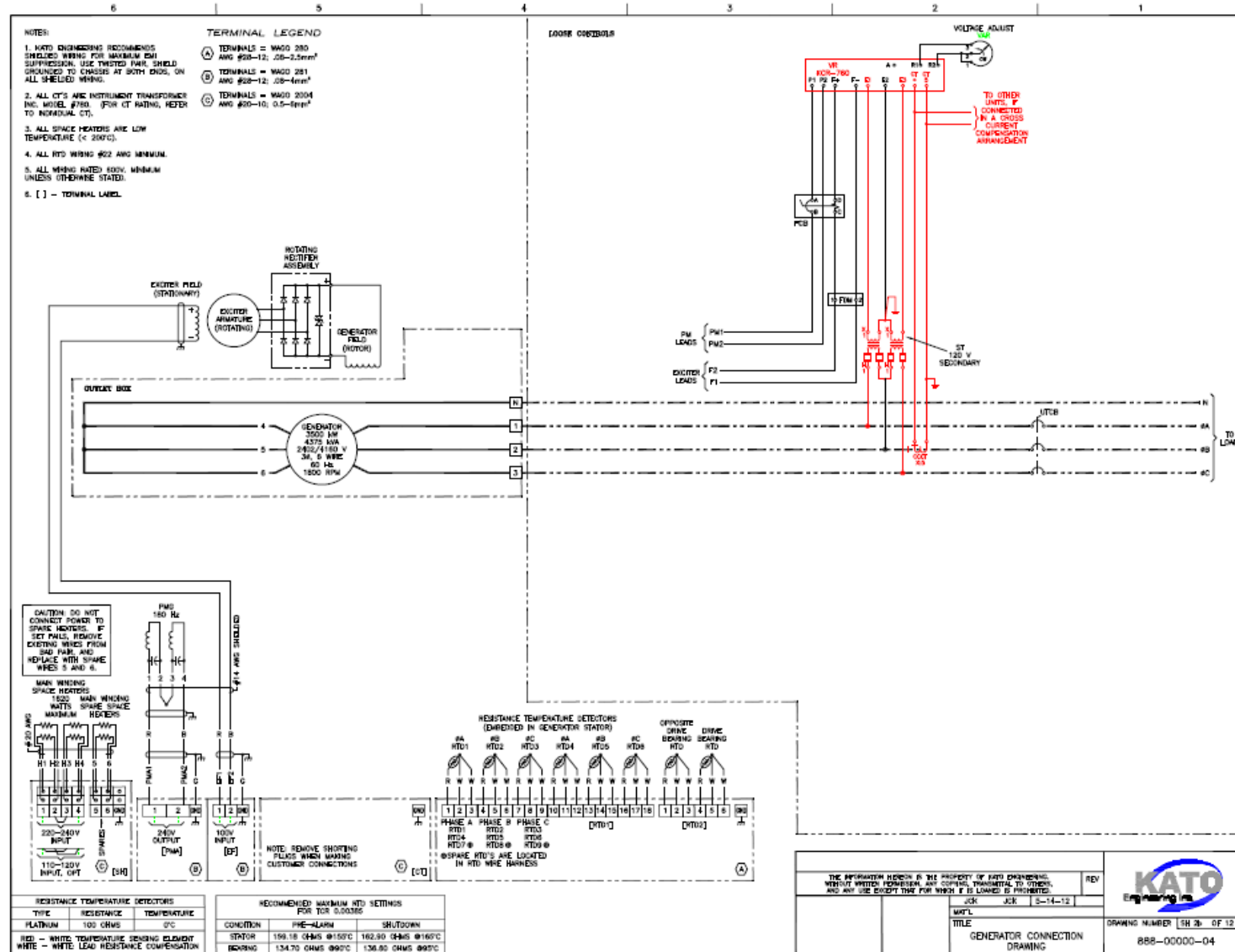
Paralleling controls are not required

Paralleled Applications (Micro Grid)

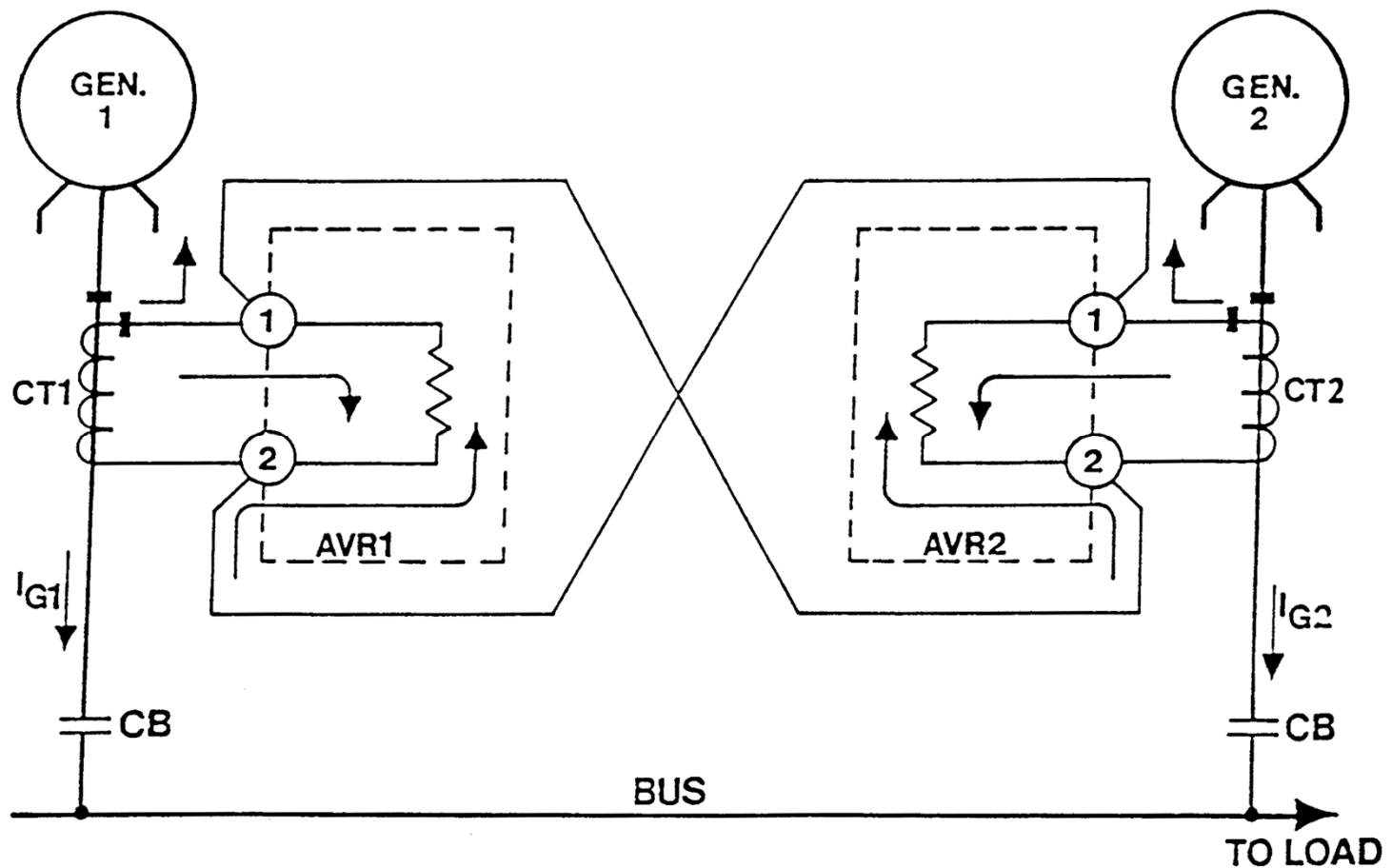
- For operating in parallel with similar sized units (non utility or larger gen)
- “Cross current” paralleling controls typical



