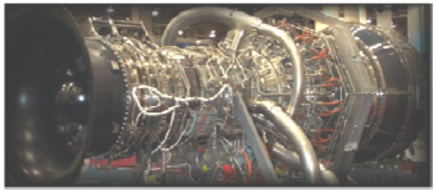
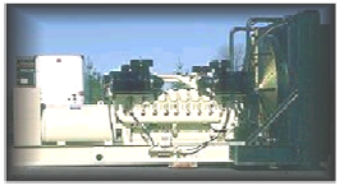
WSU Hands-On Generator Protection Track Overview



CHUCK MOZINA

Consultant – Beckwith Electric

Chuck Mozina -- is a Consultant, Protection and Protection Systems for Beckwith Electric and resides in Palm Harbor (near Tampa), Florida. His consulting practice involves projects relating to protective relay applications, protection system design and coordination. He specializes in generator and power plant protection.

Chuck is an active 20-year member of the IEEE Power System Relay Committee (PSRC) and is the past chairman of the Rotating Machinery Subcommittee. He is active in the IEEE IAS I&CPS, PCIC and PPIC committees, which address industrial system protection. He is a former U.S. representative to the CIGRE Study Committee 34 on System Protection and has chaired a CIGRE working group on generator protection. He also chaired the IEEE task force that produced the tutorial "The Protection of Synchronous Generators," which won the PSRC's 1997 Outstanding Working Group Award. Chuck is the 1993 recipient of the Power System Relay Committee's Career Service Award and he recently received the 2002 IAS I&CPS Ralph Lee Prize Paper Award. His papers have been republished in the IAS Industrial Applications Magazine.

Chuck has a Bachelor of Science in Electrical Engineering from Purdue University and is a graduate of the eight month GE Power System Engineering Course. He has authored a number of papers and magazine articles on protective relaying. He has over 25 years of experience as a protection engineer at Centerior Energy, a major investor-owned utility in Cleveland, Ohio where he was the Manager of the System Protection Section. He is also a former instructor in the Graduate School of Electrical Engineering at Cleveland State University as well as a registered Professional Engineer in the state of Ohio.

- A major US manufacturer of :
  - Digital multifunction generator,interconnection and transformer protection
  - Generator synchronizing and bus transfer equipment
  - Voltage control devices for LTC transformer, regulators, and capacitor banks
  - Packaged systems using Beckwith products

Introduction

- Contrary to popular belief, generators do experience shorts and abnormal electrical conditions
- Proper protection can mitigate damage to the machine in many cases
- Generator Protection Areas:
  - Short Circuits in the generator itself
  - Abnormal electrical conditions may be caused by the generator or the system

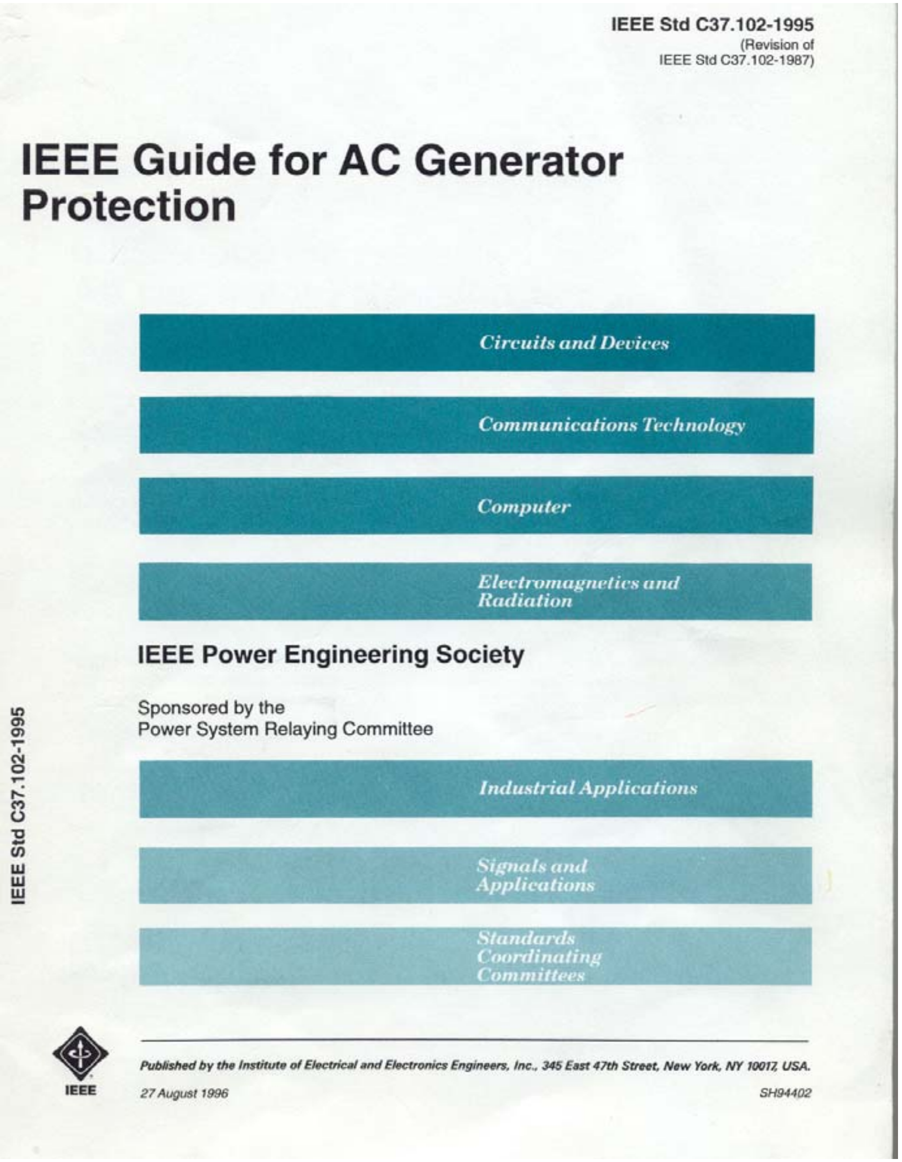
Generator Protection

- **Internal Faults**
  - Stator Phase
  - Stator and Field Ground
- **System Back Up for Faults**
  - Phase and Ground
- **Abnormal Operating Conditions**
  - Overvoltage
  - Overexcitation
  - Load Unbalance
  - Loss of Field
  - Loss of Synchronism
  - Frequency
  - Loss of prime mover
  - Inadvertent Energizing
  - Compromised potential source (blown fuse)
  - Open trip circuit

IEEE Standards

- Latest developments reflected in:
  - Std. 242: IAS Buff Book
  - C37.102: IEEE Guide for Generator Protection
  - C37.101: IEEE Guide for AC Generator Ground Protection
  - C37.106: IEEE Guide for Abnormal Frequency Protection for Power Generating Plants

These are created/maintained by the IEEE PSRC & IAS
They are updated every 5 years



IEEE Std C37.102-1995
(Revision of
IEEE Std C37.102-1987)

IEEE Guide for AC Generator Protection

Circuits and Devices

Communications Technology

Computer

Electromagnetics and Radiation

IEEE Power Engineering Society

Sponsored by the
Power System Relaying Committee

Industrial Applications

Signals and Applications

Standards Coordinating Committees

IEEE Std C37.102-1995

IEEE

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27 August 1996 *SH94402*

C37.102-2006 Updated Version now available which has significant changes and additions.

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IEEE PES
Power & Energy Society®

IEEE TUTORIAL ON THE PROTECTION OF SYNCHRONOUS GENERATORS

Second Edition, 2010

Special Publication of the
IEEE Power System Relaying Committee

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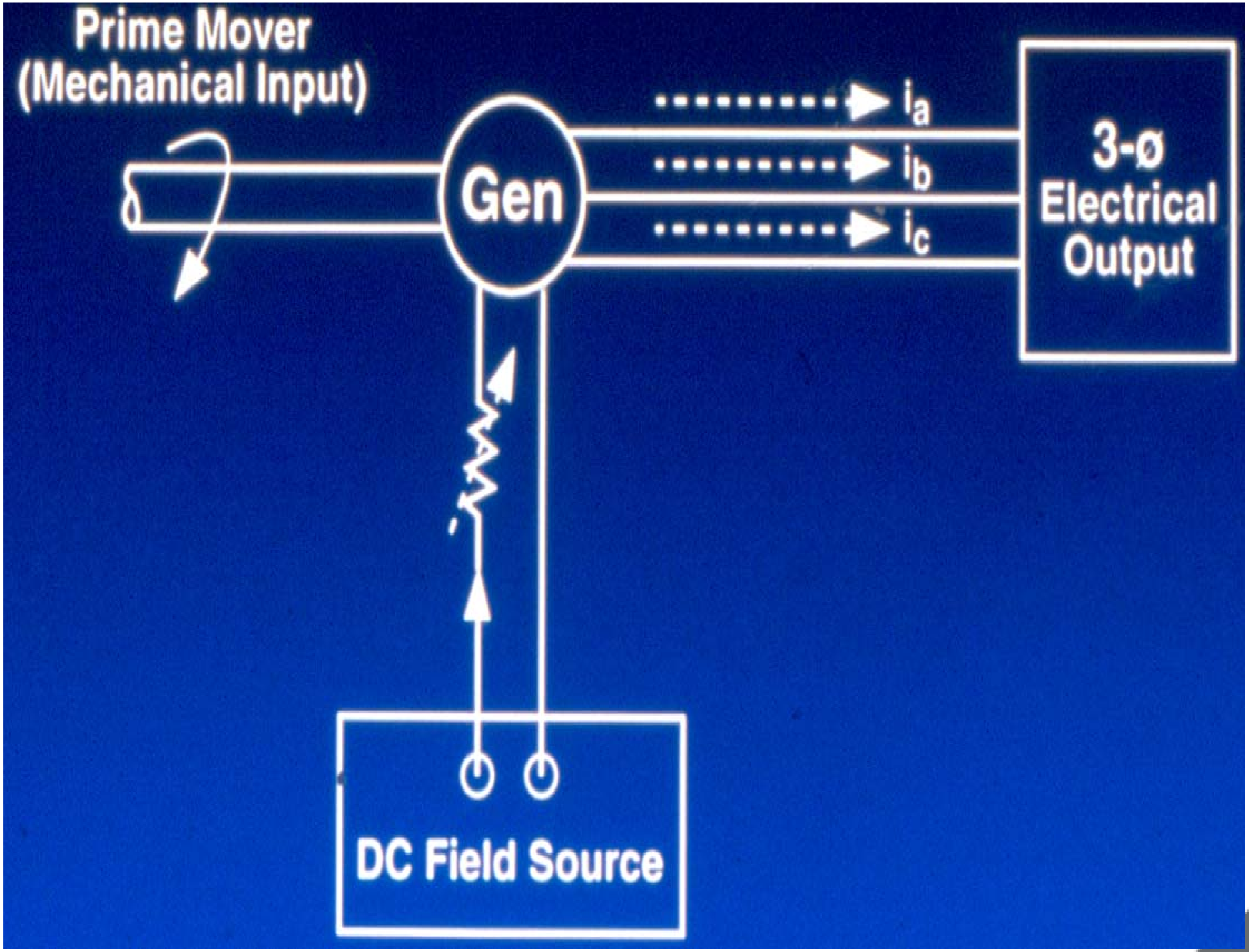
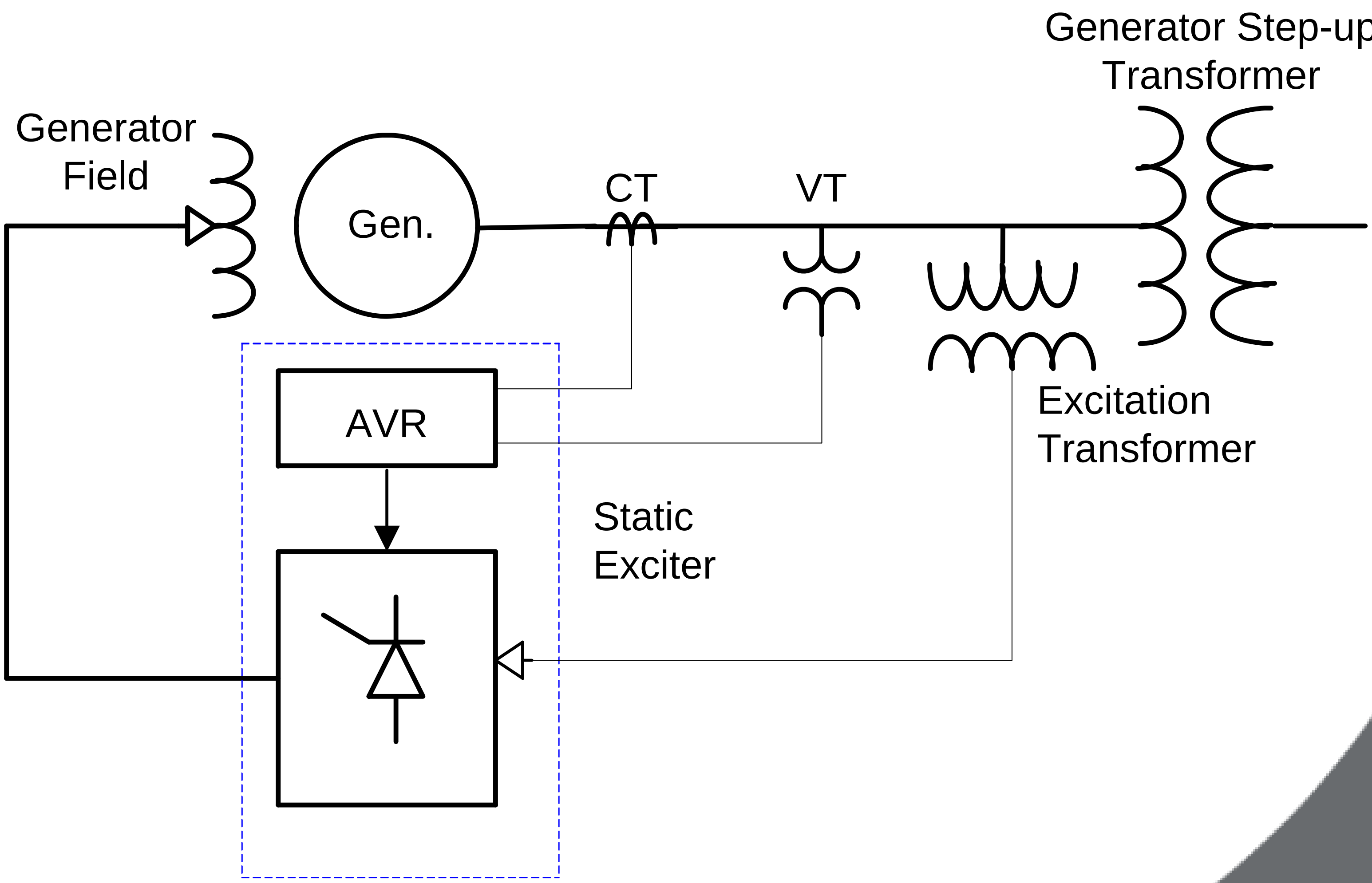
FUNDAMENTALS

- Basic Synchronous Generators
- Connections to the system
- Short Circuits
- Generator Grounding
- IEEE Guidelines
- Device Numbers

Basic Synchronous Generator



Generator Excitation & AVR Control



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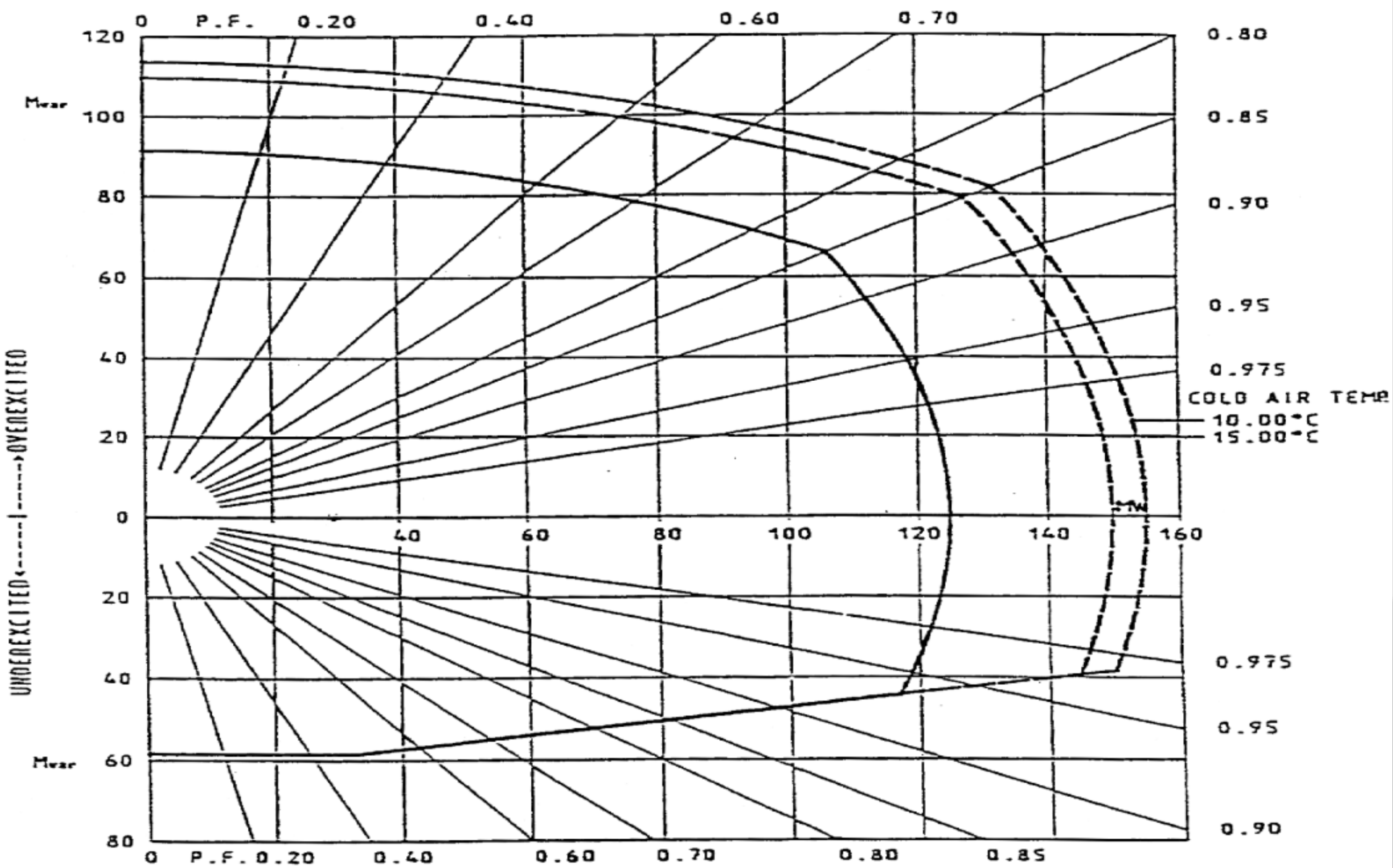
REACTIVE CAPABILITY CURVE

