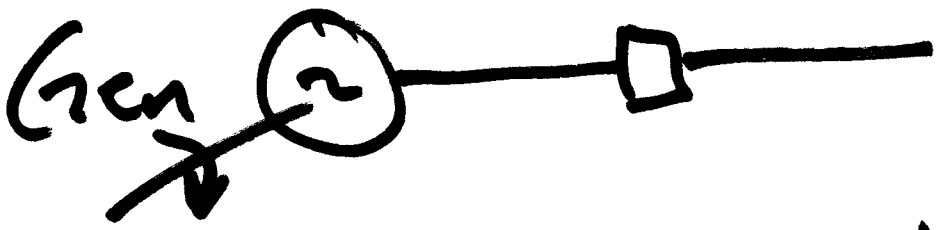
EE 5223 - Lecture 38 Wed April 12, 2023

Ongoing List of Topics:

- URL: https://pages.mtu.edu/~bamork/EE5223/index.htm
- Term Project - Follow timeline, see posting on web page
- Homework - will e-mail details for remainder of semester.
- Final presentations: Mon of Finals week. Volunteers for 5-6 projects to present.
- Gen Protection - Ch. 8, Basic Protection issues
  - IEEE Publication 95TP102 - Prot of Synch Gens
  - IEEE C37.102 - Guide for AC Generator Protection
  - IEEE C37.101, C37.106 - Ground Protection, Abnormal Freq Protection
  - Out-of-step issues
  - Kundur Text, see in text book listing.
- Next: Motor Protection, Real-time Communications