Voltage Regulator with CCCT

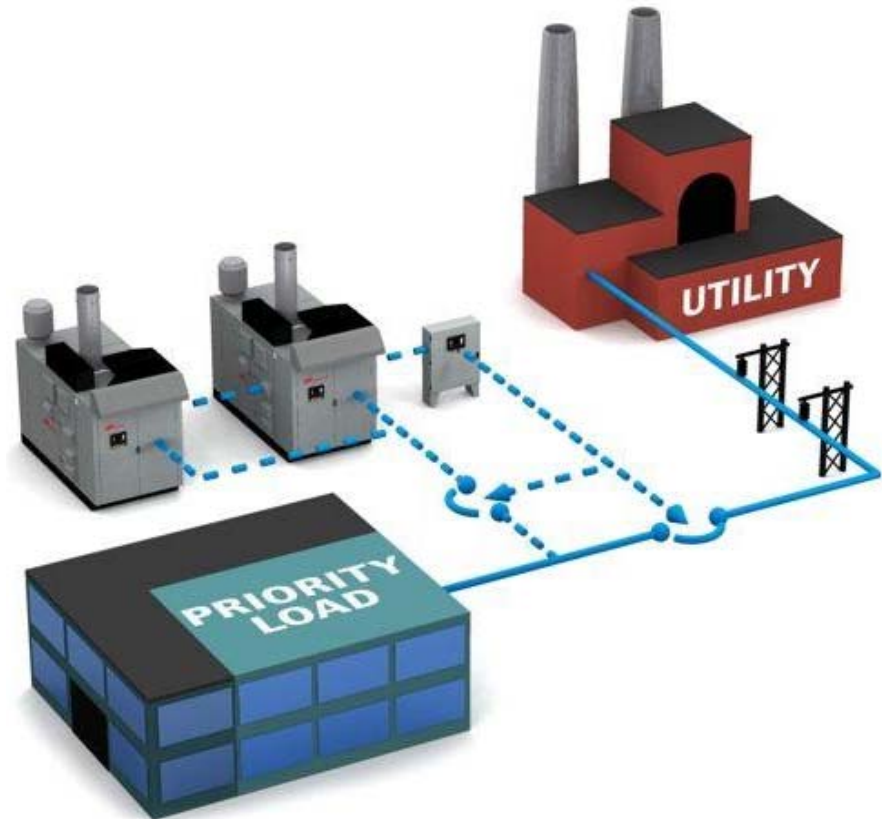


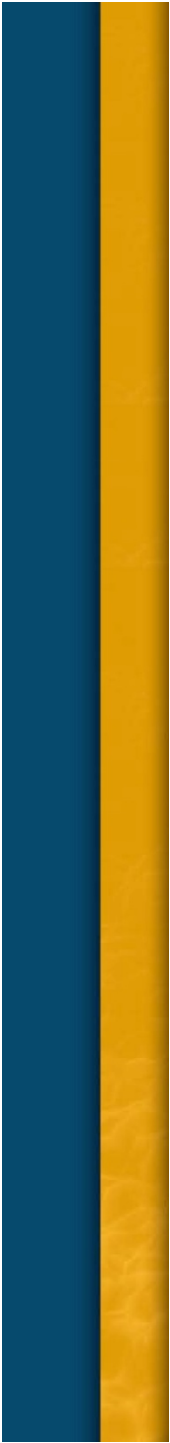
Cross-Current Compensation Balanced kVAR Loading