REVISION		
a		
b		
c		
d		
e		

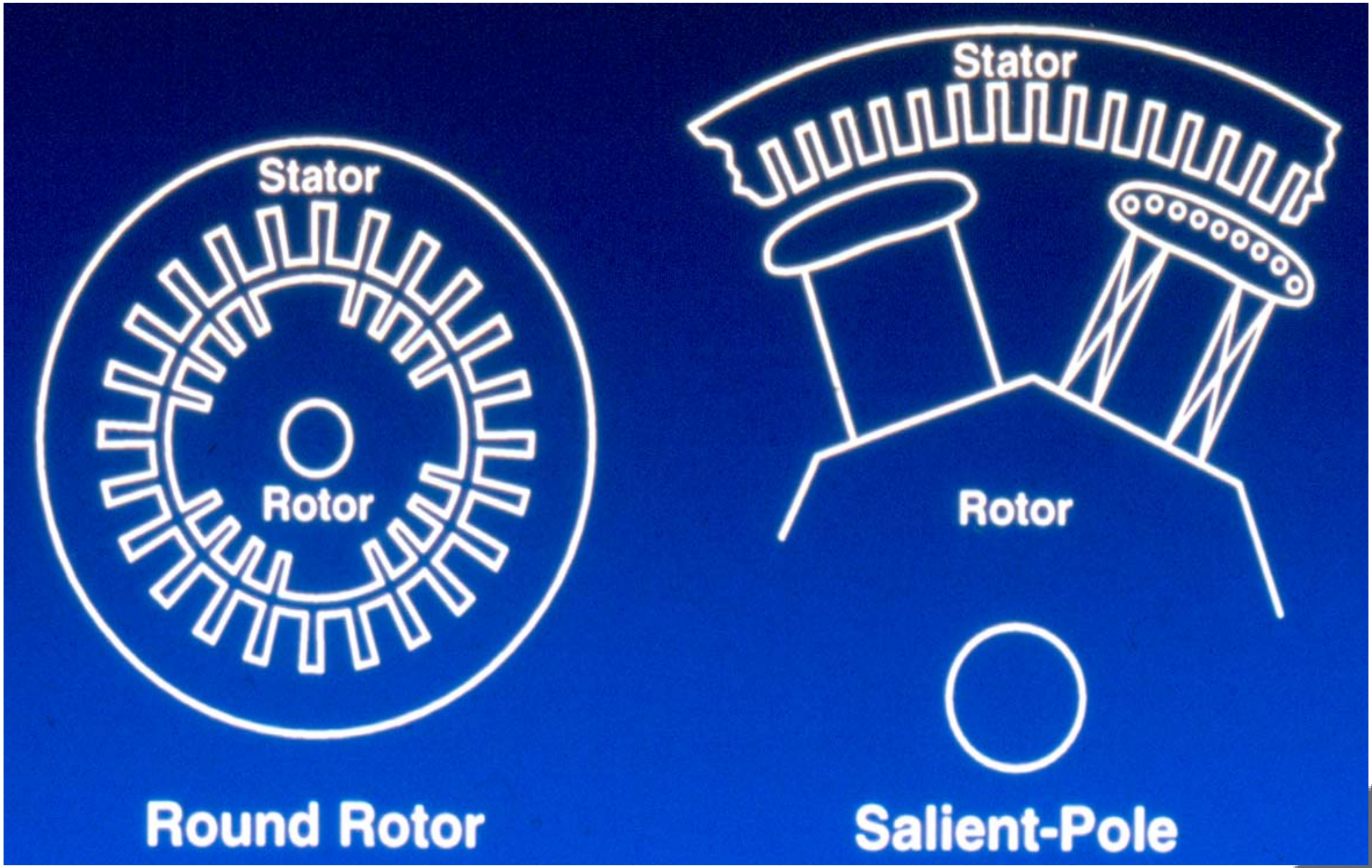
GENERATOR–TYPE: TLRI 93/33–36

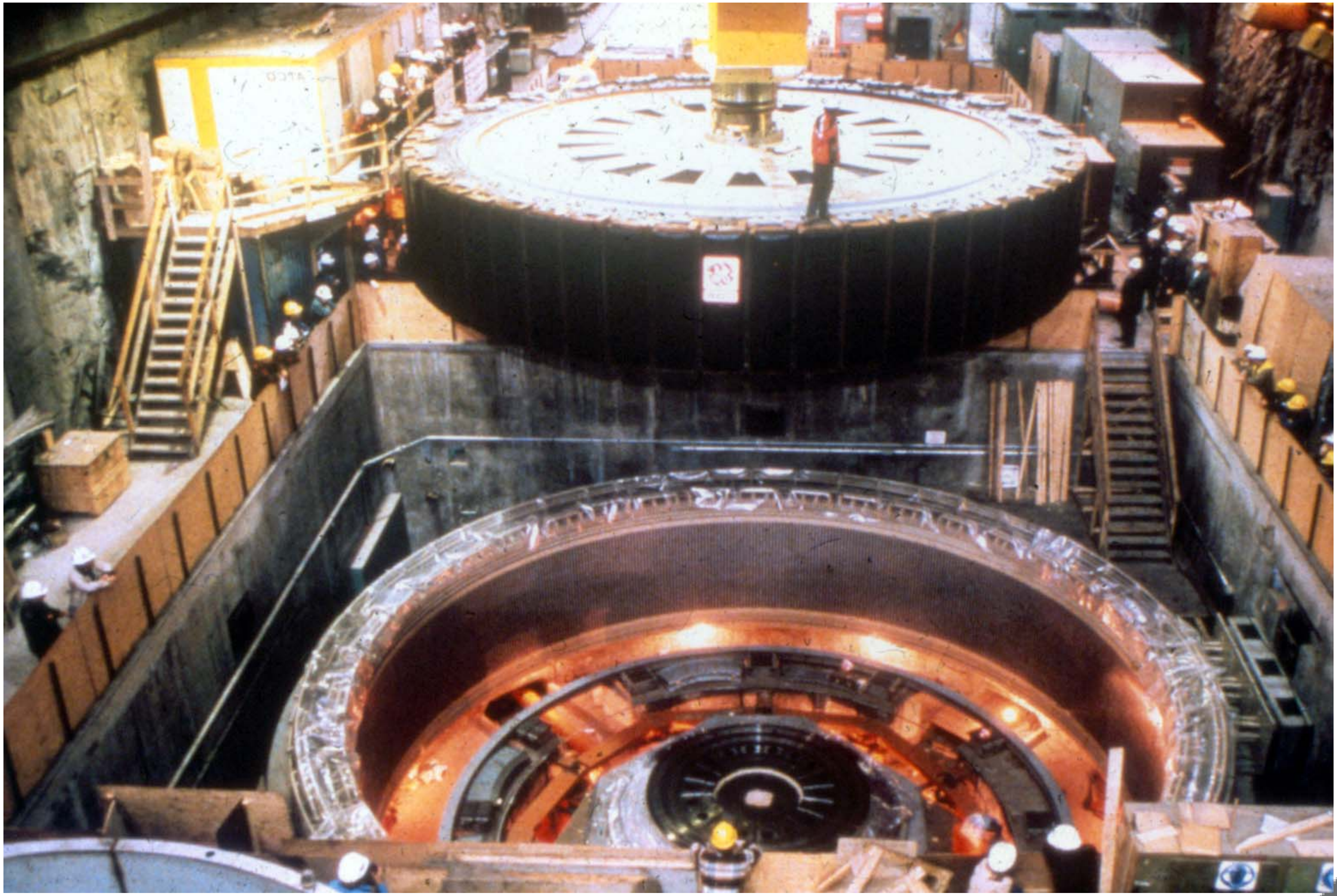
RATED GENERATOR OUTPUT	S_N	=	125.000	MVA
RATED ARMATURE VOLTAGE	U_N	=	13.800	kV
RATED ARMATURE CURRENT	I_N	=	5.230	kA
RATED FREQUENCY	F_N	=	60.0	Hz
POWER FACTOR	P.F.	=	0.850	
COLD AIR TEMPERATURE	T_K	=	40.00	Cel



V84.2 Generator Data Frame Size TLRI 93/33–36 0.85 P.F. Insulation Class B	
	1E93.117