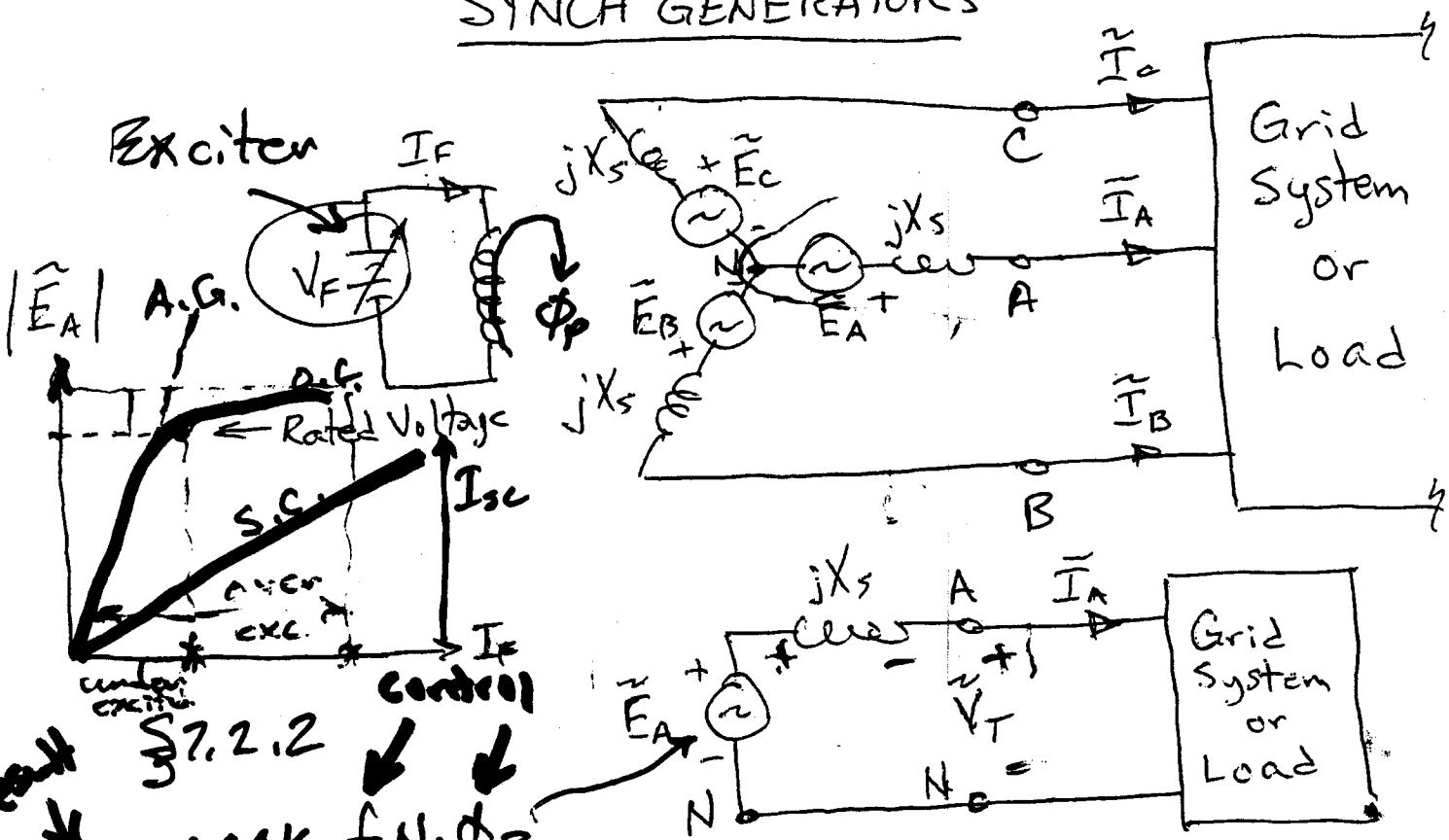
Generators

- Large Synch Machines
  - Steam - cylindrical (also gas turb)
  - Hydro - salient pole
- Wind Gen
  - Ind Mach
    - Squirrel Cage) Full Con verter
    - Wound Rotor
    - DFIG

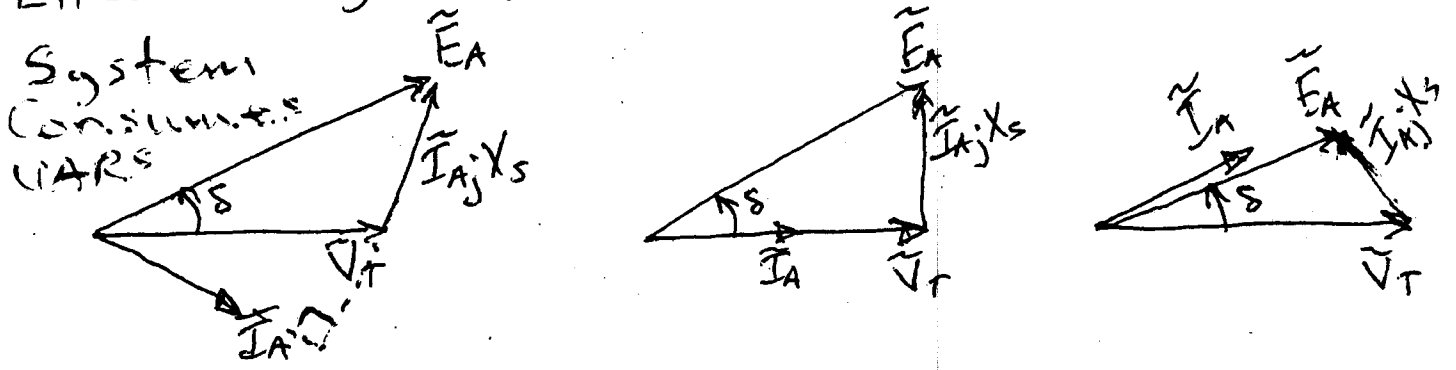


1) Frequency (a bit above 60 Hz)
2) Voltage mag
3) Phase Angle
4) Phase sequence (1st time)

SYNCH GENERATORS



Effect of System (or load) Power Factor:



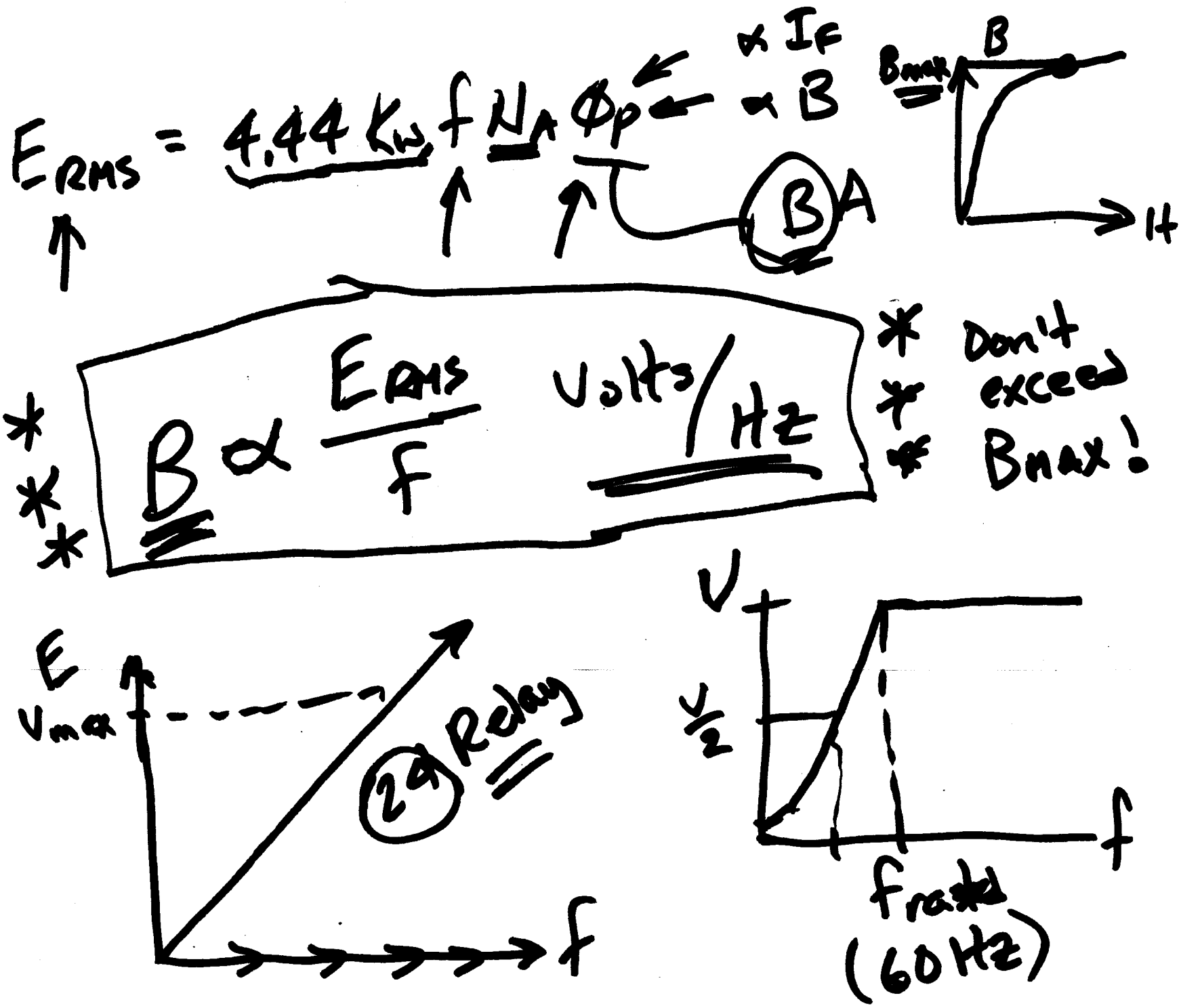
LAGGING

Over-excited
($|\tilde{E}_A|$ is > rated voltage)

UNITY

LEADING

Under-Excited
($|\tilde{E}_A|$ < rated voltage.


$E_{RMS} = 4.44 K_w f N_A \Phi_p$
$\propto I_F$
$\propto B$
B
B_{max}
H
BA
$B \propto \frac{E_{RMS}}{f}$
Volts/Hz
* Don't exceed B_{max}!
E_{max}
29 Relay
f
V_t
V_2
f_{rated}
(60 Hz)

SEL-300G Generator Relay

Protect, Monitor, and Control Your Generator

Apply the SEL-300G for comprehensive protection and control of small, medium, and large generators.