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

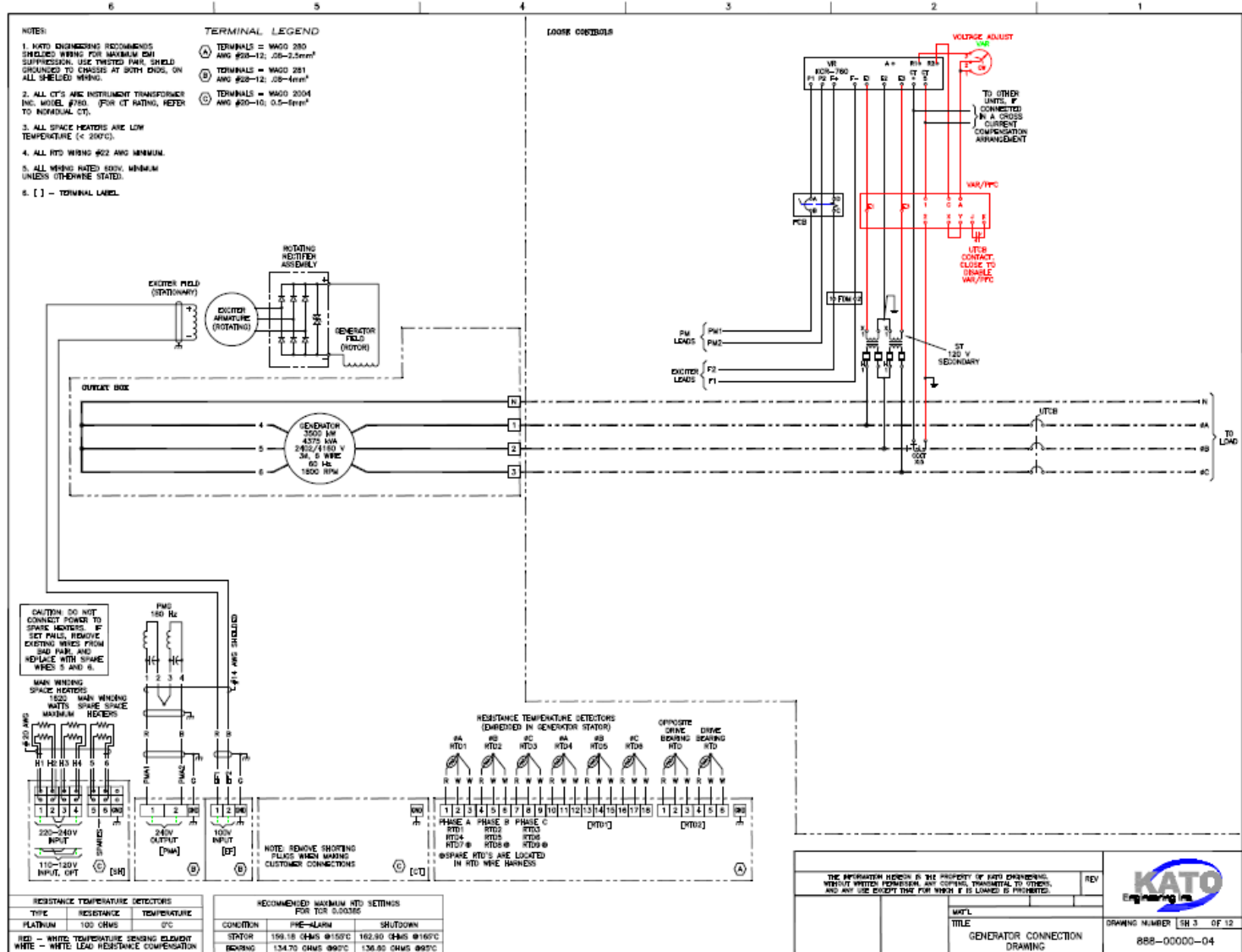




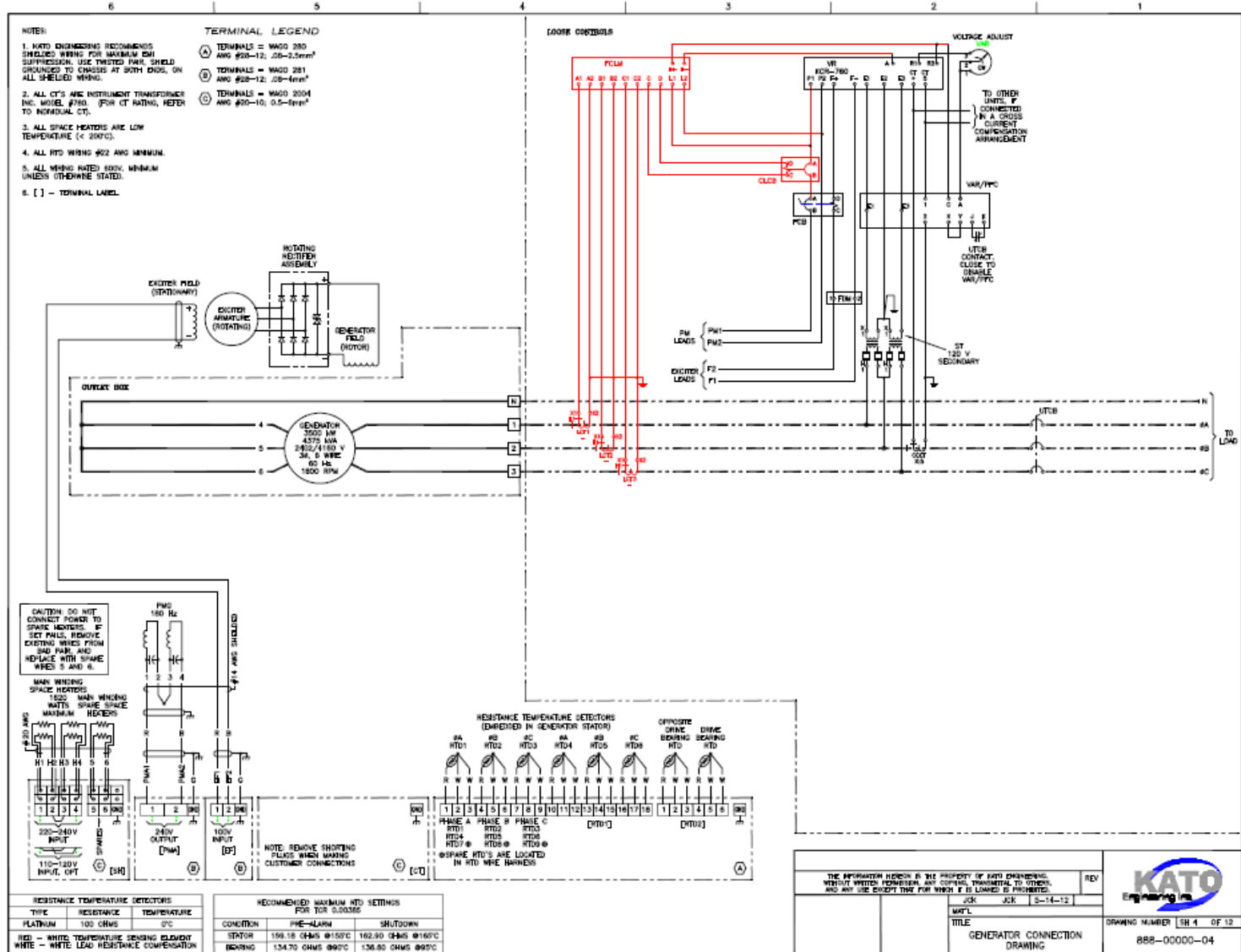
Reactive Load (VAR/PF) Control

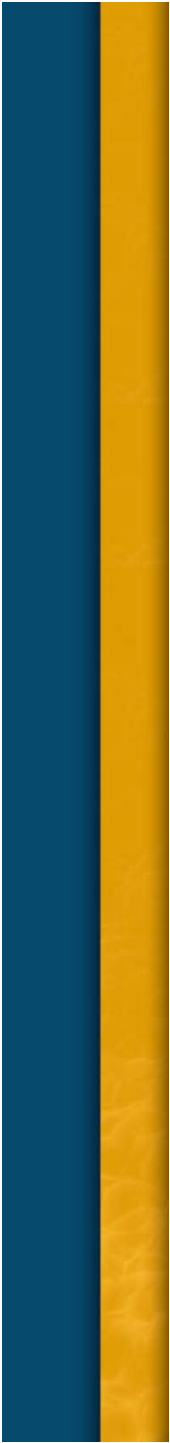
- For operating in parallel with utility
- Don't use pure VAR control on single, isolated generator.
 - Voltage control issues arise.
 - Must be disabled when generator is not paralleled.
 - Use voltage control mode (Standard mode)

VAR/PF Control



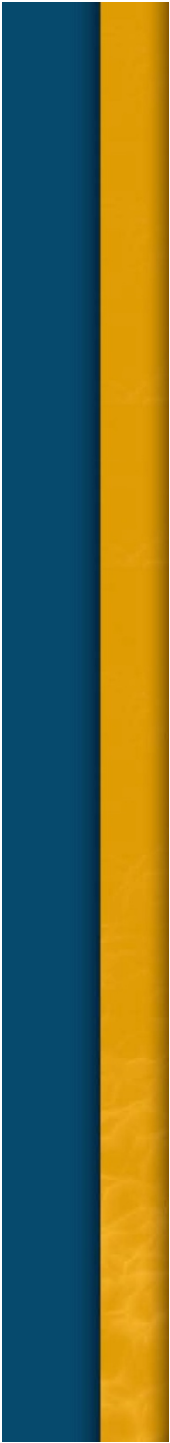
Current Limiting (300%)