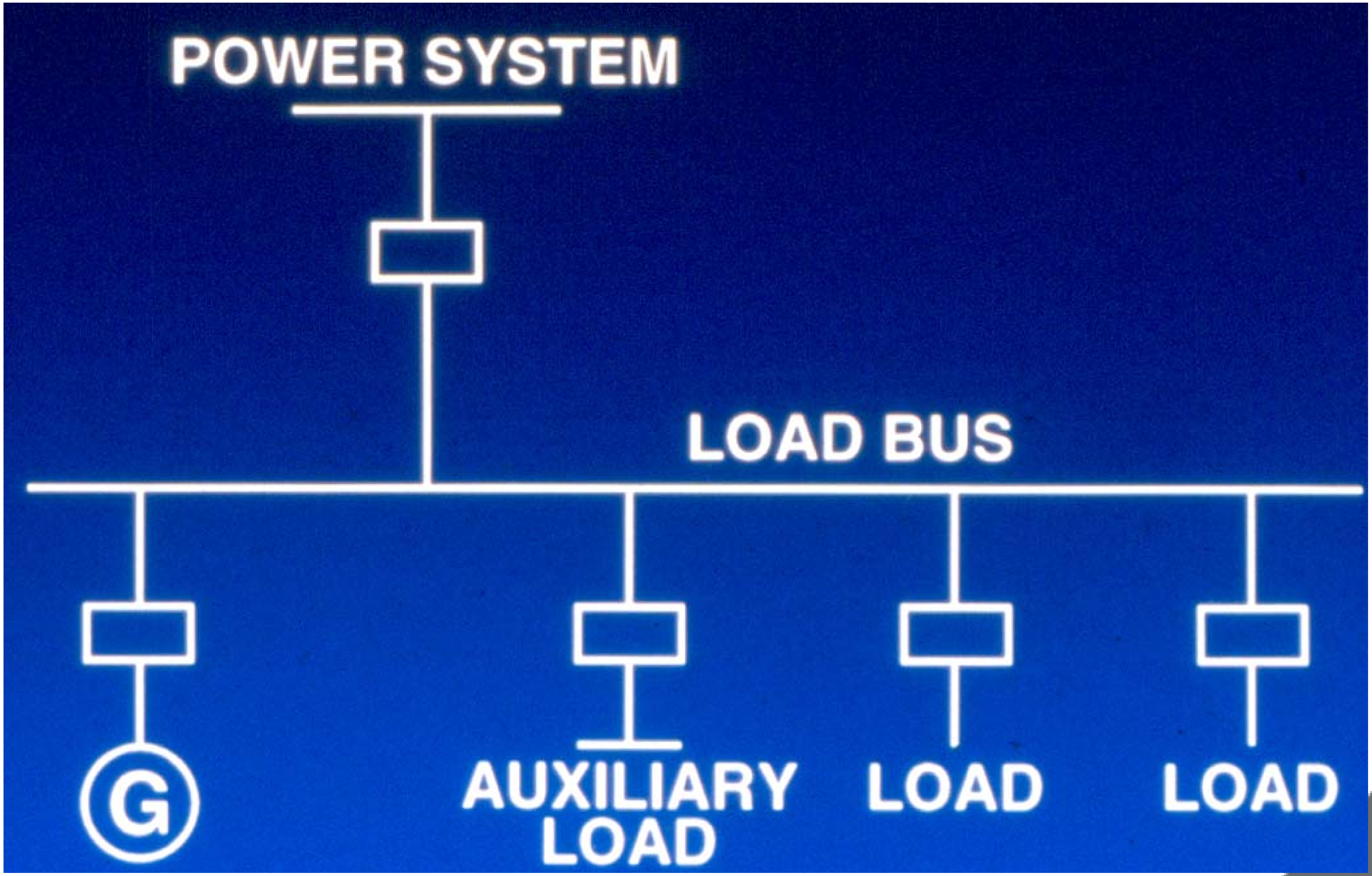
Synchronous Generator Types



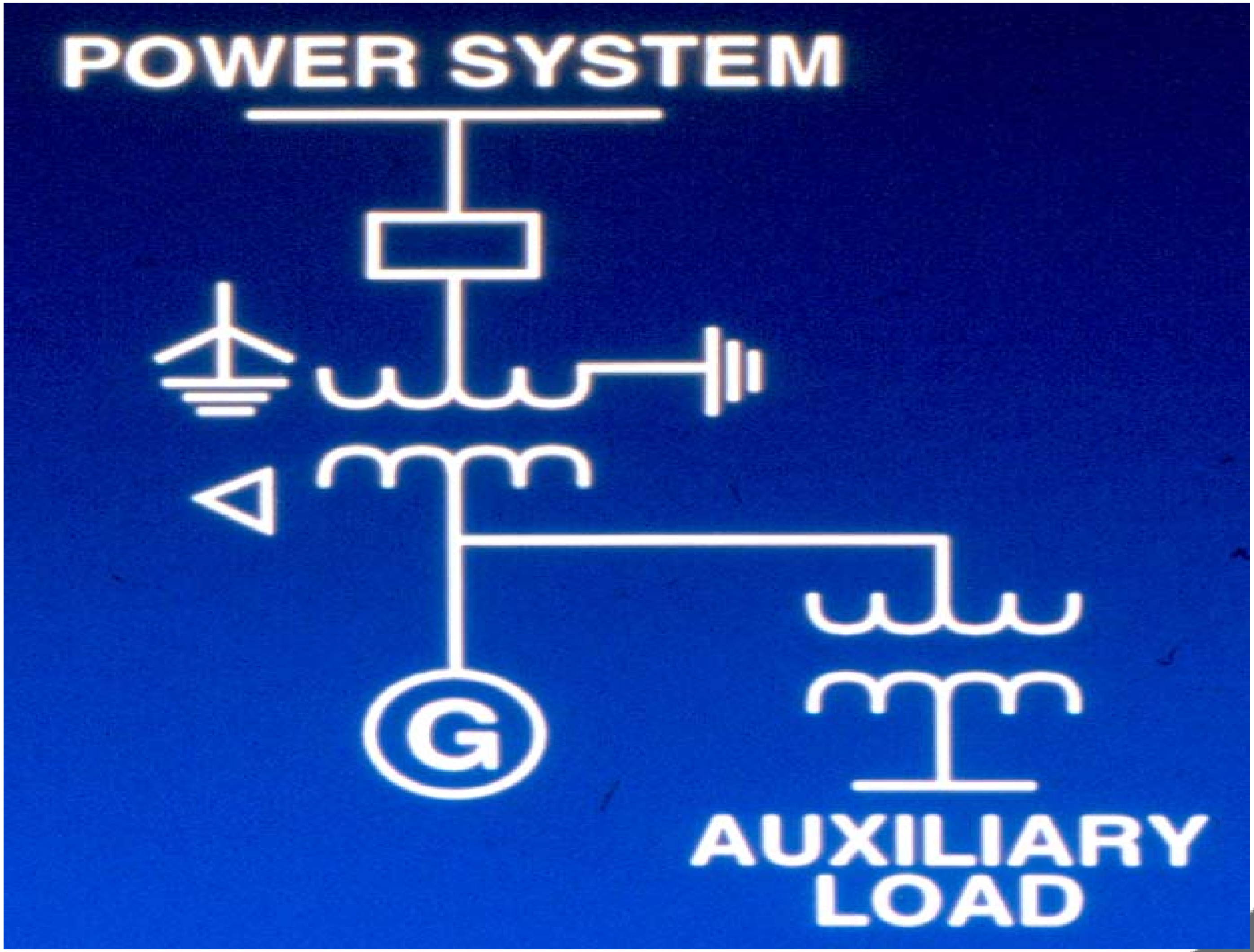



CRANE MFG. & SERVICE CORP.
MILWAUKEE, WIS.
CAPACITY 300/25 TON · SERIAL Nº 717

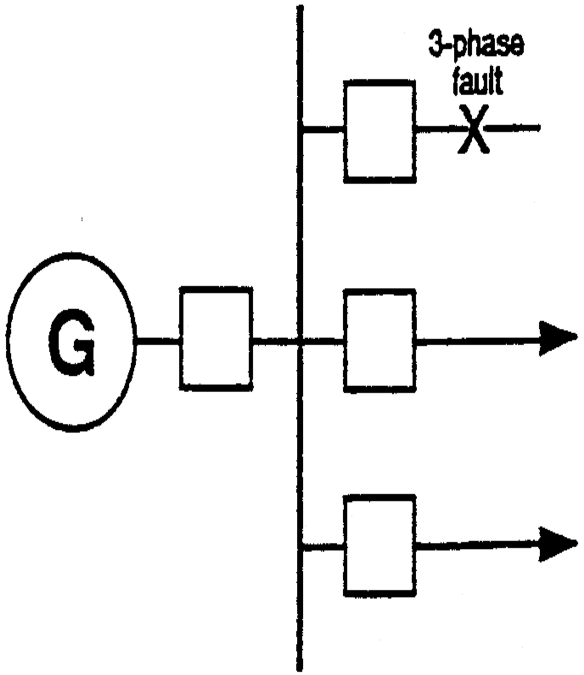
Direct Connected Generator

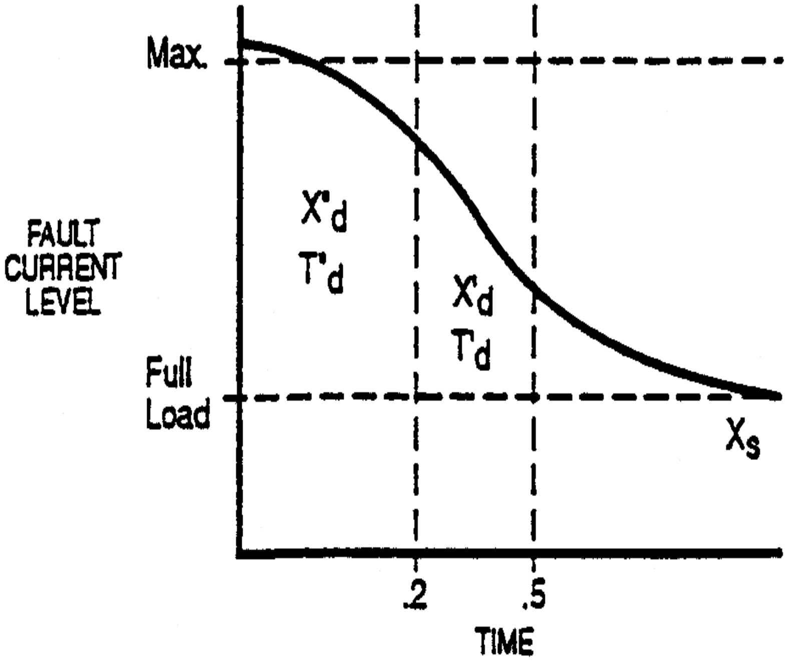


Unit Connected Generator to Power System

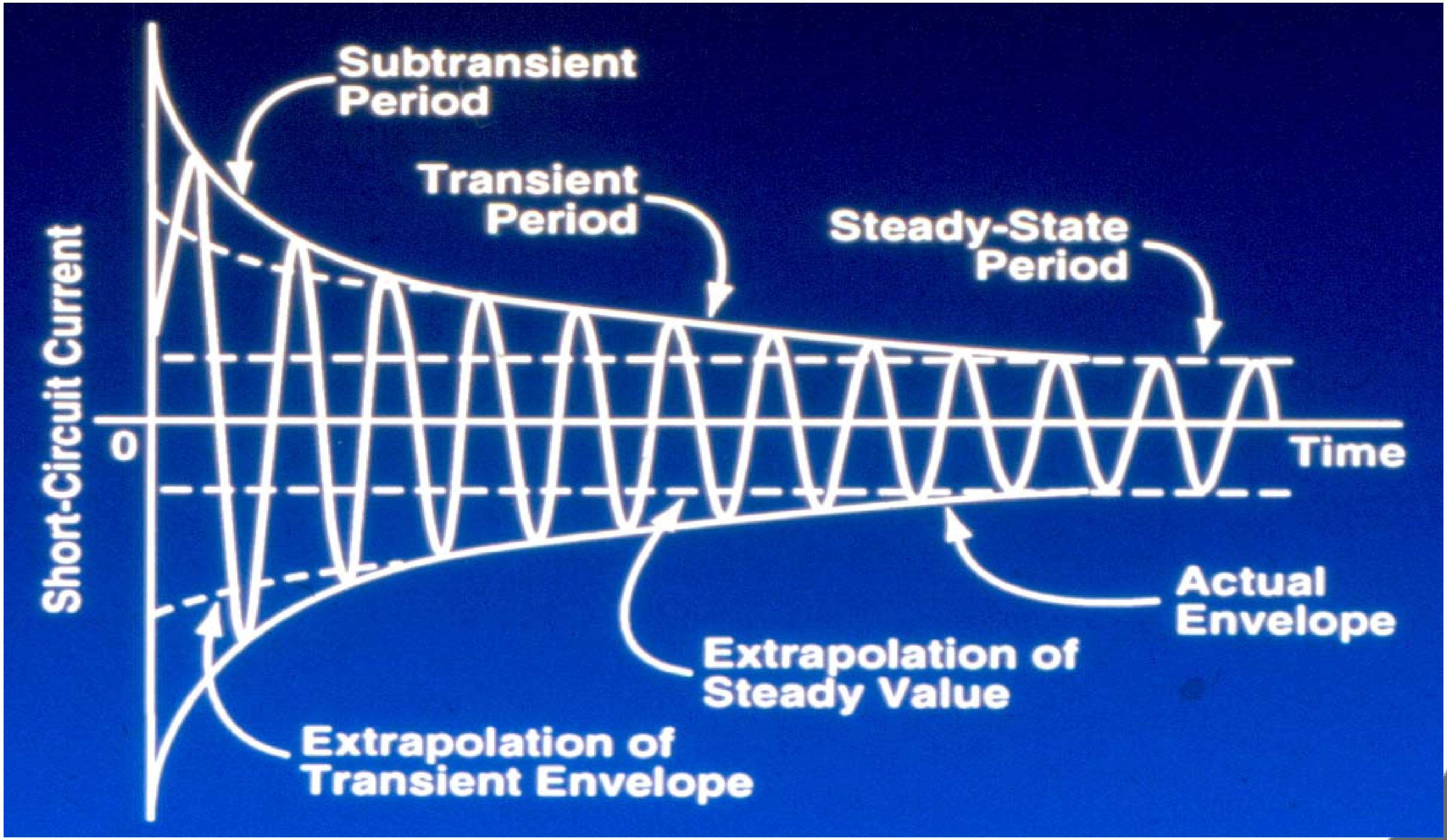


GENERATOR CURRENT DECAY

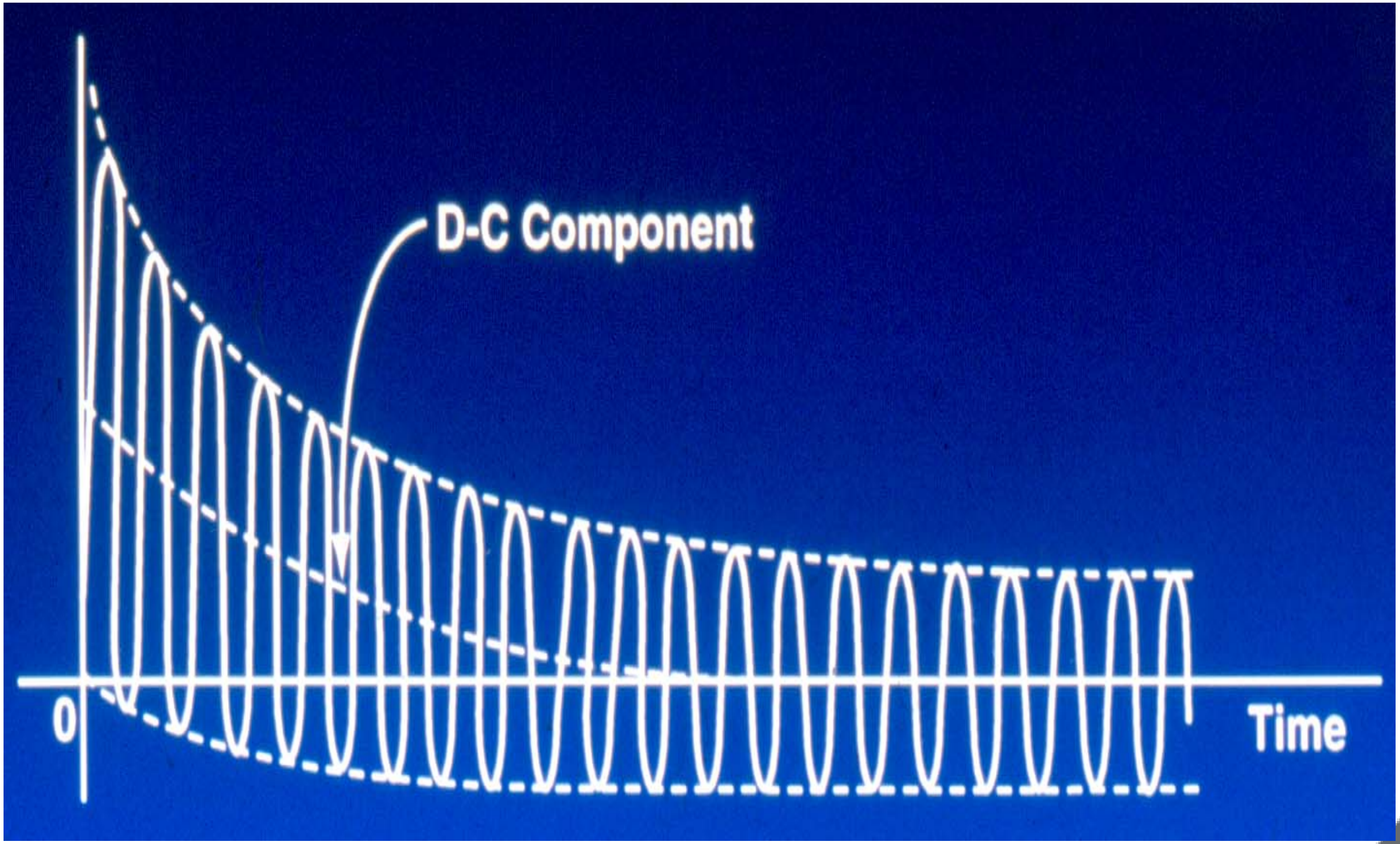




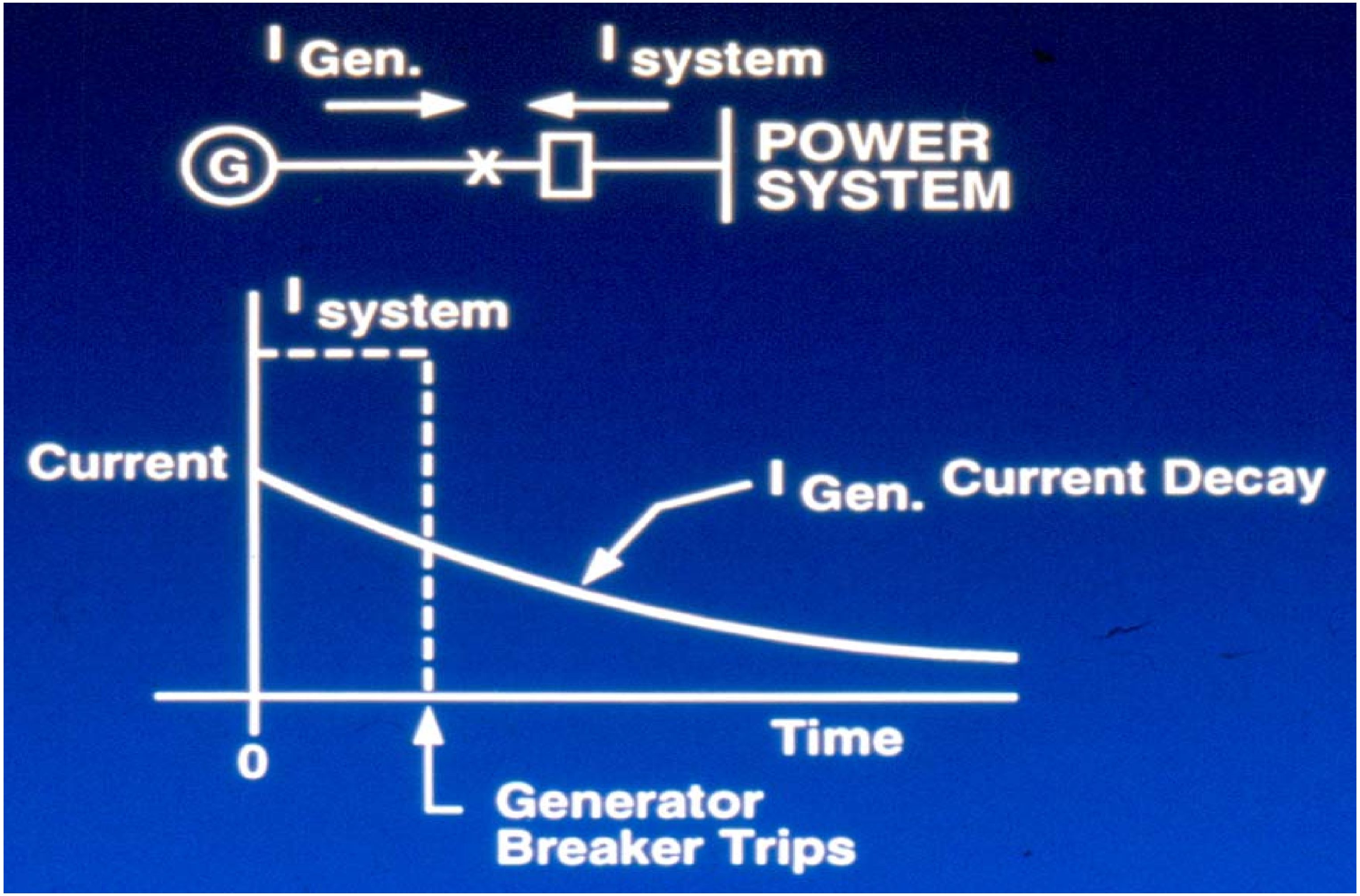
Symmetrical Trace of a Generator



Generator Short-Circuit Currents Phase



Generator Terminal Fault Current



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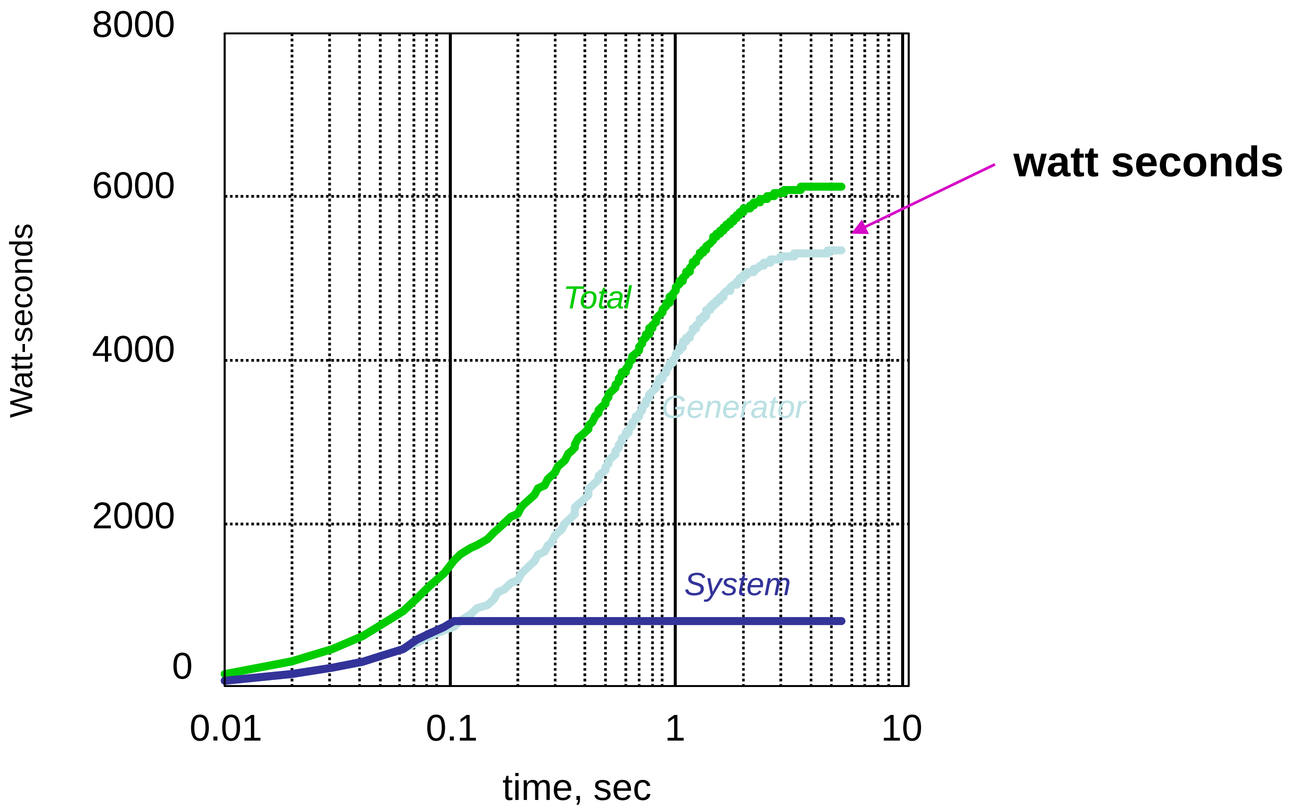
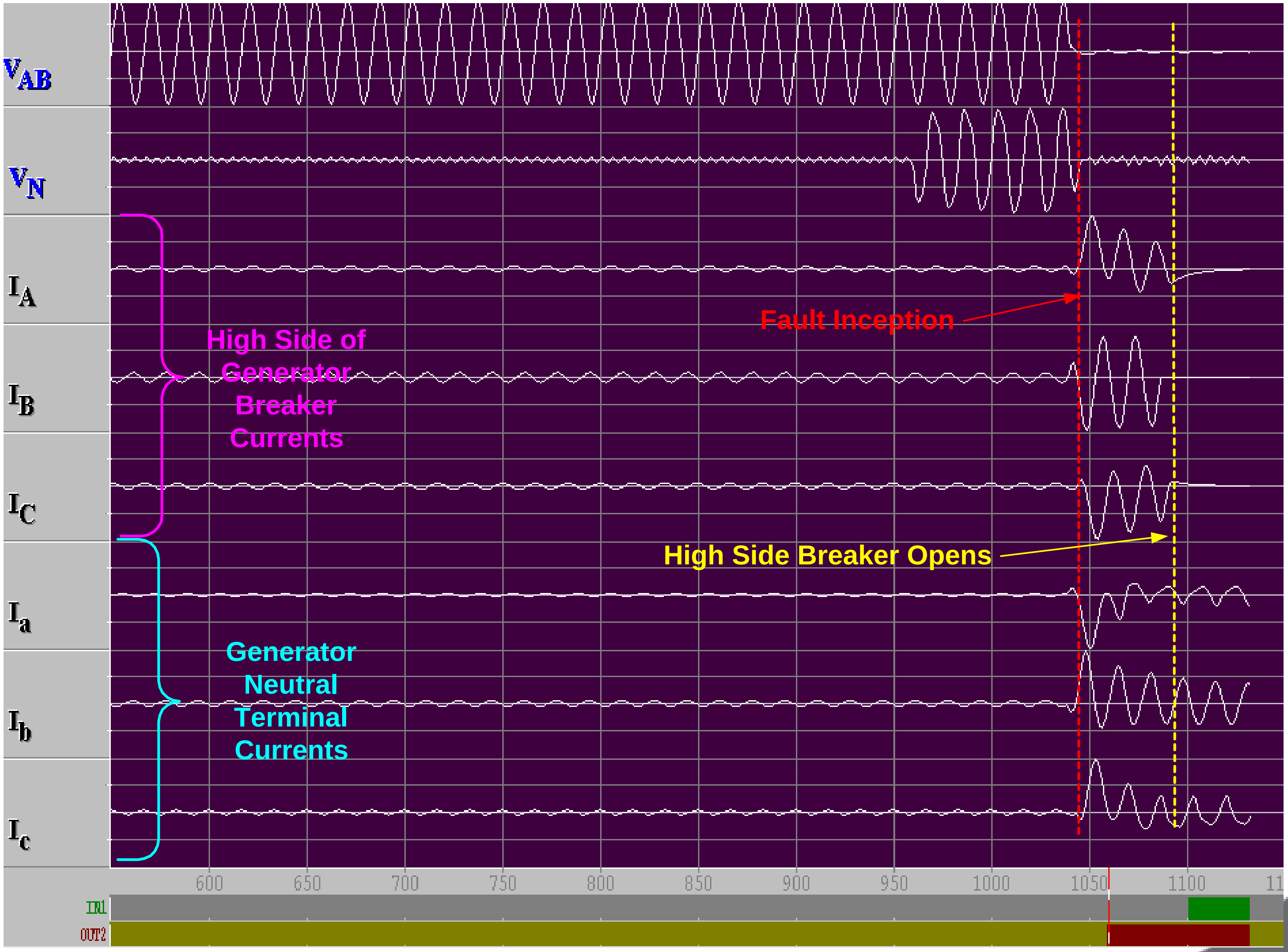
Accumulation of damage over time:

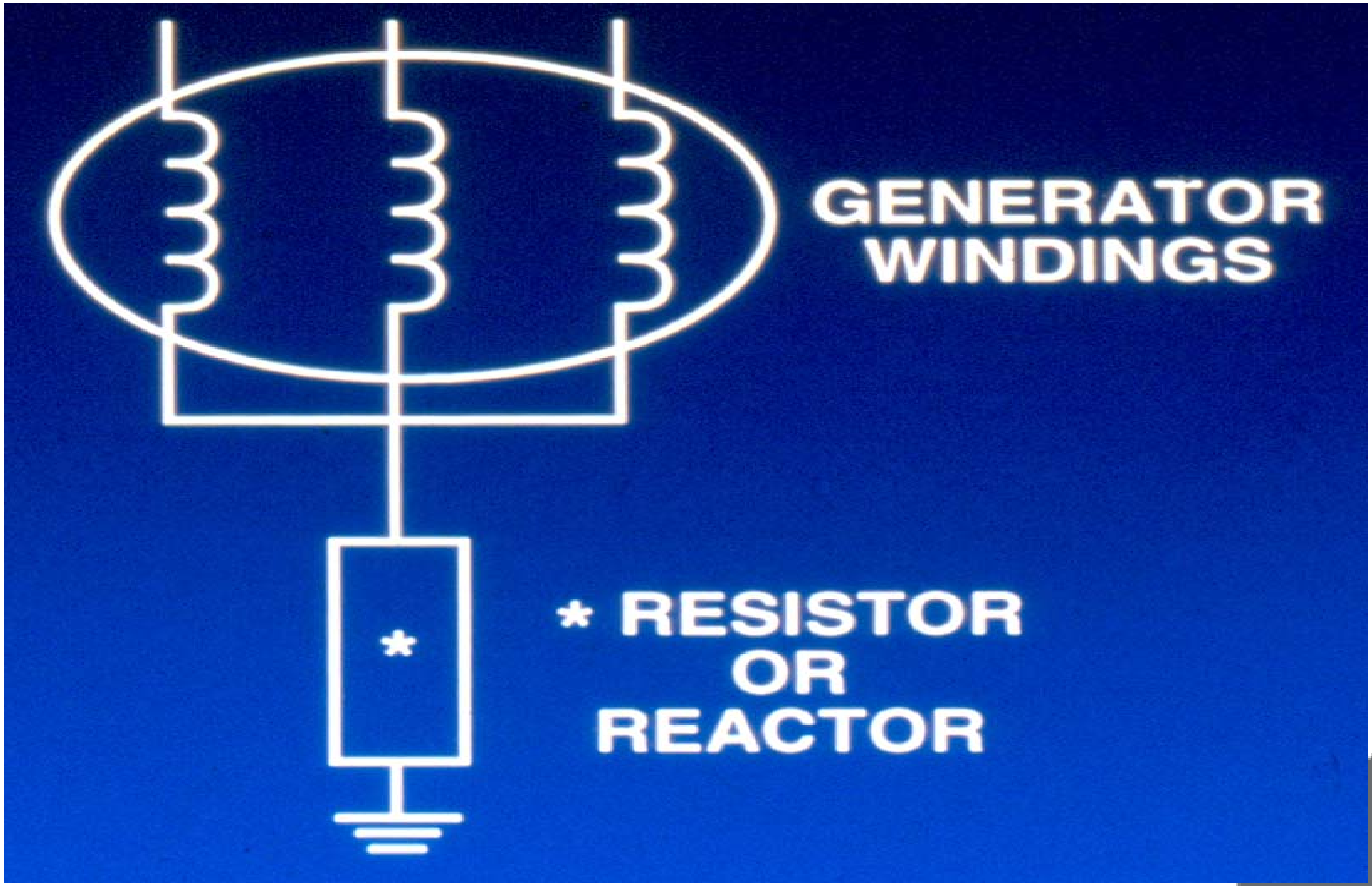


Most of the damage occurs in the period after the generator breaker opens

Multi-Phase Generator Fault Oscillograph

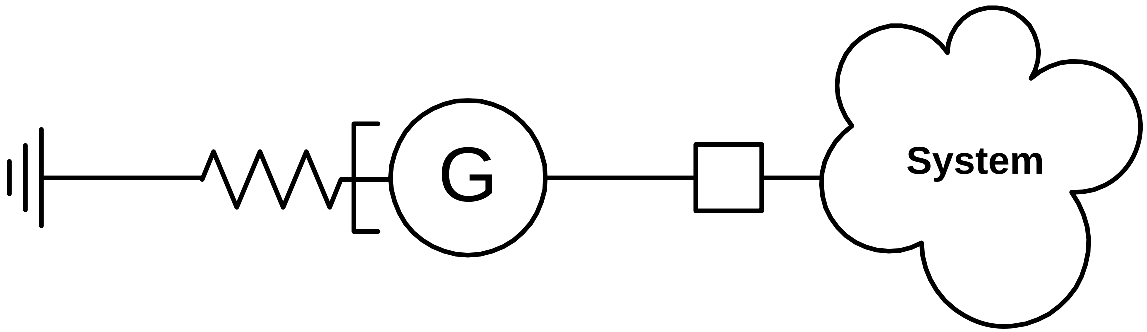


Low Impedance Grounding

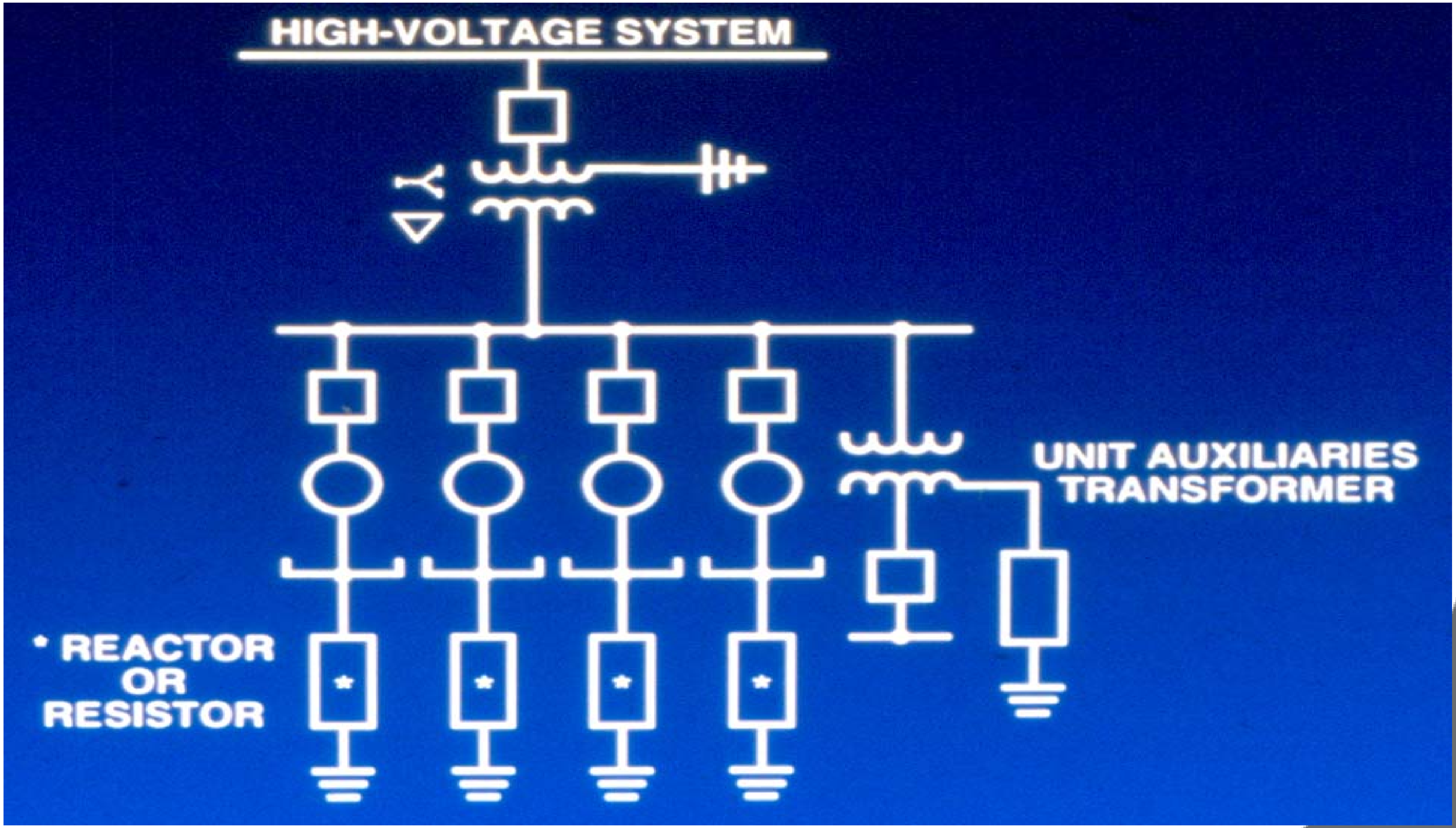


Types of Generator Grounds

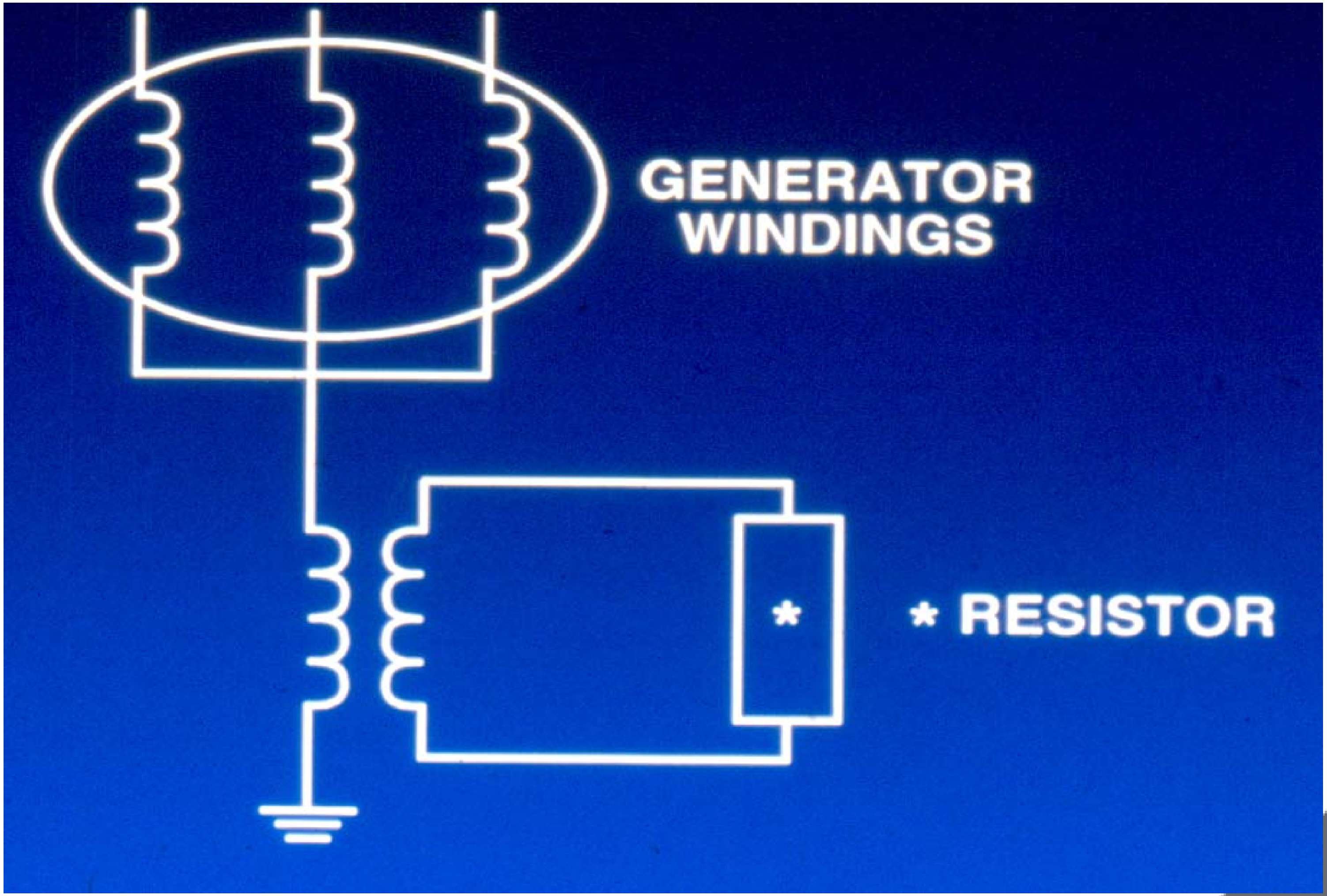
- Low Impedance
  - Usually a good ground source
  - Generator still likely to be damaged on internal ground fault
    - Ground fault current typically 200-400 A
    - This Level of Ground Current Can Cause unacceptable damage



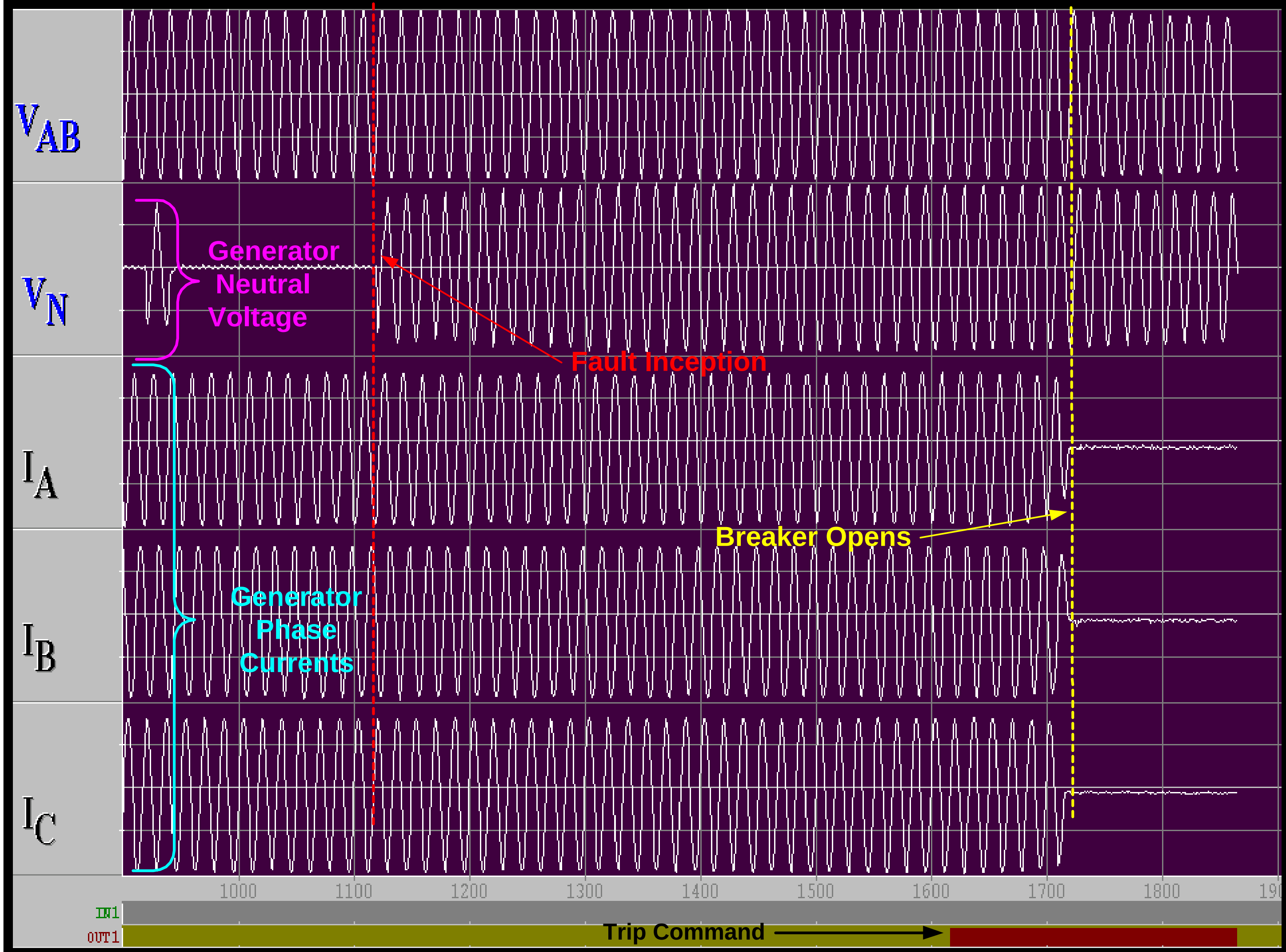
Low Impedance Grounding Generators Bussed Together