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

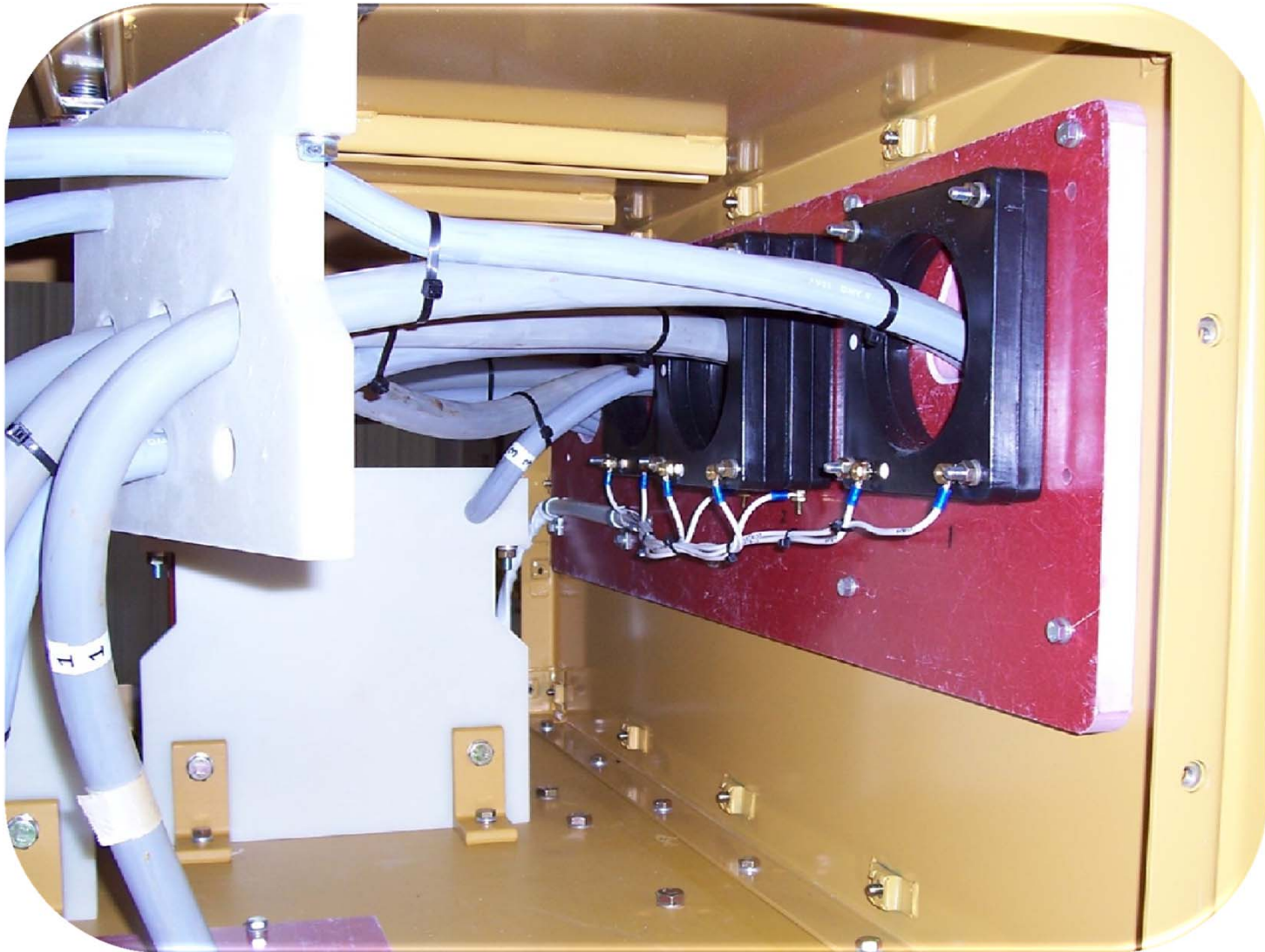


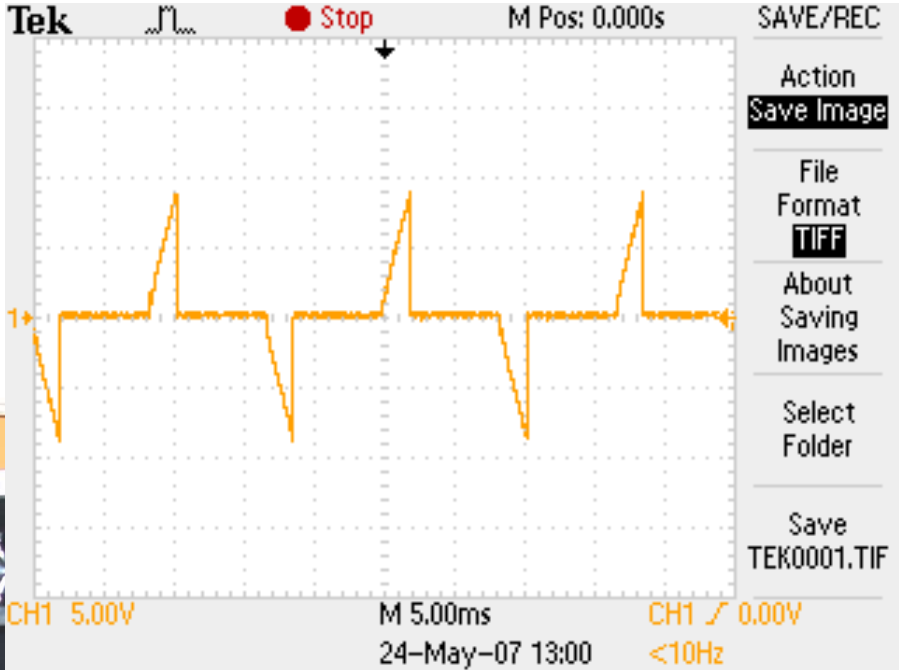
Donut type



Donut type with
lead support

Current Transformer Installation





Potential Transformer Installation



NOTES:

1. KATO ENGINEERING RECOMMENDS SHIELDED WIRING FOR MAXIMUM EMI SUPPRESSION. USE TWISTED PAIR, SHIELD GROUNDING TO CHASSES AT BOTH ENDS, ON ALL SHIELDED WIRING.
2. ALL CTS ARE INSTRUMENT TRANSFORMER INC. MOVES #100. FROM CT RATING, REFER TO NOMINAL CT.
3. ALL SPACE HEATERS ARE LOW TEMPERATURE (< 200°C).
4. ALL RTD WIRING #22 AWG MINIMUM.
5. ALL WIRING RATED 100V, MINIMUM UNLESS OTHERWISE STATED.
6. [] - TERMINAL LABEL.

TERMINAL LEGEND

TERMINALS = WAGO 280
ANG #28-12; .05-.25mm²

TERMINALS = WAGO 281
ANG #28-12; .05-.4mm²

TERMINALS = WAGO 2004
ANG #20-10; 0.5-1mm²

WIRING DIAGRAM:

The diagram shows the electrical connections for the generator. Key components include:

- GENERATOR:** 2500 kW, 4375 A, 2400/1100 V, 3A, 3 WIRE, 60 Hz, 1800 RPM.
- EXTERNAL FIELD (STATIONARY) and EXCITER FIELD (ROTATING):** Connected to the generator's field winding.
- OVERLINE BOX:** Contains the generator's output terminals (1-5).
- RESISTANCE TEMPERATURE DETECTORS (RTDs):** Located in the generator stator, including RTD1 through RTD12.
- OPPOSITE DRIVE BEARING DETECTORS:** Located in the opposite drive bearing.
- WIRING:** Shows connections for 240V, 110V, and 220V inputs, and 240V output. Includes a note to remove shorting plates when making customer connections.

TERMINAL LEGEND:

TERMINALS = WAGO 280
ANG #28-12; .05-.25mm²

TERMINALS = WAGO 281
ANG #28-12; .05-.4mm²

TERMINALS = WAGO 2004
ANG #20-10; 0.5-1mm²

WIRING DIAGRAM:

The diagram shows the electrical connections for the generator. Key components include:

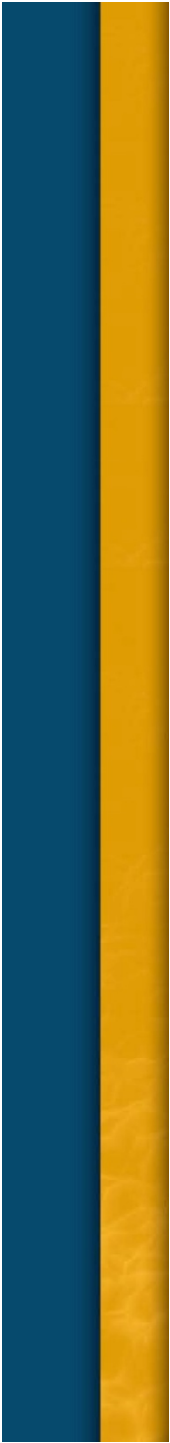
- GENERATOR:** 2500 kW, 4375 A, 2400/1100 V, 3A, 3 WIRE, 60 Hz, 1800 RPM.
- EXTERNAL FIELD (STATIONARY) and EXCITER FIELD (ROTATING):** Connected to the generator's field winding.
- OVERLINE BOX:** Contains the generator's output terminals (1-5).
- RESISTANCE TEMPERATURE DETECTORS (RTDs):** Located in the generator stator, including RTD1 through RTD12.
- OPPOSITE DRIVE BEARING DETECTORS:** Located in the opposite drive bearing.
- WIRING:** Shows connections for 240V, 110V, and 220V inputs, and 240V output. Includes a note to remove shorting plates when making customer connections.

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

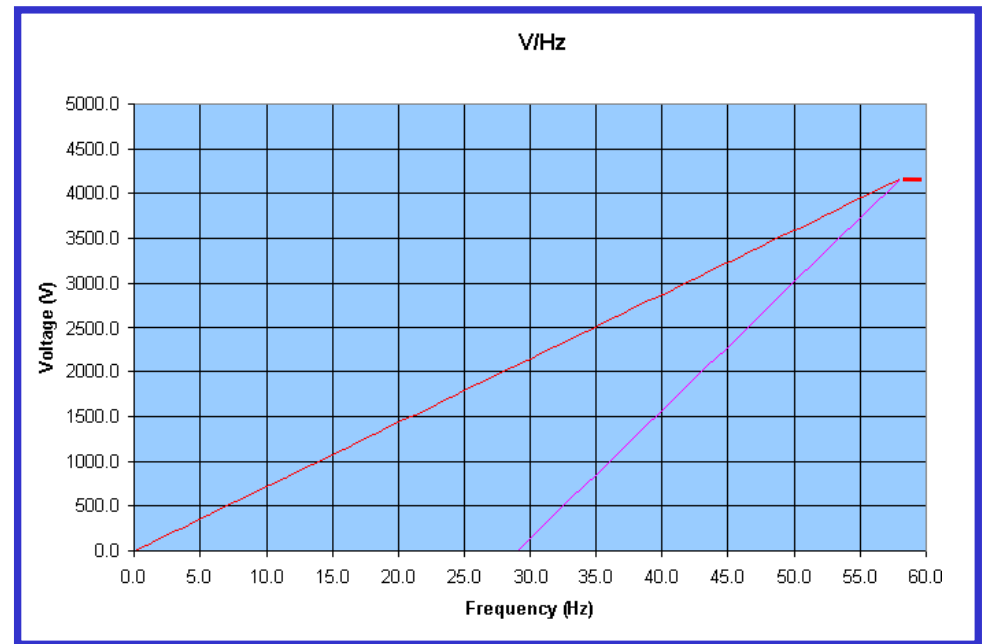
ANSI Device Numbers

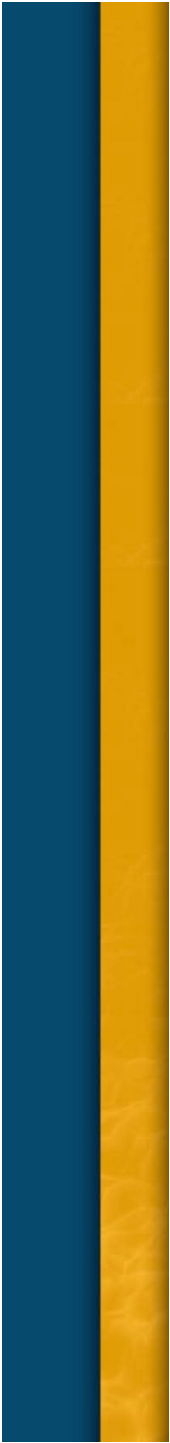
List of ANSI/IEEE Device Numbers and Acronyms

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

Under Frequency

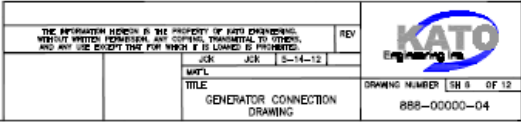
- Control-type operates through voltage regulator
 - Controls generator voltage proportional to frequency
- Protection-type may be needed to protect other equipment
 - Required to trip generator offline upon under frequency detection



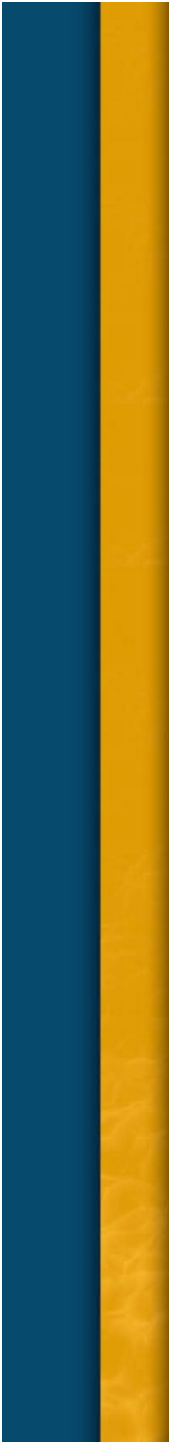


Over-Voltage Protection

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

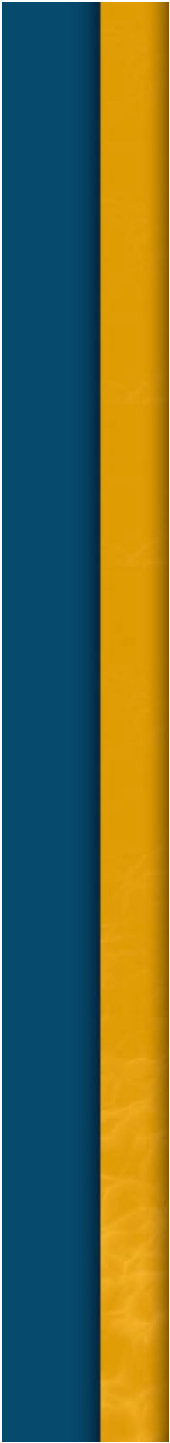






Additional Generator Protection

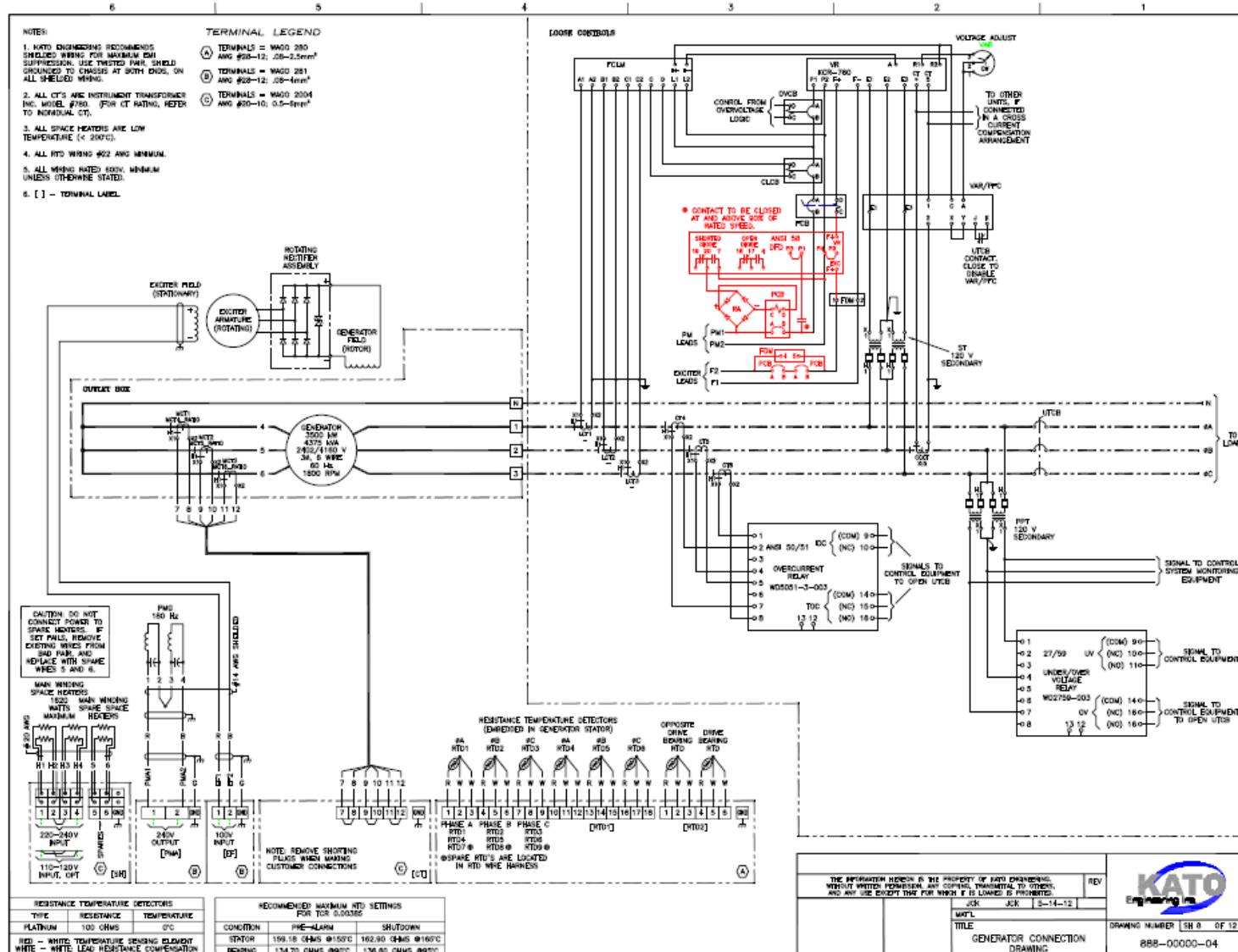
- Required for some but not every installation (specification driven).
 - Exciter diode fault protection
 - Negative sequence over current
 - Differential over current
 - Lightning arrestors and surge capacitors