High Impedance Grounding

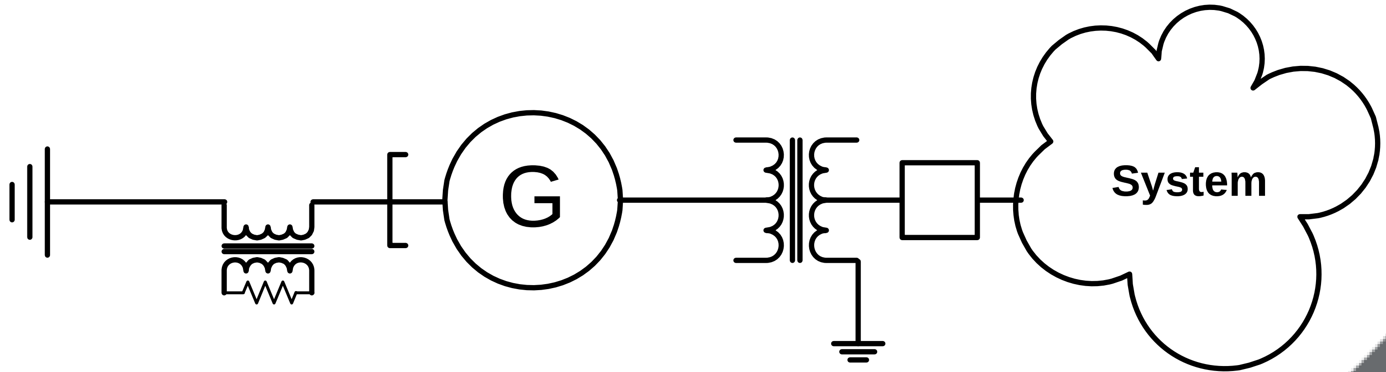


Oscillograph of STATOR Ground Fault



Types of Generator Grounds

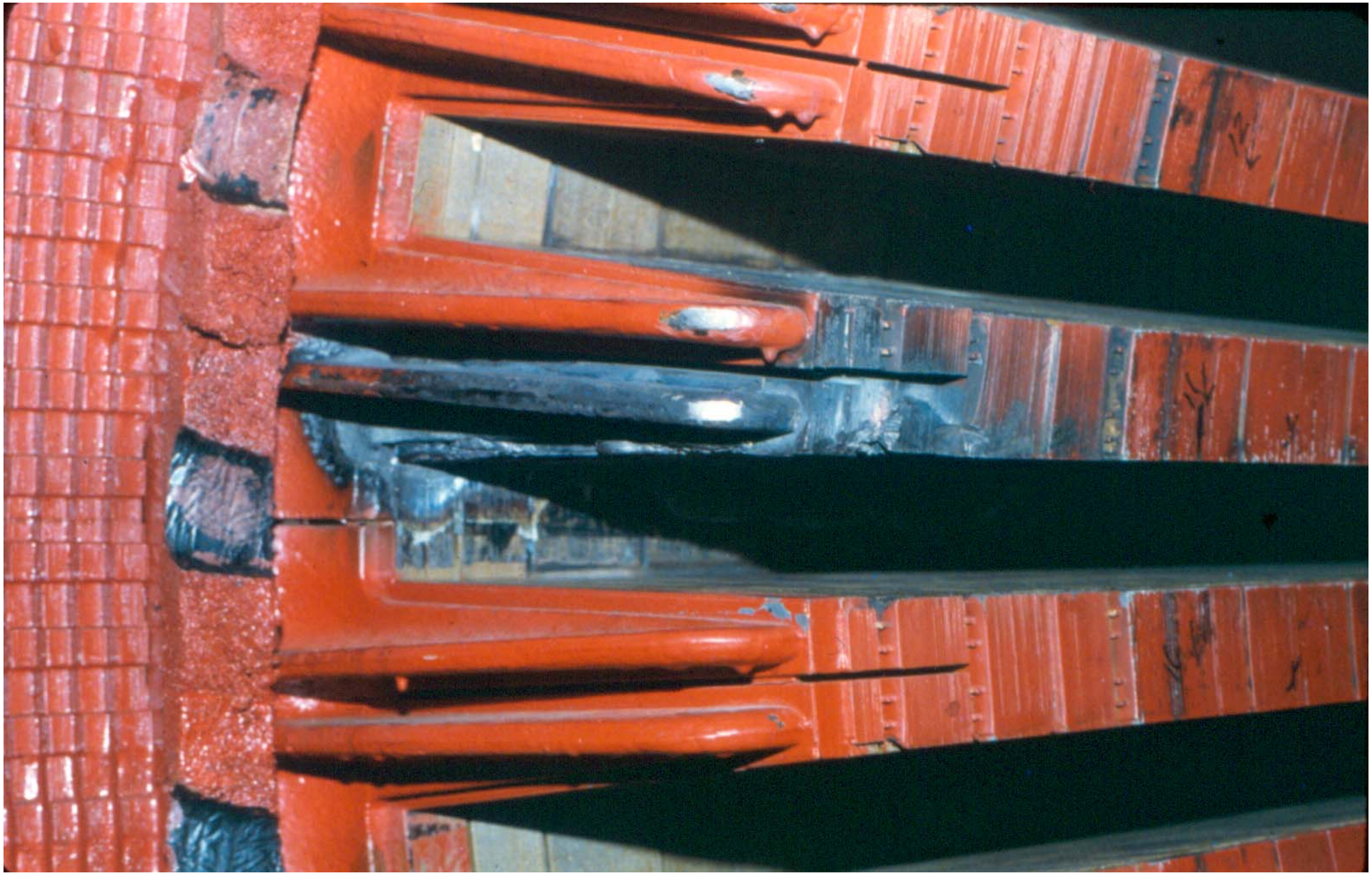
- High Impedance
  - Moderately expensive
  - Used when generators are unit connected
  - System ground source obtained from generator grounding transformer
  - Generator damage minimized or mitigated from ground fault
  - Ground fault current typically <=10A



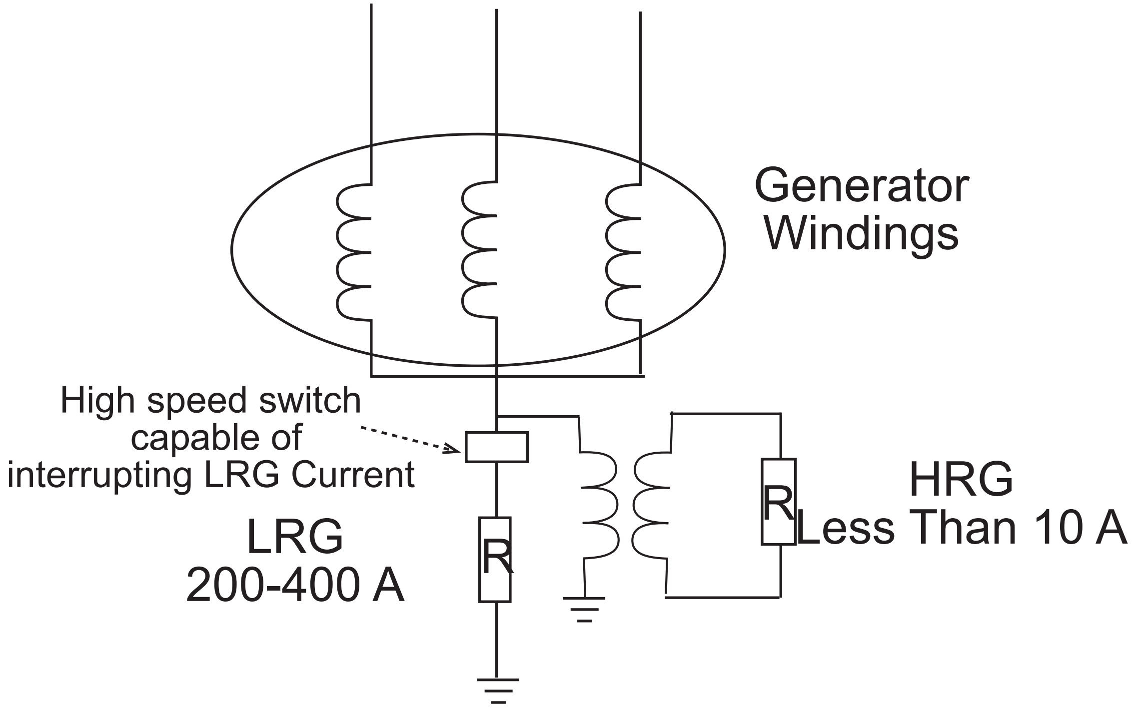
Stator Iron Burning

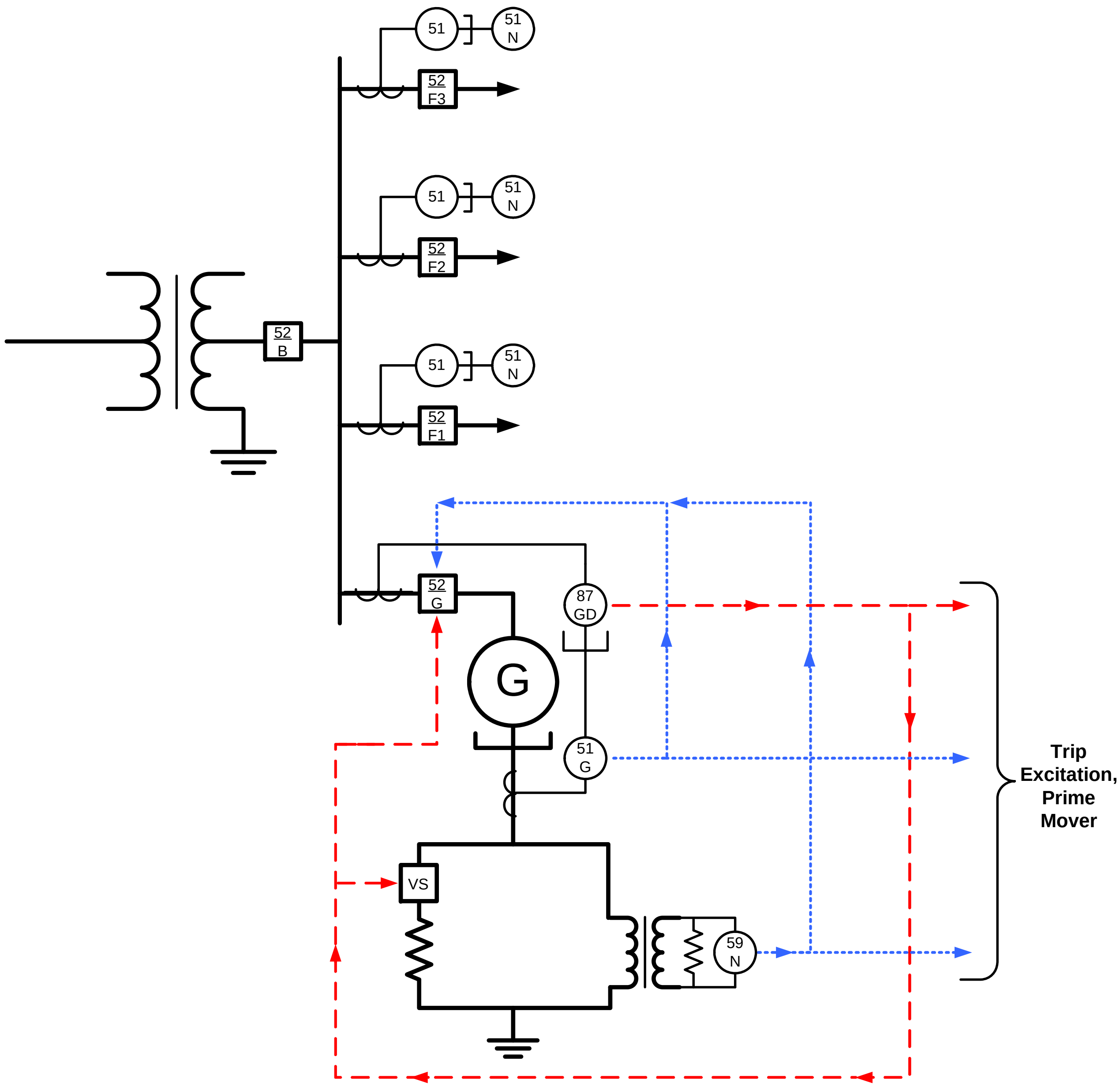
- Pictures of stator damage after an internal ground fault
- This generator was high impedance grounded, with the fault current less than 10A
- Some iron burning occurs, but the damage is repairable vs. low impedance grounded machines where the damage is typically severe.


GARLOCK



Dual (Hybrid) Grounding





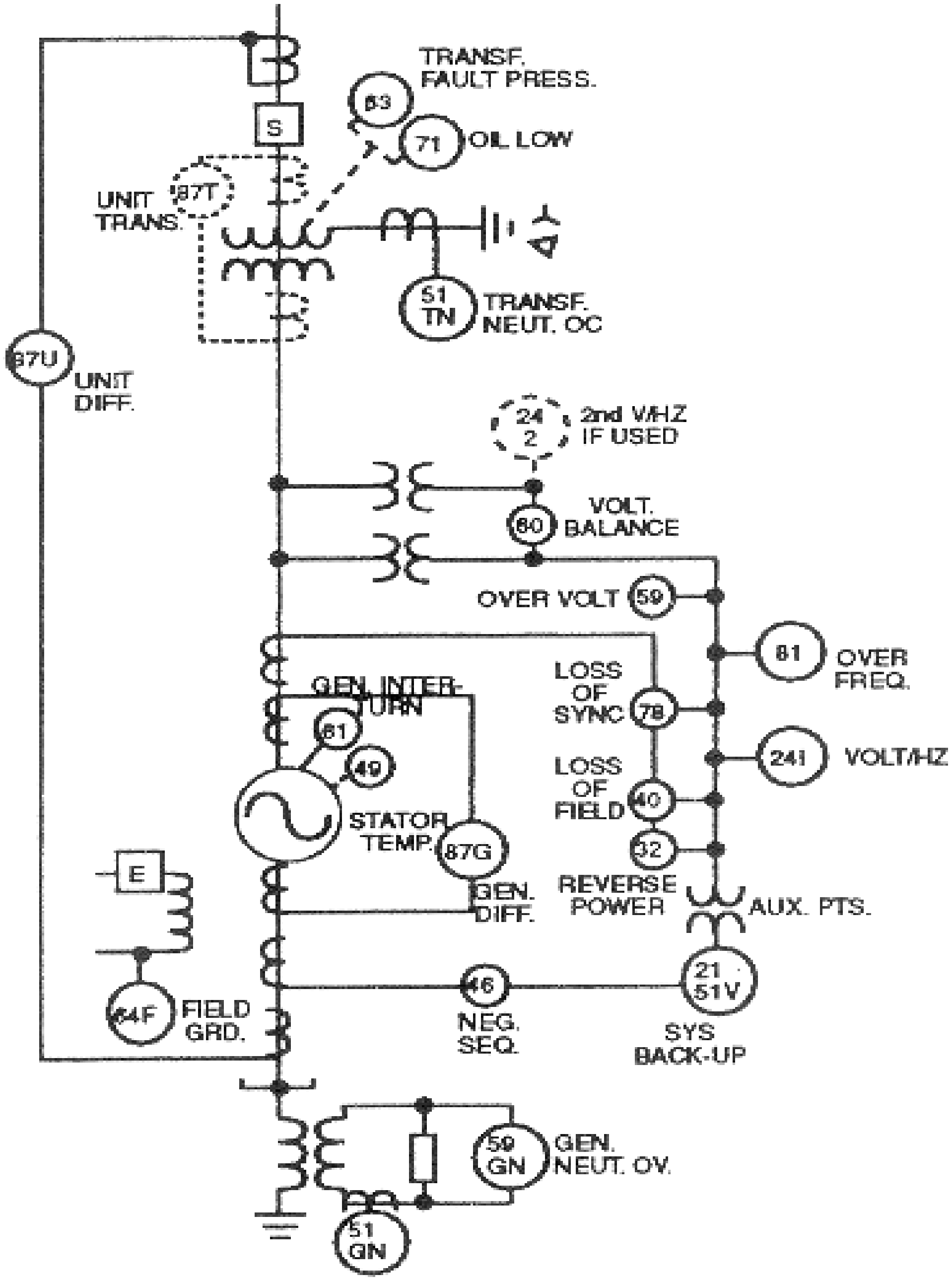
HYBRID GROUNDING

Converts from low to high Impedance Grounding if internal generator fault is detected.