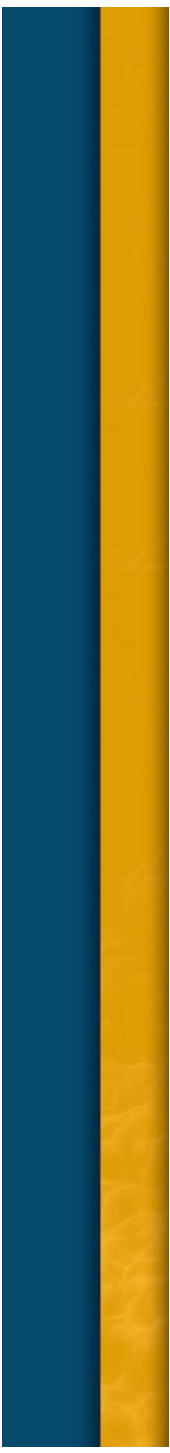


Exciter Diode Failure Protection

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

Diode Fault Protection

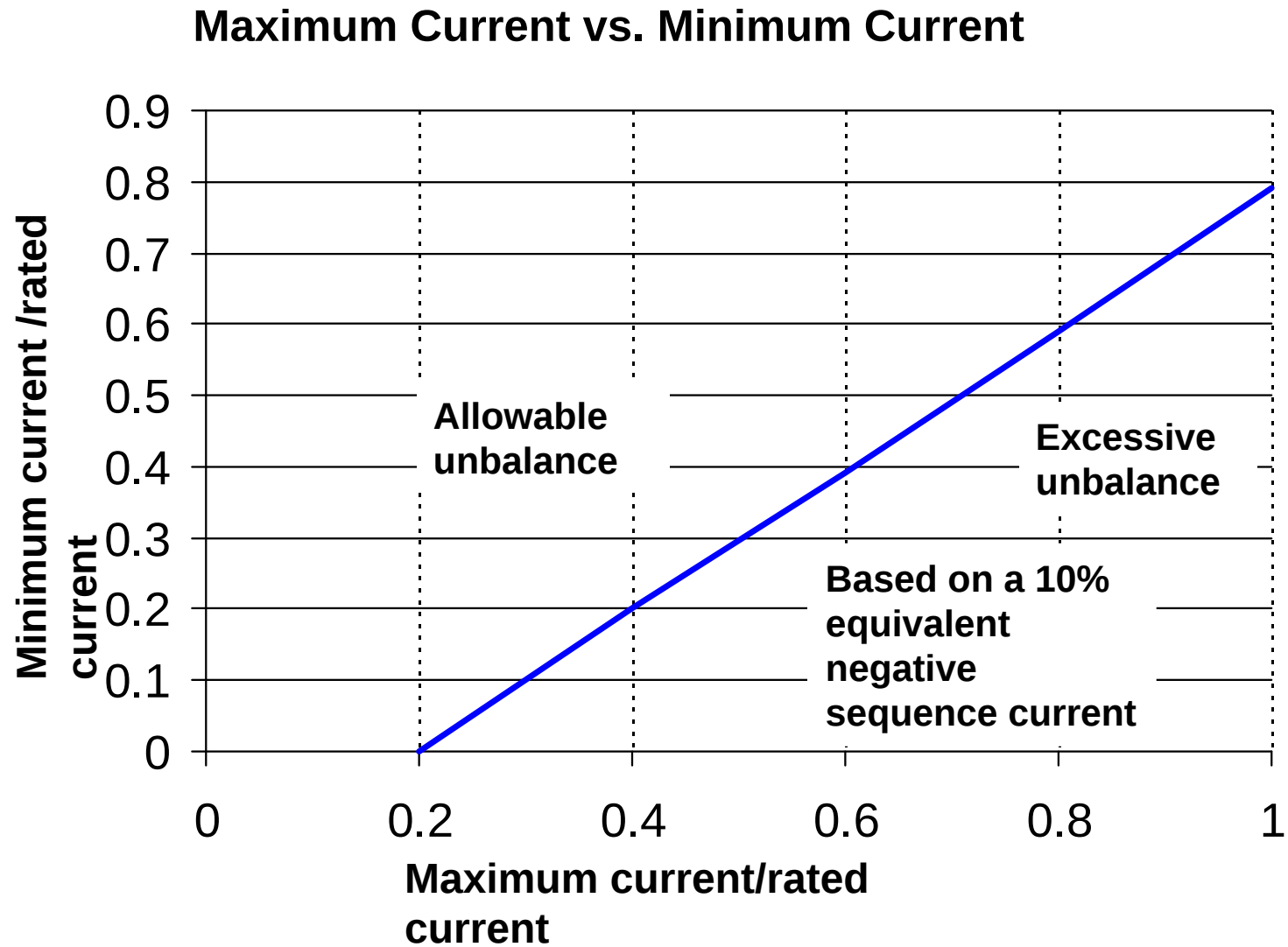




Negative Sequence Protection

- 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



NOTES:

1. KATO ENGINEERING RECOMMENDS SHIELDED WIRING FOR MAXIMUM EMI SUPPRESSION. USE TWISTED PAIR, SHIELD GROUND TO CHASSIS AT BOTH ENDS, ON ALL SHIELDED WIRING.
2. ALL CT'S ARE INSTRUMENT TRANSFORMER INC. MODEL #780. (FOR CT RATING, REFER TO INDIVIDUAL CT).
3. ALL SPACE HEATERS ARE LOW TEMPERATURE (< 200°F).
4. ALL ITS WIRING #22 AND MINIMUM.
5. ALL WIRING RATED 100% MINIMUM (UNLESS OTHERWISE STATED).
6. [] - TERMINAL LABEL.

TERMINAL LEGEND

(A) AND #20-12; .05-.25mm²
 (B) AND #20-12; .05-.4mm²
 (C) TERMINALS = WAGO 2004 AND #20-10; 0.5-1mm²

WIRING DIAGRAM:

The diagram illustrates the electrical connections for the generator system, including the generator, exciter, and various control and monitoring components. Key components and connections include:

- Generator:** 3000 kW, 4375 A, 240/160 V, 50 Hz, 1800 RPM. It is connected to the main busbar (A) and the exciter field (stationary) and exciter armature (rotating).
- Exciter:** 1500 W, 4375 A, 240/160 V, 50 Hz, 1800 RPM. It is connected to the generator field and the exciter armature.
- Control and Monitoring:** Includes a control panel with various relays (e.g., ANR 46, ANR 50/51, ANR 52, ANR 53, ANR 54, ANR 55, ANR 56, ANR 57, ANR 58, ANR 59, ANR 60, ANR 61, ANR 62, ANR 63, ANR 64, ANR 65, ANR 66, ANR 67, ANR 68, ANR 69, ANR 70, ANR 71, ANR 72, ANR 73, ANR 74, ANR 75, ANR 76, ANR 77, ANR 78, ANR 79, ANR 80, ANR 81, ANR 82, ANR 83, ANR 84, ANR 85, ANR 86, ANR 87, ANR 88, ANR 89, ANR 90, ANR 91, ANR 92, ANR 93, ANR 94, ANR 95, ANR 96, ANR 97, ANR 98, ANR 99, ANR 100), switches, and indicators. It also includes a voltage adjuster and a current compensator.
- Resistance Temperature Detectors (RTDs):** Located in the generator stator and exciter, they monitor the temperature of the windings. The diagram shows connections for RTD1 through RTD12, RTD13 through RTD18, and RTD19 through RTD24.
- Spine Bearing Sealing RTD:** A single RTD used for monitoring the temperature of the spine bearing sealing.
- Wiring Details:** The diagram shows the routing of wires from the generator and exciter to the control panel, including the use of shielded and twisted pair wiring for EMI suppression. It also shows the connection of the RTDs to the control panel.