Device	Function	Discussed in Tutorial Section
21	Distance Relay. Backup for system and generator zone phase faults.	11
24	Volts/Hz protection for generator overexcitation.	6
32	Reverse power relay. Anti-motoring protection.	14
40	Loss-of-field protection.	8
46	Negative sequence unbalance current protection for the generator.	10

Device	Function	Discussed in Tutorial Section
49	Stator Thermal Protection.	14
51GN	Time overcurrent ground relay.	4 & 11
51TN	Backup for ground faults.	4 & 11
51V	Voltage-controlled or voltage-restrained time overcurrent relay. Backup for system and generator phase faults.	11
59	Overvoltage protection.	6
59GN	Overvoltage relay. Stator ground fault protection for a generator.	4

Device	Function	Discussed in Tutorial Section
78	Loss-of-synchronism protection.	9
81	Frequency relay. Both underfrequency protection.	5
86	Hand-reset lockout auxiliary relay.	14
87G	Differential relay. Primary phase-fault protection for the generator.	2
87N	Stator ground fault differential .	4
87T	Differential relay. Primary protection for the transformer.	2
87U	Differential relay for overall generator and transformer protection.	2



FROM IEEE C37.102

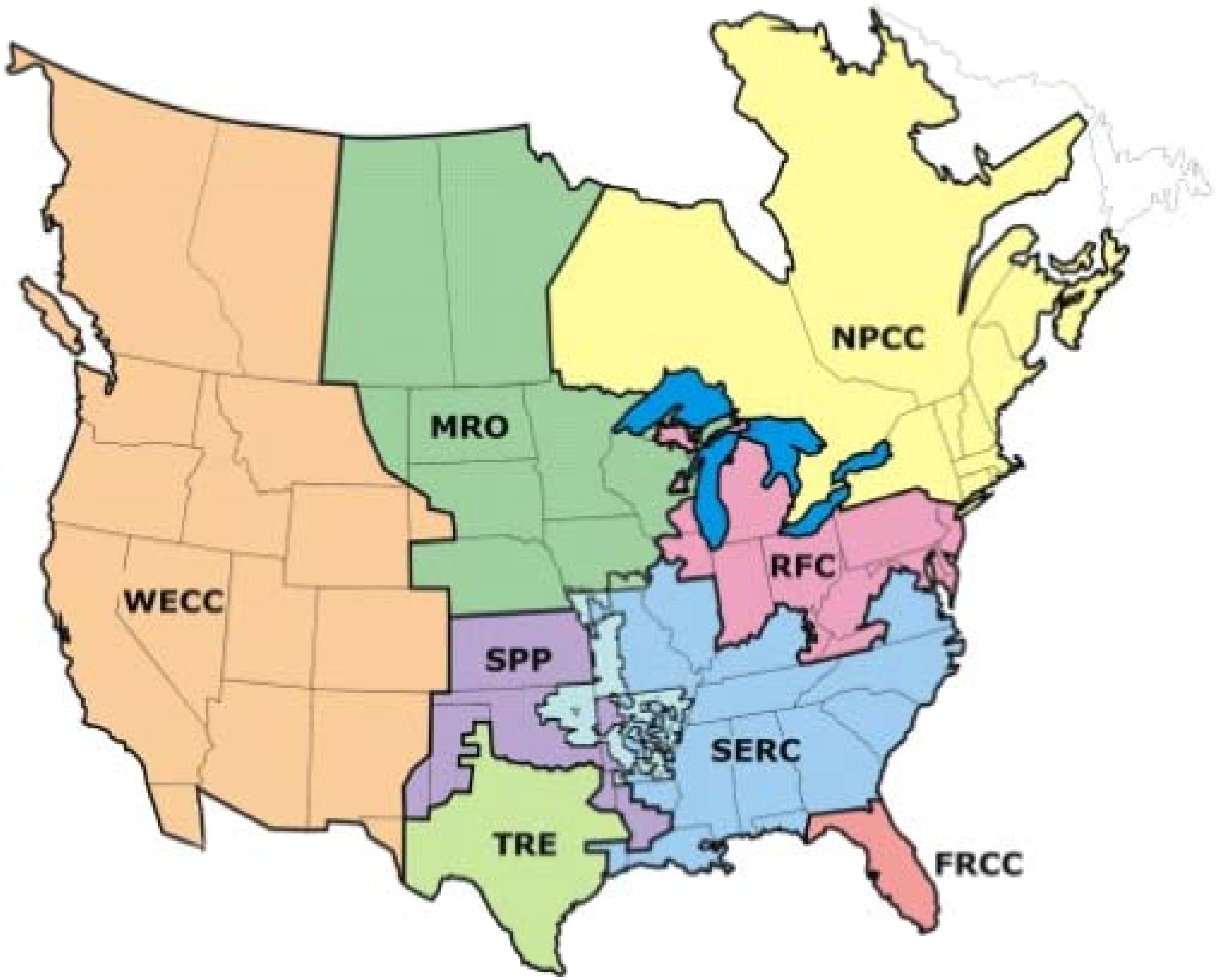
Unit Connected, High Z Grounded

NERC PROTECTION SYSTEM MAINTENANCE REQUIREMENTS

NERC REGIONAL RELIABILITY ORGANIZATIONS (RROs)

Regional Entities

Florida Reliability Coordinating Council (FRCC)
Midwest Reliability Organization (MRO)
Northeast Power Coordinating Council (NPCC)
Reliability*First* Corporation (RFC)
SERC Reliability Corporation (SERC)
Southwest Power Pool, Inc. (SPP)
Texas Regional Entity (TRE)
Western Electricity Coordinating Council (WECC)



NERC RELIABILITY STANDARDS TRANSMISSION SYSTEM - GENERATOR MAINTENANCE AND TESTING:

PRC-005-1 TRANSMISSION AND GENERATION PROTECTION SYSTEM MAINTENANCE AND TESTING

R1. Each Transmission Owner and any Distribution Provider that owns a transmission Protection System and each Generator Owner that owns a generation Protection System shall have a Protection System maintenance and testing program for Protection Systems that affect the reliability of the BES. The program shall include:

- **R1.1** Maintenance and testing intervals and their basis
- **R1.2** Summary of maintenance and testing procedures

NERC RELIABILITY STANDARDS TRANSMISSION SYSTEM - GENERATOR MAINTENANCE AND TESTING:

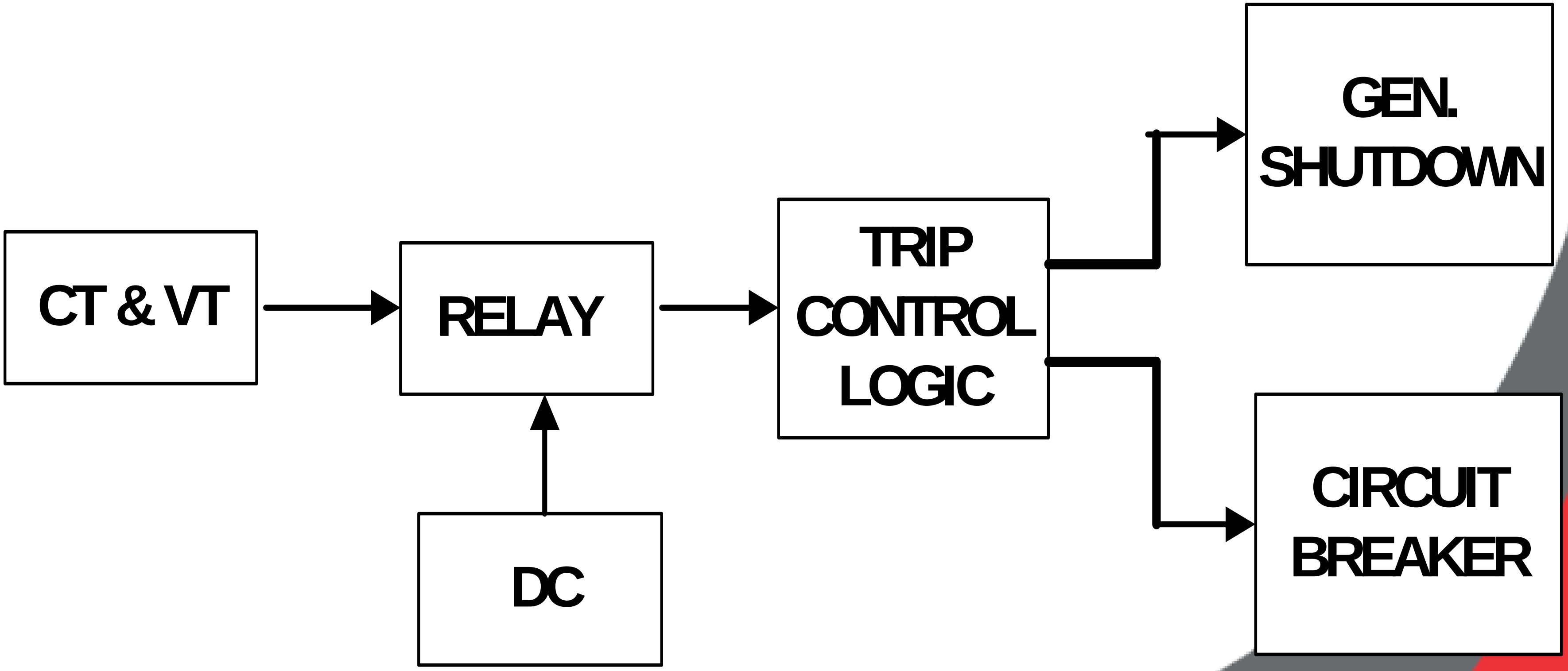
PRC-005-1 EVIDENCE OF COMPLIANCE

R2.1 Evidence Protection System devices were maintained and tested within the defined intervals.

R2.2 Date each Protection System device was last tested/maintained.

NERC RELIABILITY STANDARDS TRANSMISSION SYSTEM - GENERATOR MAINTENANCE AND TESTING:

NERC PROTECTION SYSTEM DEFINED:



NERC RELIABILITY STANDARDS TRANSMISSION SYSTEM - GENERATOR MAINTENANCE AND TESTING:

CATEGORIES OF PROTECTION SYSTEMS:

UNMONITORED – -------------- Electromechanical and Solid State (no self-testing)

PARTIALLY MONITORED –- Digital Relays with Failure Alarms Send to a Manned Location (Relay Self-Testing)

THOROUGHLY MONITORED – Same as Above Monitoring, Plus Additional Monitoring of Alarms and Performance Measured Values

FULLY MONITORED - --------- Same as Above, Plus Continuous Monitoring of all Components of the Protection System

NERC RELIABILITY STANDARDS TRANSMISSION SYSTEM - GENERATOR MAINTENANCE AND TESTING:

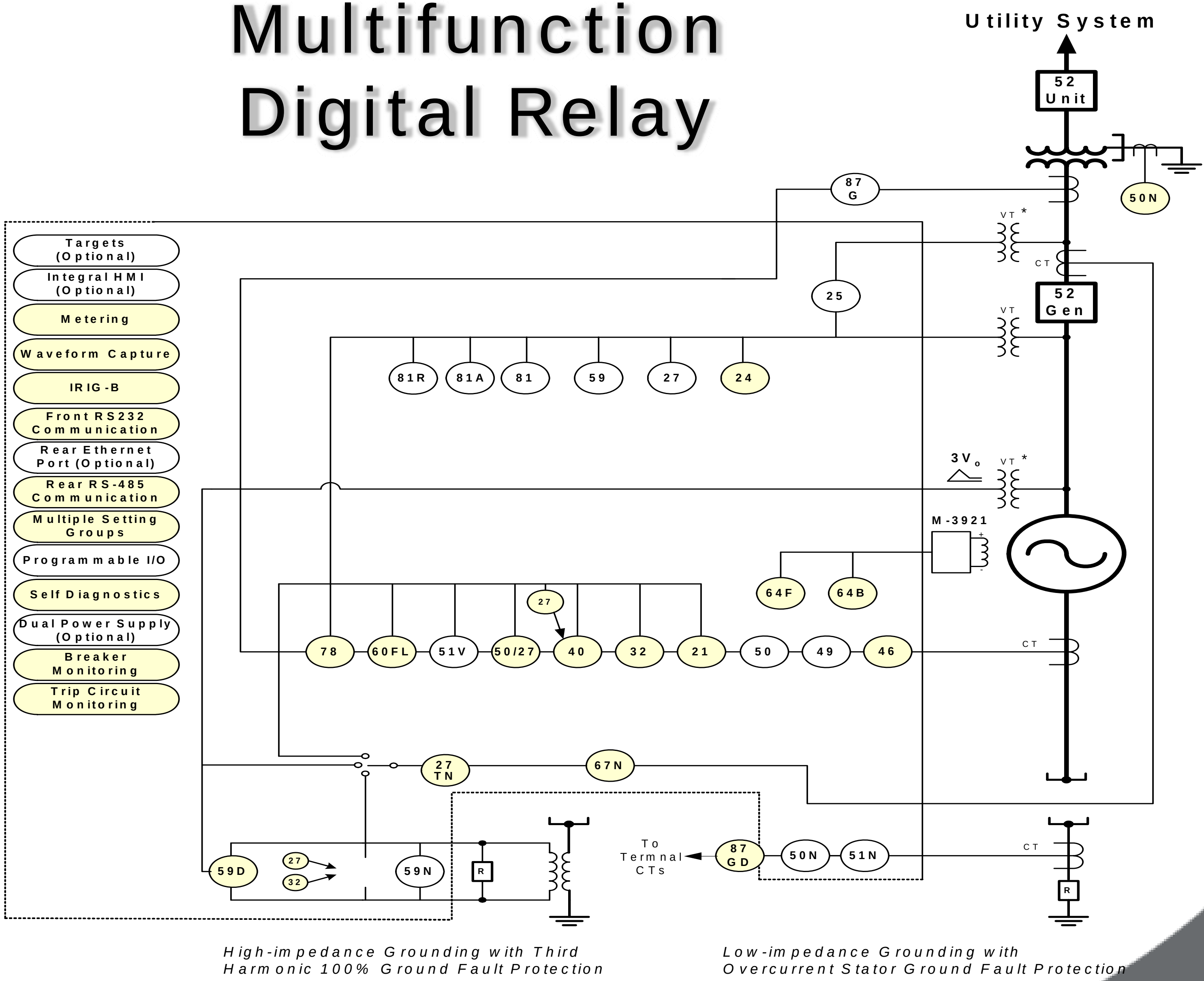
Category	Component	Maximum Verification Interval				Verification Activities
Reference Figure 1		Un-monitored	Partial Monitoring	Thorough Monitoring	Full Monitoring	
1.	Testing and calibration of protective relays.	5 years	7 years	10 years	Continuous Monitoring and Verification	Test the functioning of relays with Simulated inputs, including calibration. Verify that settings are as specified.
2.	Verification of instrument transformer outputs and correctness of connections to protection system.	7 years	7 years	10 years	Continuous Monitoring and Verification	Verify the current and voltage signals to the protection system, and instrument transformer circuit grounding
3.	Verification of protection system tripping including circuit breaker tripping, auxiliary tripping relays and devices, lockout relays, telecommunications-assisted tripping schemes, and circuit breaker status indication required for correct operation of protection system.	5 years	7 years	10 years	Continuous Monitoring and Verification	Perform trip tests for the whole system at once, and/or component operating tests with overlapping of component verifications. Every operating circuit path must be fully verified, although one check of any path is sufficient. A breaker only need be tripped once per trip coil within the specified. Telecommunications-assisted line protection systems may be verified either by end-to-end tests, or by simulating internal or external faults with forced channel signals.
4.	Station battery supply	1 month	7 years	Continuous Verification	Continuous Monitoring and Verification	Verify voltage of the station battery once a month if not monitored.

APPLICATION OF MULTIFUNCTION DIGITAL GENERATOR PROTECTION

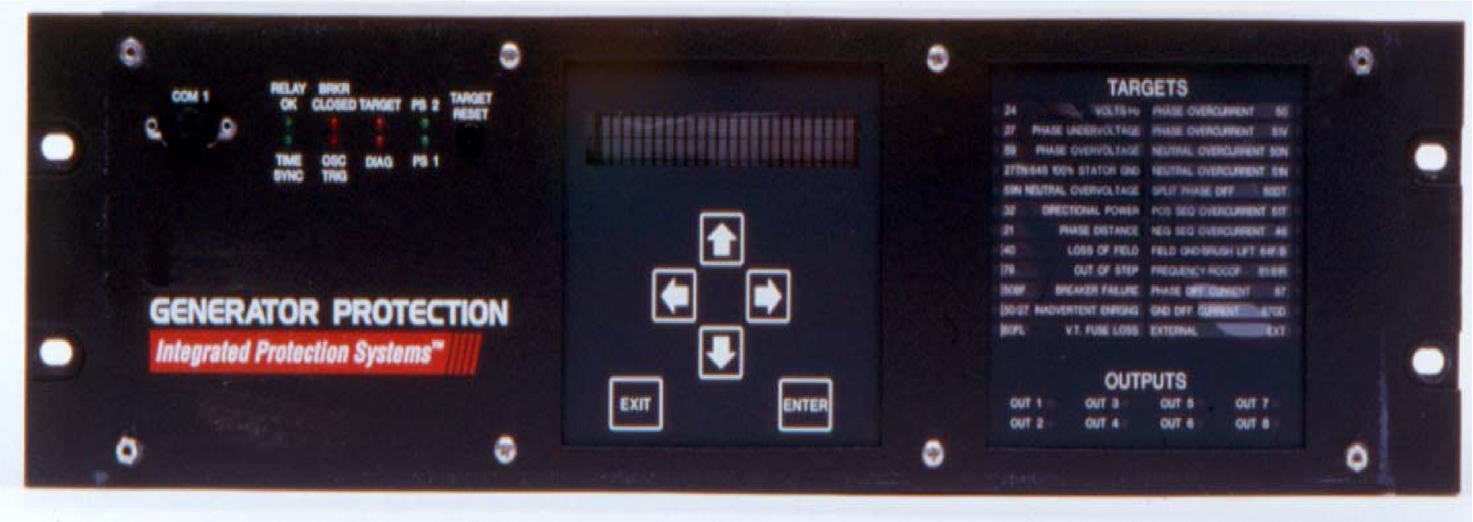
Evolution of Technology in Generator Protection

- Single Function Electromechanical
- Single Function Static
- Single Function Microprocessor-Based
- Multifunction Digital Relays
  - → Almost all new generating facilities use this technology
  - → All generator protection functions in on hardware platform

Multifunction Digital Relay

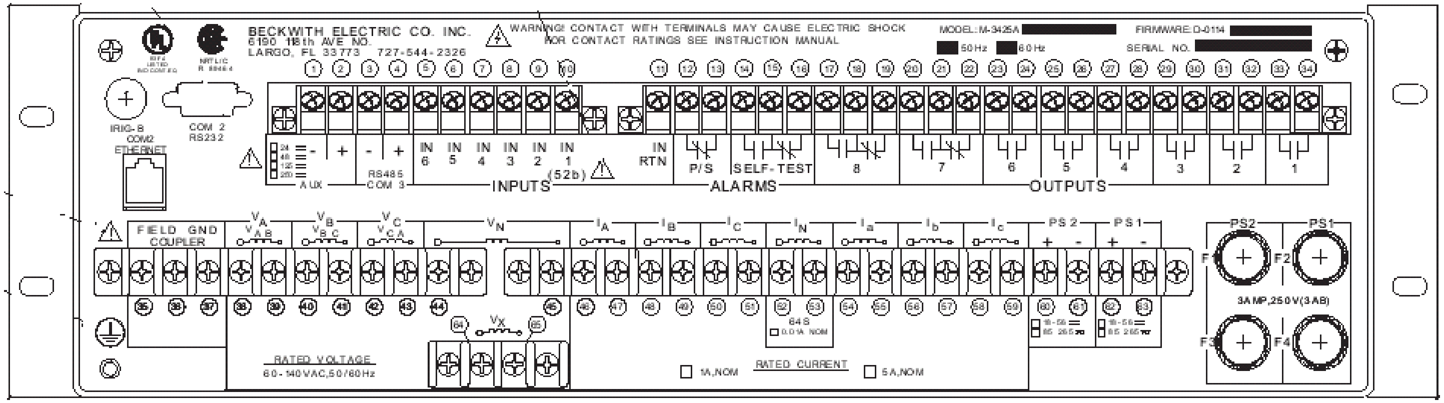


Multifunction Digital Relay

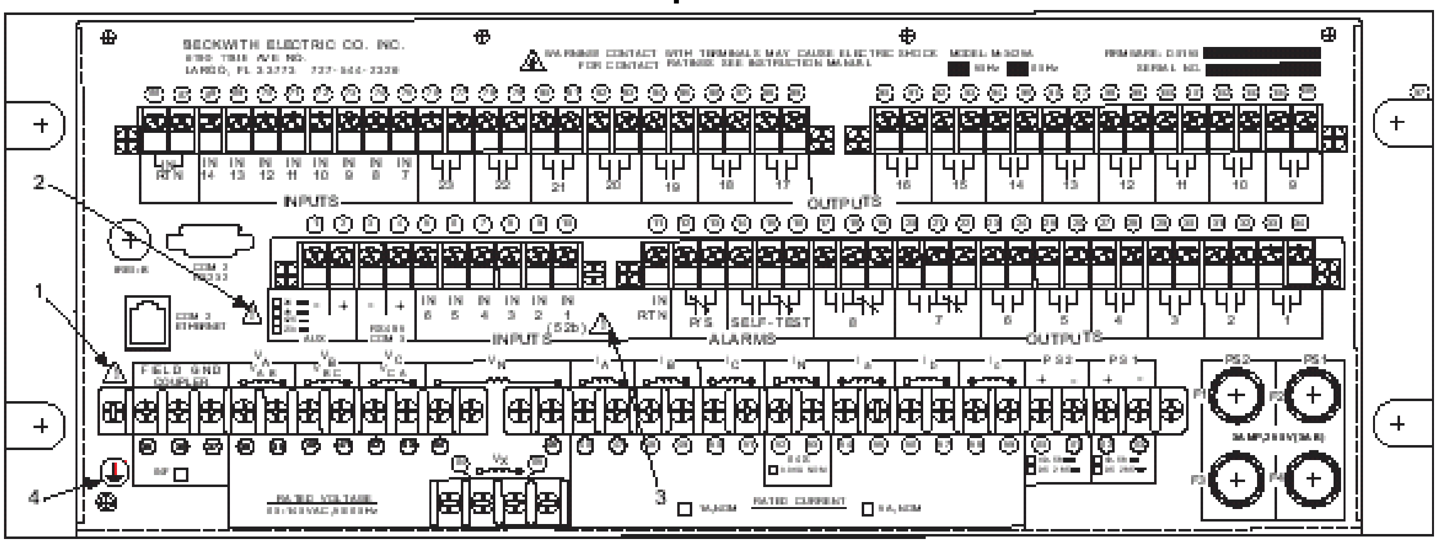


I/O M-3425A

Standard



Expanded



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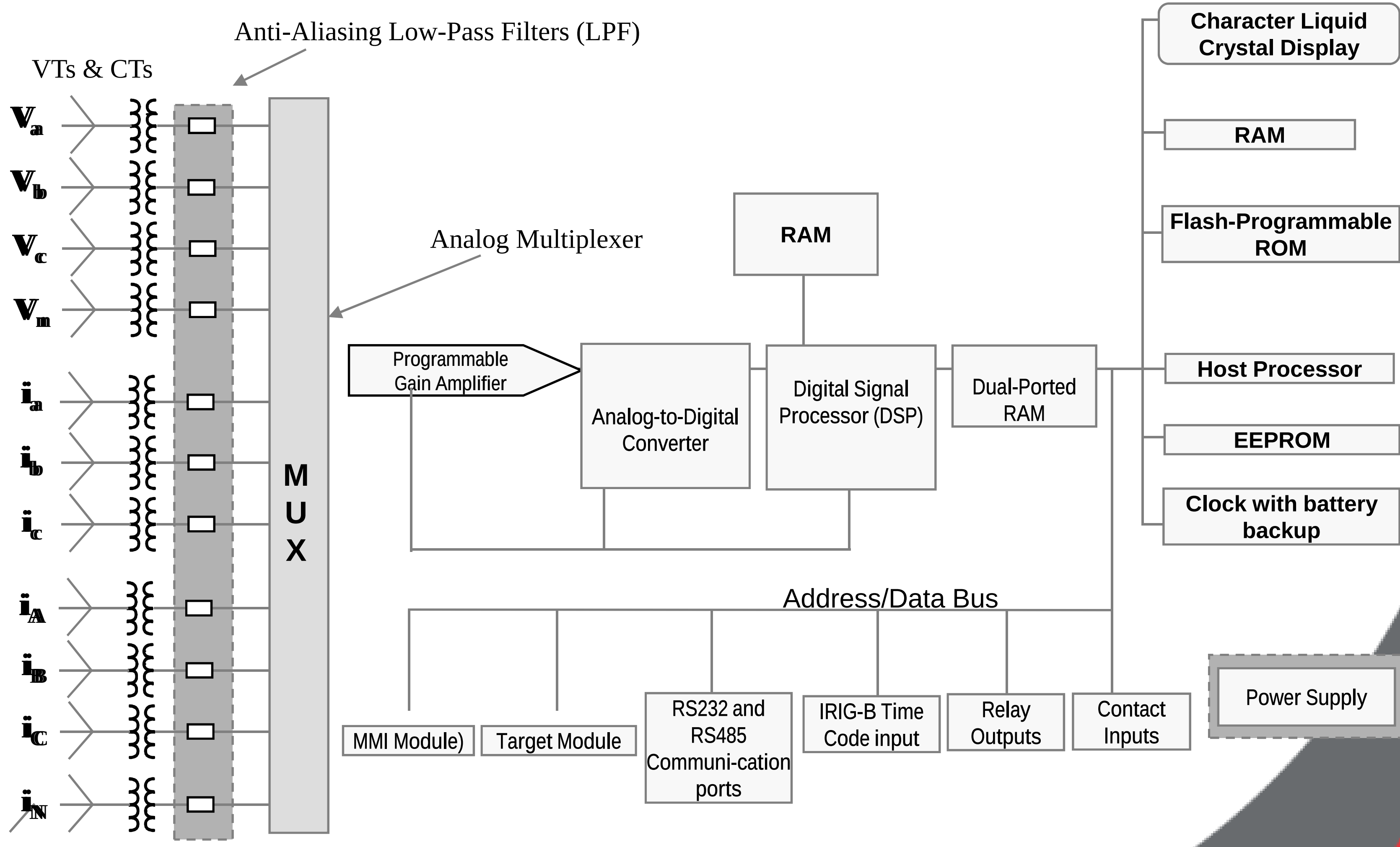
Multifunction Digital Relays

Advantages

- Advance technology: reduced maintenance
- Reduced panel space: more economical, lower price per function, more complete protection on smaller generators
- Flexibility
- Communication capability
- System integration
- Self-diagnostics: reduced maintenance
- Oscillographic capability
- System Integration (Input to DCS Systems)

Hardware Block Diagram



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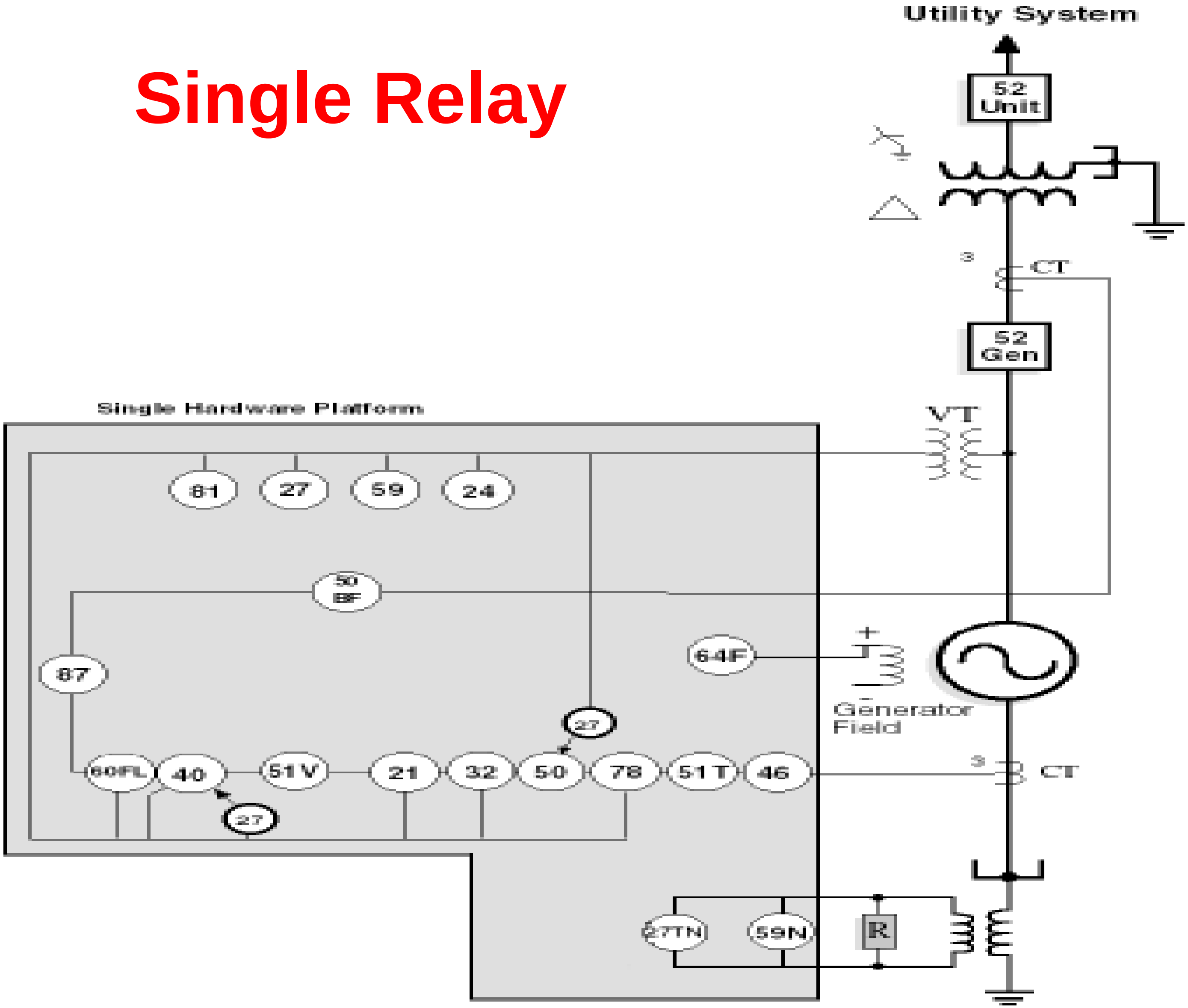
Single Relay

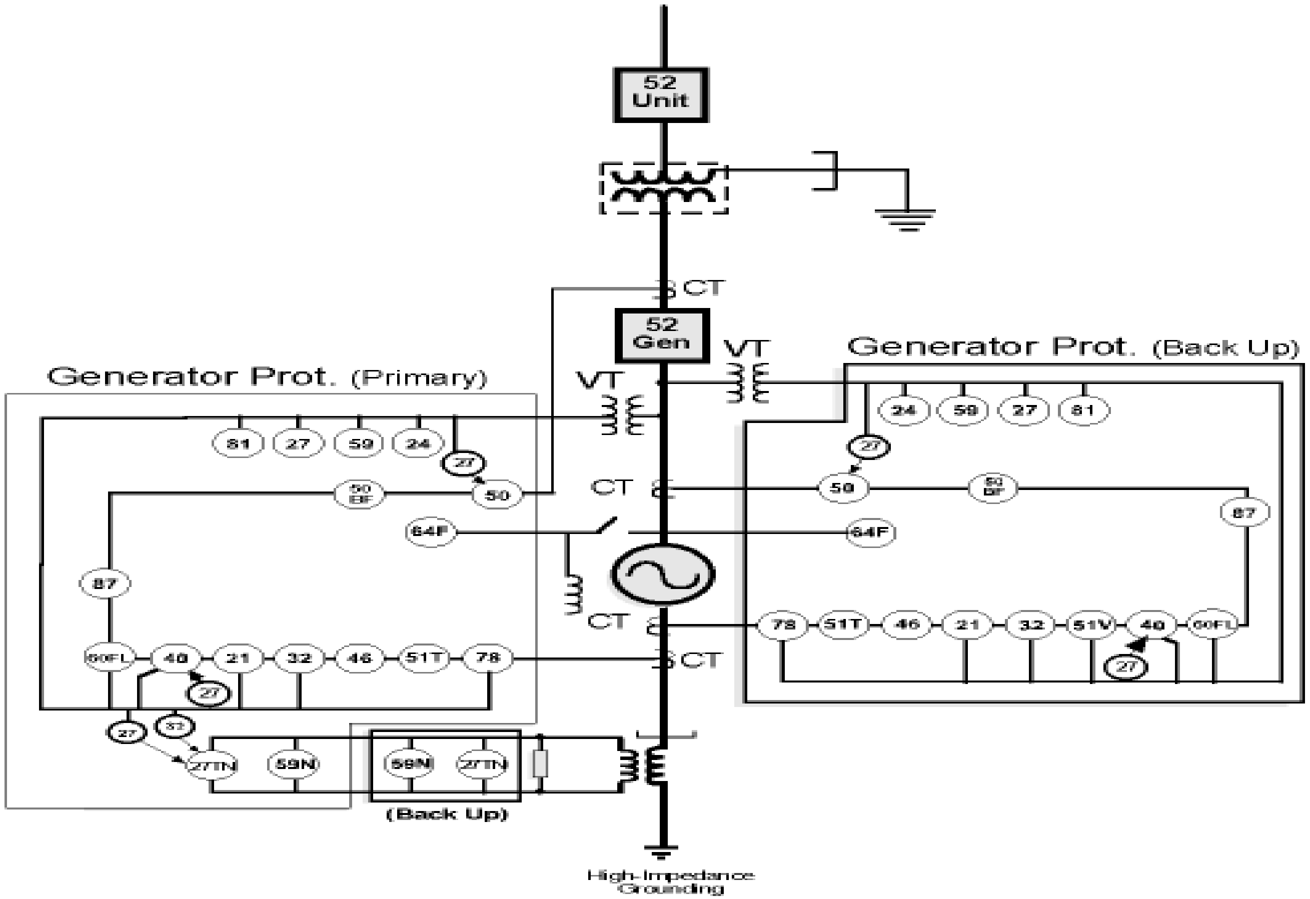


Levels of Redundancy

- **Strategy #1**
  - Use a single multifunction relay
  - If you have a relay failure:
    - Rely on self-test features to detect failure (MTBF Typically 100 years)
    - Remove generator from service
    - Install spare relay
    - Recommission
    - Return generator to service

- **Cost of Strategy #1**
  - No primary and backup
  - Production loss for generator during off period
  - Moderately sized utility generators (150MW) can result in production losses of over $100,000/day or more.

Dual Relay Approach



Levels of Redundancy

- **Strategy #2**
  - Use duel relay approach
  - Have defined primary and backup systems
  - If you have a relay failure:
    - Continue to run the generator
    - Replace the failed relay
    - Recommission
    - Place the new relay in service

- **Cost of Strategy #2**
  - Purchase and installation of a second relay

Level of Redundancy

- Most new generators are gas turbines or steam unit as part of a combined cycle plant
- On these projects - generator protection is “pre-packaged” by generator manufactures
- Standard offering by many generator manufactures is a single multifunction relay package

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Multifunction Generator Protection Application Considerations

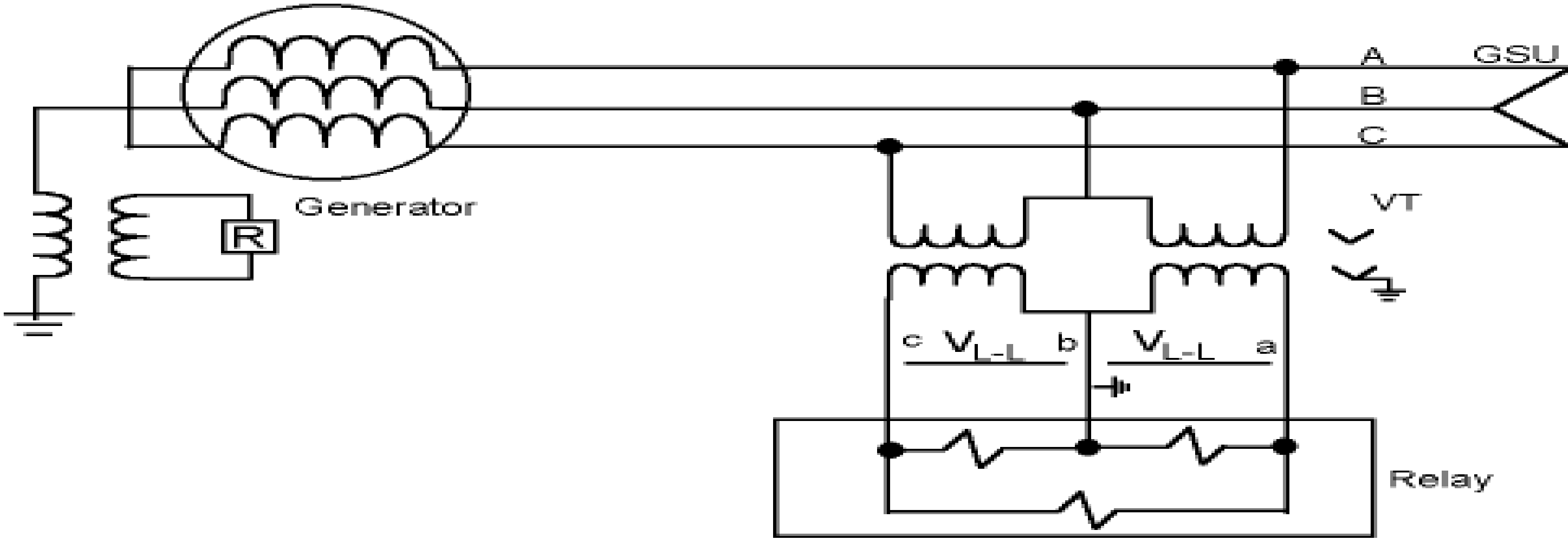
Level of Redundancy

- There is no remote backup protection for most generation fault/abnormal operation consideration
- Utilities need to be aware that if more redundancy is desired - they need to ask for it before generator is ordered