RECOMMENDED MAXIMUM RTD SETTINGS FOR TOR 0.00355

CONDITION	PRE-ALARM	SHUTDOWN
STATOR	158.18 OHMS @150°C	162.80 OHMS @160°C
BEARING	134.70 OHMS @90°C	136.80 OHMS @95°C

WIRING TABLE:

TYPE	RESISTANCE	TEMPERATURE
PLATINUM	100 OHMS	0°C

RED - WHITE TEMPERATURE SENSING ELEMENT
WHITE - WHITE LEAD RESISTANCE COMPENSATION

RESISTANCE TEMPERATURE DETECTORS		
TYPE	RESISTANCE	TEMPERATURE
PLATINUM	100 OHMS	0°C

RED - WHITE: TEMPERATURE SENSING ELEMENT
 WHITE - WHITE: LEAD RESISTANCE COMPENSATION

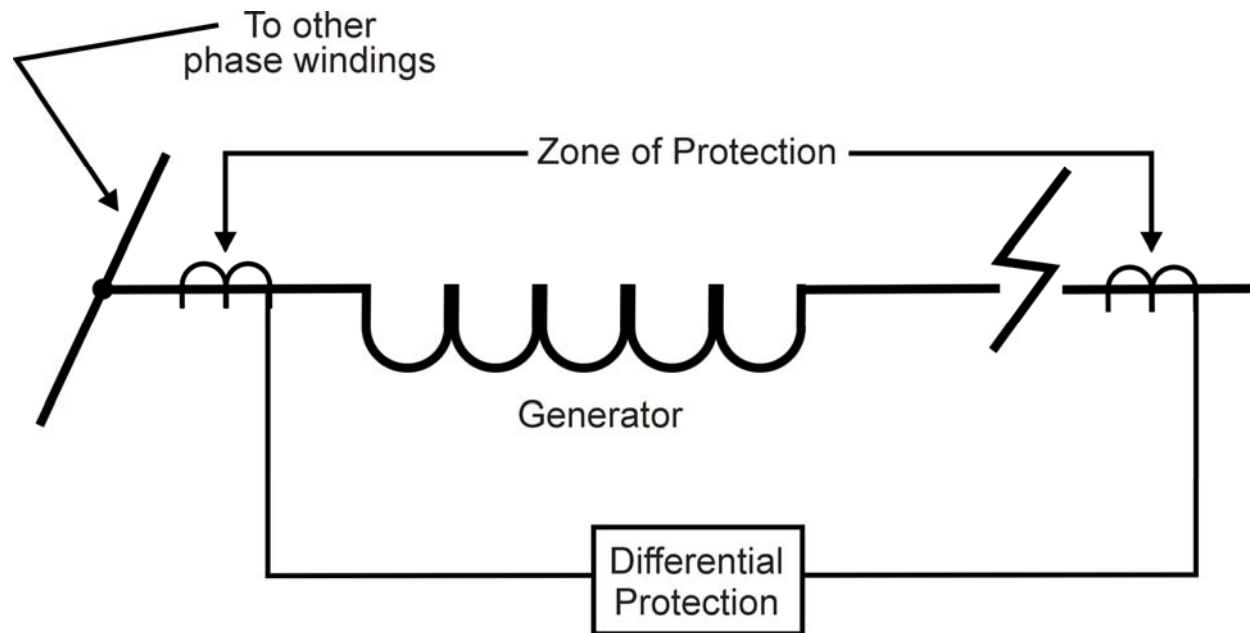
RECOMMENDED MAXIMUM RTD SETTINGS FOR TOR 0.00365		
CONDITION	PRE-ALARM	SHUTDOWN
STATOR	159.18 CHMS @155°C	162.80 CHMS @165°C
BEARING	134.70 CHMS @95°C	136.80 CHMS @95°C

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JCK	JCK	S-14-12
MAT'L		
TITLE		
GENERATOR CONNECTION DRAWING		

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.



NOTES:

1. KATO ENGINEERING RECOMMENDS SHIELDED WIRING FOR MAXIMUM CM SUPPRESSION. USE TWISTED PAIR, SHIELD GROUND TO CHASSIS AT BOTH ENDS, ON ALL SHIELDED WIRING.
2. ALL CTS ARE INSTRUMENT TRANSFORMERS INC. MODEL #710. (FOR CT RATINGS, REFER TO INDIVIDUAL CTS).
3. ALL SPACE HEATERS ARE LOW TEMPERATURE (< 200°C).
4. ALL ITO WIRING #22 AWG MINIMUM.
5. ALL WIRING RATED 600V MINIMUM UNLESS OTHERWISE STATED.
6. [] - TERMINAL LABEL.

TERMINAL LEGEND

(A) TERMINALS = WAGO 280
ANG #28-12; .08-.25mm²

(B) TERMINALS = WAGO 281
ANG #28-12; .08-.6mm²

(C) TERMINALS = WAGO 2004
ANG #20-10; 0.5-.6mm²

WIRING DIAGRAM

The diagram illustrates the electrical connections for a generator system, including the generator, exciter, control equipment, and various sensors. Key components include:

- Generator:** 4575 kVA, 240V/1150 V, 3φ, 0 W/HP, 60 Hz, 1800 RPM.
- Exciter:** 1500 VAR WINDING, 240V OUTPUT, 100V INPUT.
- Control Equipment:** Includes a voltage adjuster, overcurrent relay, negative sequence relay, and under-voltage relay.
- Sensors:** Resistance temperature detectors (RTDs) for stator windings and bearings, and thermal protection relays (TPR).

RECOMMENDED MAXIMUM RTD SETTINGS FOR TOR 0.00385

TYPE	RESISTANCE	TEMPERATURE
PLATINUM	100 OHMS	°C
RED - WHITE THERMOCOUPLES ORIGINALLY EQUIPPED	100 OHMS	°F
WHITE - WHITE LEAD RESISTANCE COMPENSATION	100 OHMS	°F

CAUTION: DO NOT CONNECT POWER TO SPARE WINDINGS. IF SET PULLS, REMOVE EXCITING WINDINGS FROM S&D PANEL AND REPLACE WITH SPARE WIRES 5 AND 6.

MARK WINDING SPACE HEATERS: 1500 VAR WINDING, 240V OUTPUT, 100V INPUT.

NOTE: REMOVE SHORTING PLUGS WHEN MAKING CUSTOMER CONNECTIONS.

RESISTANCE TEMPERATURE DETECTORS (EMBEDDED IN GENERATOR STATOR)

TYPE	RESISTANCE	TEMPERATURE
PLATINUM	100 OHMS	°C
RED - WHITE THERMOCOUPLES ORIGINALLY EQUIPPED	100 OHMS	°F
WHITE - WHITE LEAD RESISTANCE COMPENSATION	100 OHMS	°F

RECOMMENDED MAXIMUM RTD SETTINGS FOR TOR 0.00385

CONDITION	PHE-LOW	SHUTDOWN
STATOR	159.15 OHMS @150°C	162.80 OHMS @160°C
BEARING	134.70 OHMS @90°C	136.80 OHMS @95°C

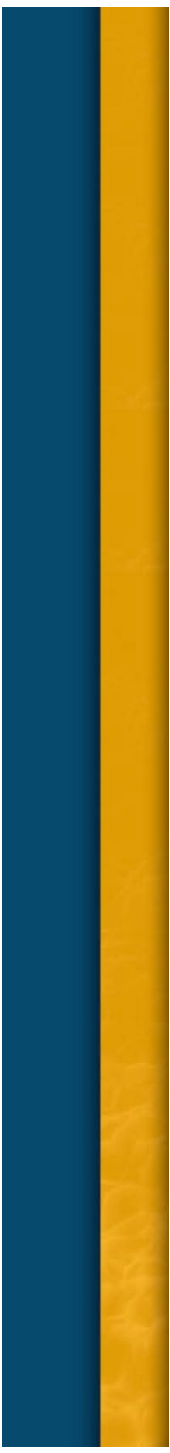
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KATO Engineering Inc.