Generator VT Connections

- These major VT generator connections are widely used
  - line to line voltage
  - line to ground
    - 4-wire
    - 3-wire
  - line to ground VT connections have unique application considerations

Line to Line VT's



- Common open delta VT connection
- Relay VT inputs connected line to line

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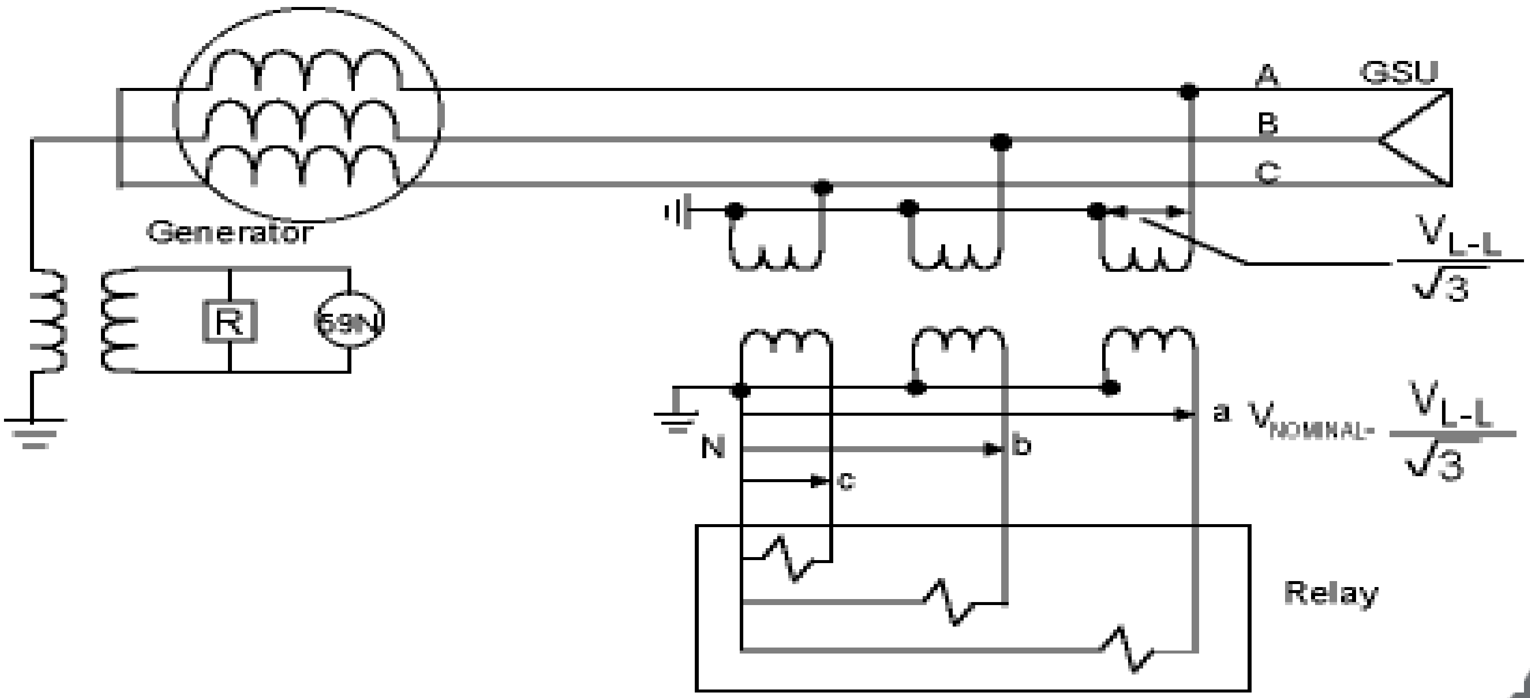
Line to Ground VT's

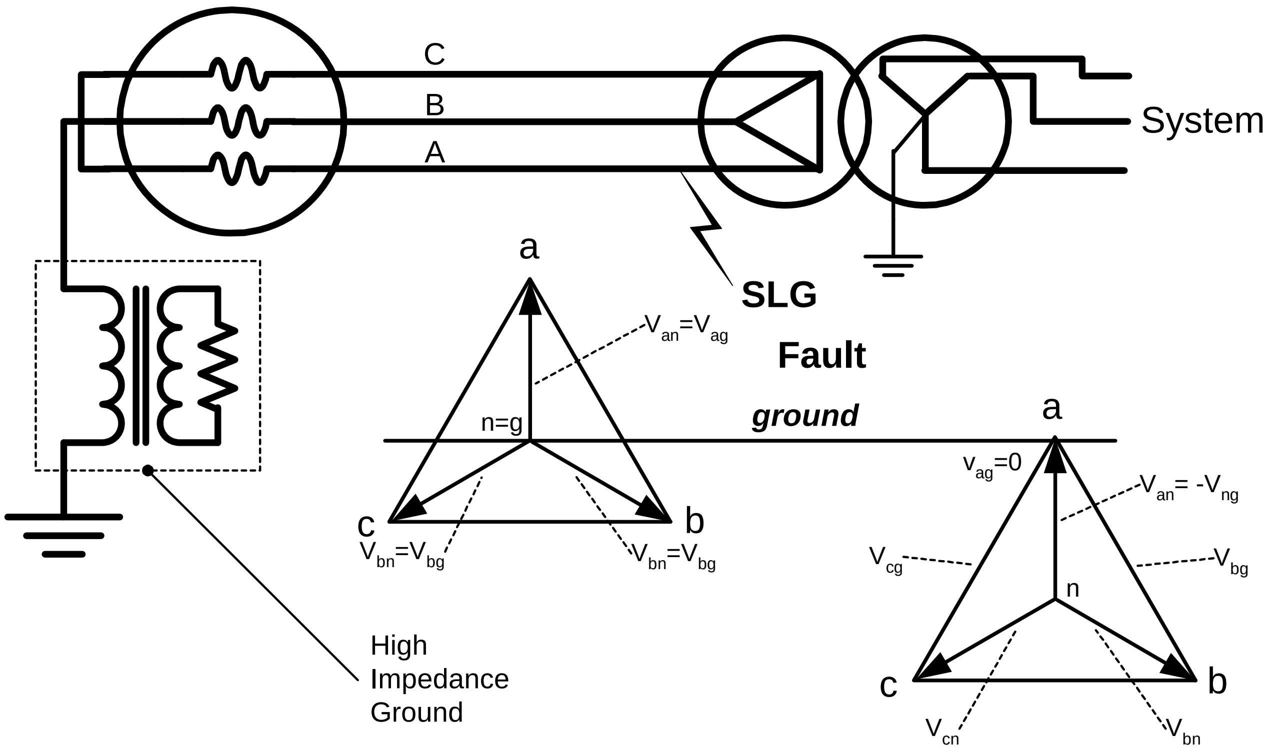
4 Wire Connection



- Relay VT input connected line to ground

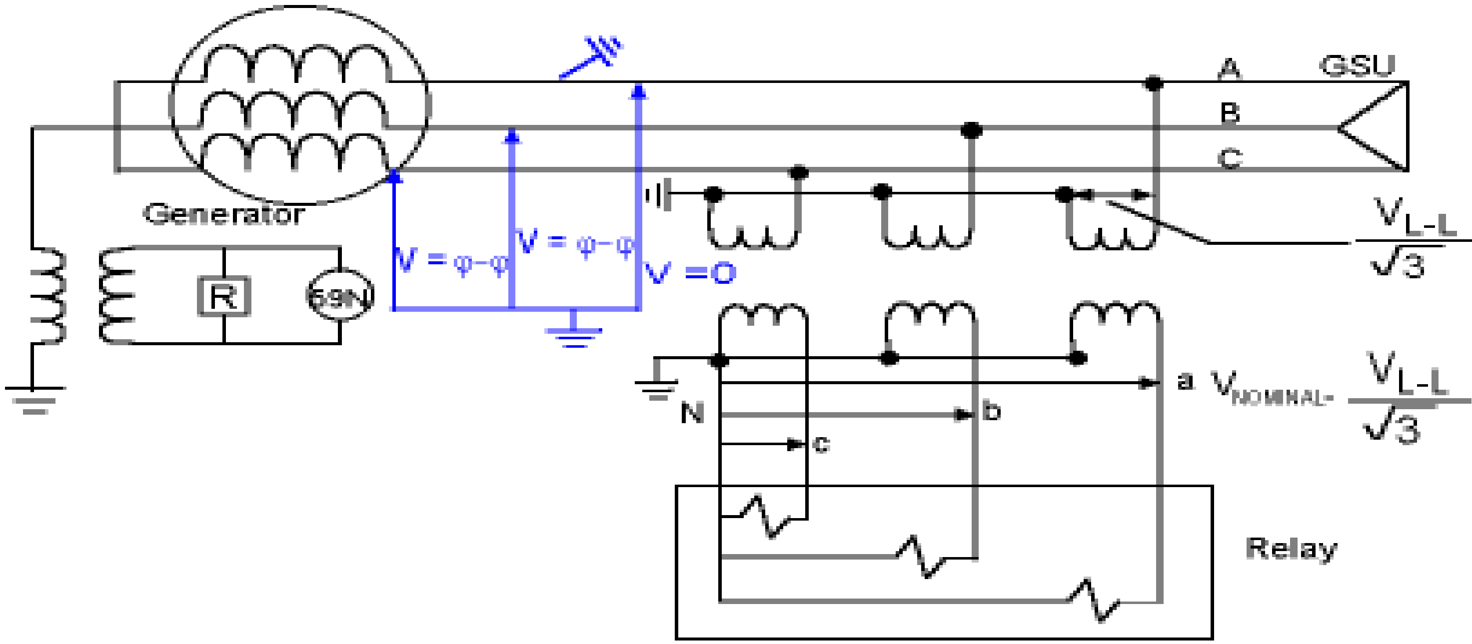
Neutral Shift on Ground Fault:

High Impedance Grounded Generator



- **A ground fault will cause LG connected phase elements through a 3Y-3Y VT to have undervoltage or overvoltage (depending on faulted phase)**

Line to Ground VT's



- Relay VT input connected line to ground
- For stator ground fault neutral shift can result in false indication of overvoltage/overexcitation
- Ideal solution is to supply voltage functions with phase to phase
- If oscillograph monitors L-G voltage, it can be used to phase identify a stator and fault.

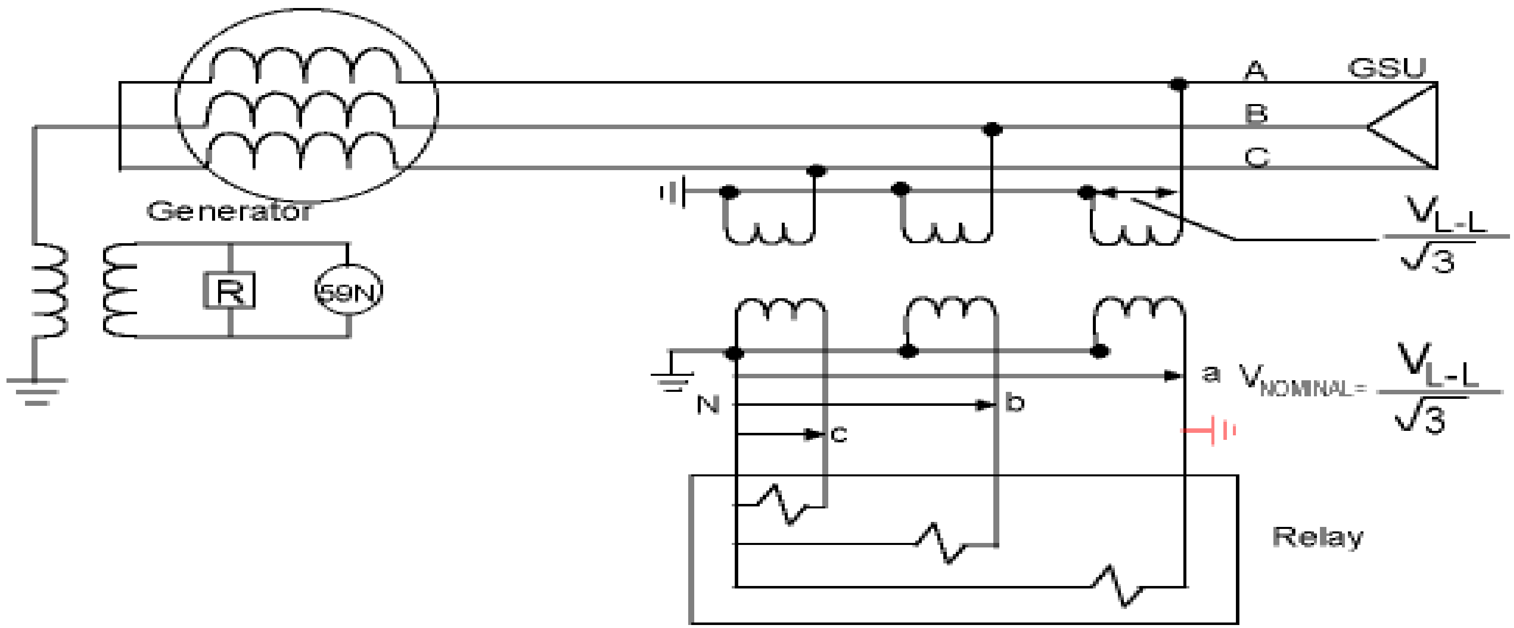
Voltage Inputs

3Y-3Y VT, secondary wired L-G (L-G to L-L selection)

Use of L-L Quantities for Phase Voltage-based elements

- **The "Line-Ground to Line-Line" selection should be used when it is desired to provide the phase voltage-based elements (27, 59, 24 functions) with phase-to-phase voltages**
- **They will not operate for neutral shifts that can occur during stator ground faults on high impedance grounded generators**
- **The oscillograph in the relays will record line-ground voltage to provide stator ground fault phase identification**

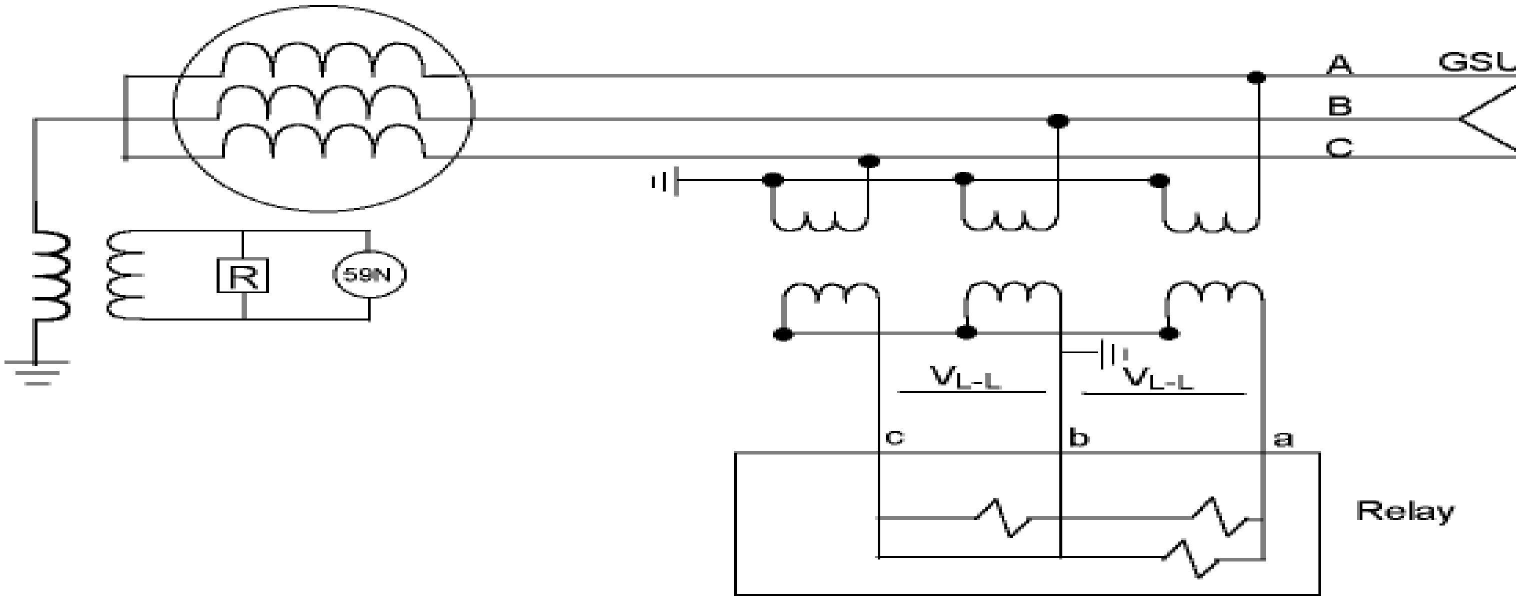
Line to Ground VT's



- Relay VT input connected line to ground
- For stator ground fault neutral shift can result in false indication of overvoltage/overexcitation
- Ideal solution is to supply voltage functions with phase to phase
- If oscillograph monitors L-G voltage, it can be used to phase identify a stator and fault
- Need to coordinate 59N relay with VT secondary fuses to avoid unit trip for a VT secondary ground fault

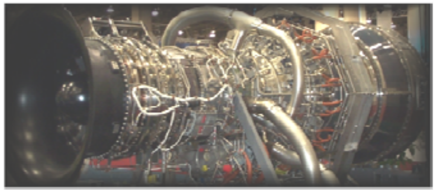
Line to Ground

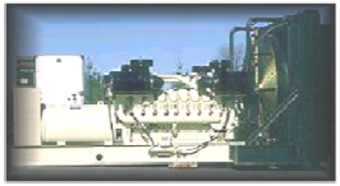
3 Wire Connection



- Relay VT inputs connected line to line
- This VT connection avoids the need to coordinate 59N with VT fusing
- Can not phase identify stator ground faults

WSU Hands- On Generator Protection Track Overview





THE END

????QUESTION ????