GENERATOR CONNECTION DRAWING

DRAWING NUMBER: GEN 10 OF 12

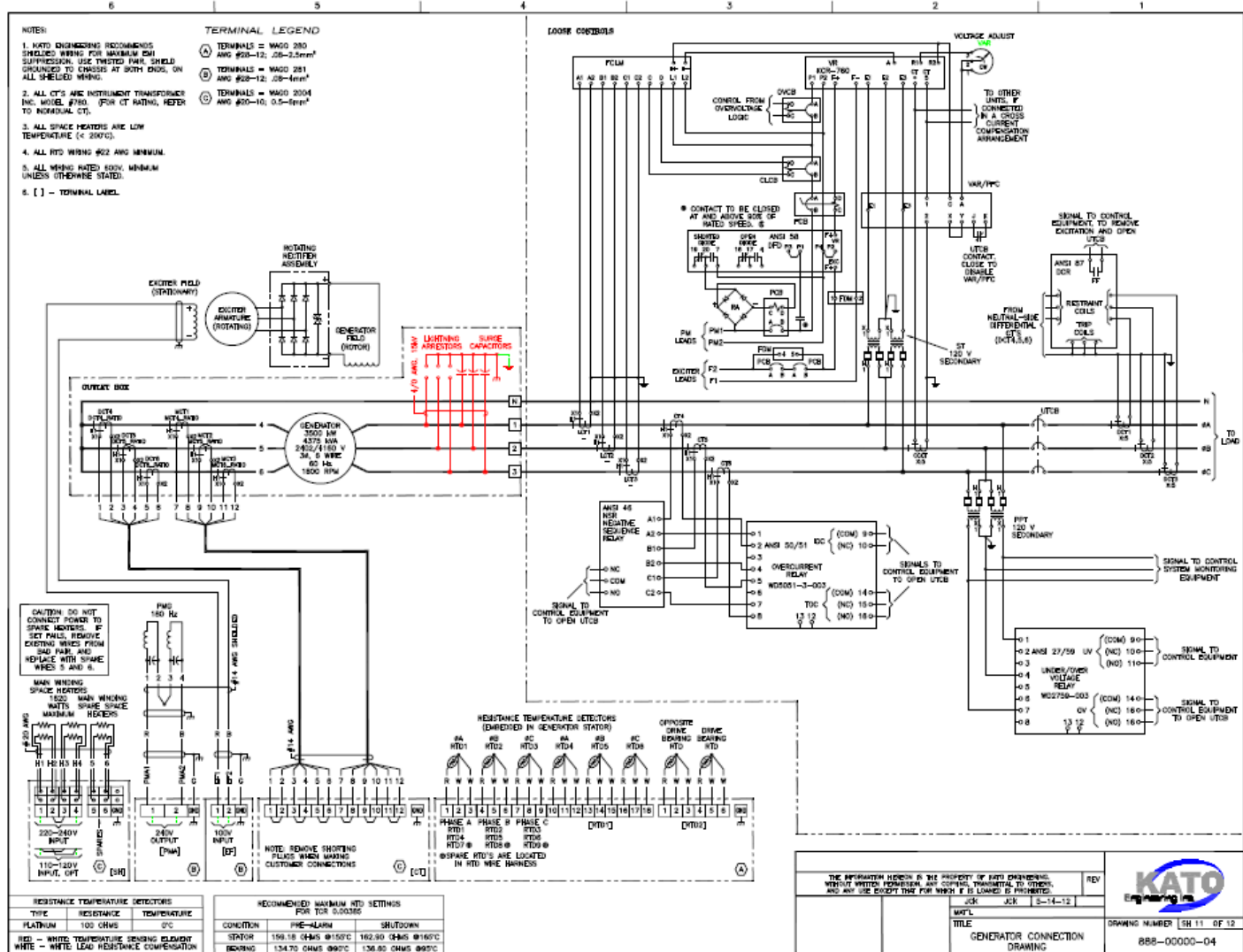
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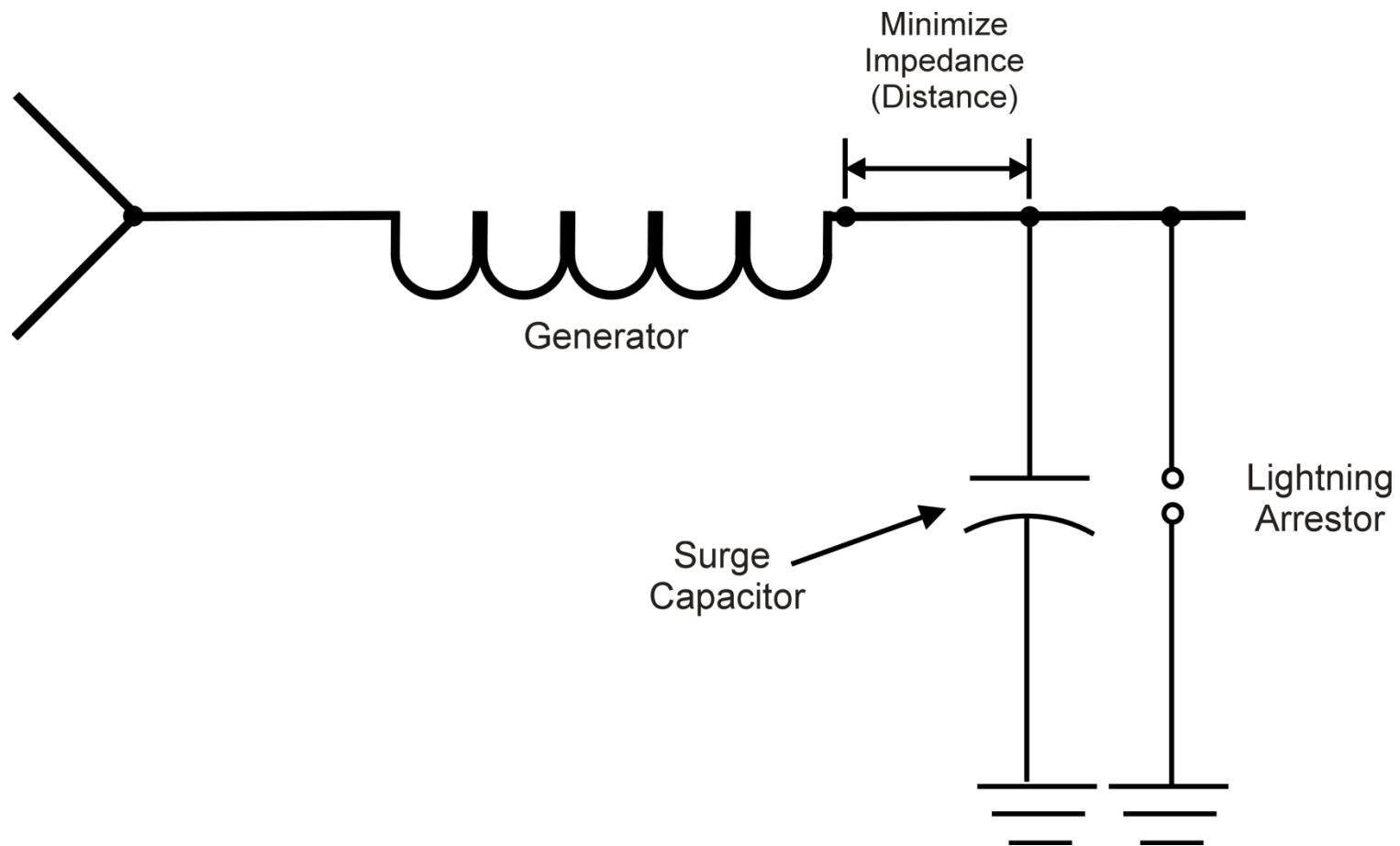
Lightning Arrestors, Surge Capacitors

- 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

IMPORTANT—these values are for the generator only where synchronism is maintained. Generator Capability Limits; Protections Required. System Engineers MUST evaluate these limits for each application. For specific system requirements, custom designs can be developed.					
Protection Type	Protection Limits	Source	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	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
Negative Sequence Current	$I_2 = 0.10$ pu max. continuous $(I_2)^2t = 40$ for I_2 above 0.10 pu unbalanced current (1 max. – 1 min.) = 20% rated amps max. continuous	NEMA MG1 32.14 / ANSI C50.12 6.2 NEMA MG1 32.13 / ANSI C50.12 6.1	High Bearing Temp	by RTD, 85°C max. continuous, 95°C max. immediate point	determined by bearing design
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	Insulation Stress	stator windings must be effectively grounded $X_0/X_1=+0$ to $+3$, $R_0/X_1=+0$ to $+1$	IEEE Std 142 (2007) 1.2 Definition (1.2.1 effectively Grounded) Greenbook Chapter 1
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	Ground (Earth) Fault	not significant to generator, however is a consideration of system design	NEMA MG-1 33.4.4.2
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 responsibility of the user	Voltage Unbalance	not significant to generator if unbalanced current (negative-sequence) is within limits	protection of loads connected to the generator is the responsibility 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	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
Over-frequency	102% at rated voltage continuous 125% overspeed for 2 minutes max.	IEC 60034-1 Figure 11 NEMA MG1 32.16	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.
Under-frequency	98% at rated voltage continuous	IEC 60034-1 Figure 11	Insulation Resistance	periodic preventive maintenance insulation resistance test and/or addition of insulation resistance monitor	IEEE 43-2000 12.3
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.			

94428 Ben Johnson	REV A	
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