Features and Benefits

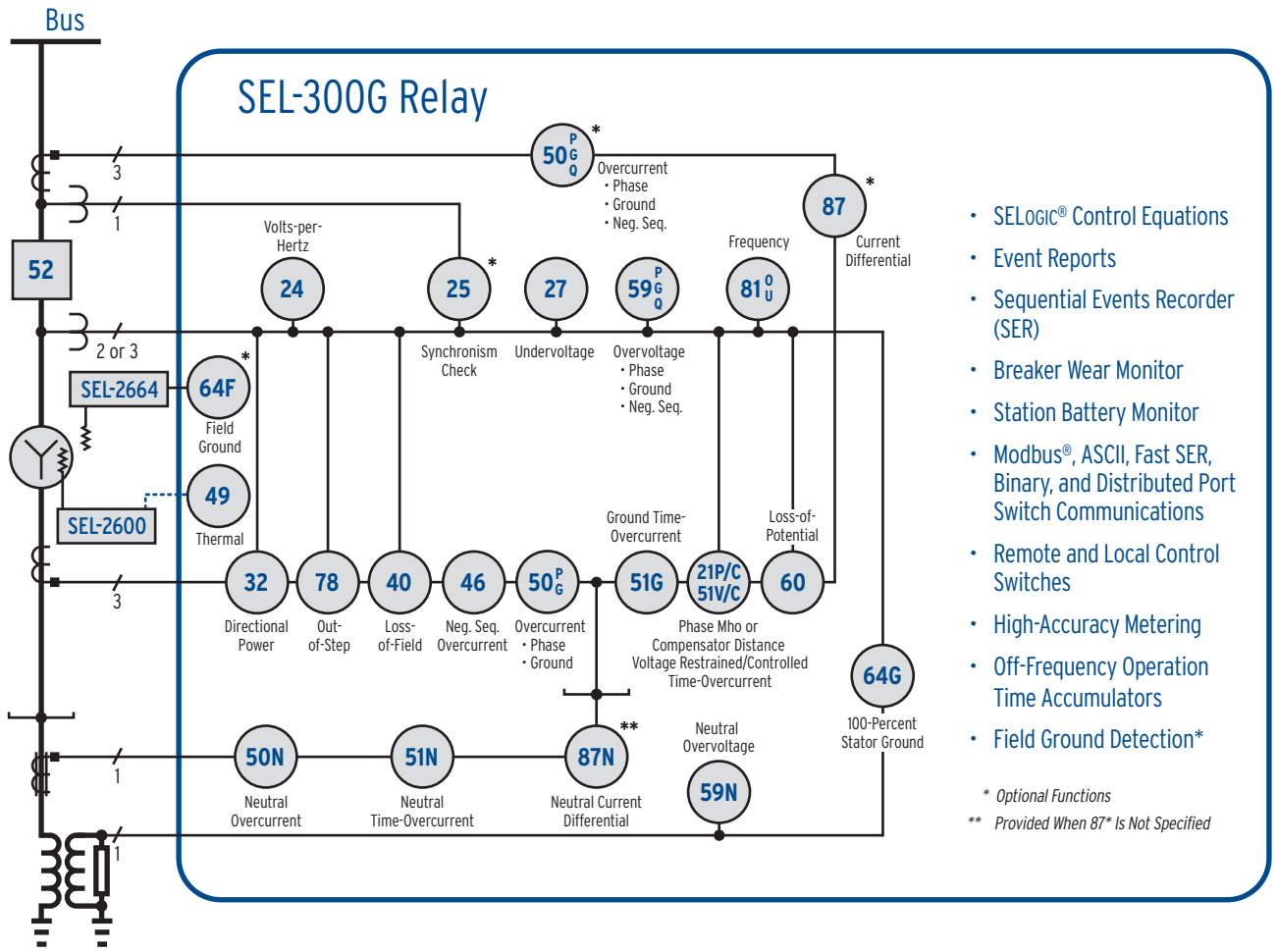
- **Limit Equipment Damage**
  Apply complete phase and neutral protection together with 100-percent stator ground fault detection. Specify optional unit differential and thermal monitoring for important machines. Use out-of-step, loss-of-excitation, overexcitation, frequency, and directional power elements for detection of abnormal operating conditions. Accurately detect generator field grounds. Make settings and check connections with ACSELERATOR® QuickSet™ SEL-5030 Software. Specify the optional synchronism check function for supervision of paralleling operations.

- **Increase Generator Availability**
  Simplify fault and system disturbance analysis with oscillographic event reports and a Sequential Events Recorder (SER). Monitor real-time and accumulated off-nominal frequency, run-time hours, full-load hours, and other important quantities. Minimize separate metering devices by using voltage, current, power, power factor, and energy metering capabilities. Monitor up to 12 machine temperatures using the SEL-2600 Series RTD Modules.

- **Provide Secure Remote Control and Monitoring**
  Use Modbus®, ASCII communications, and SEL Fast SER capabilities for control, monitoring, and alarm purposes. Control relay operation and initiate or block automation sequences from remote or local control systems using serial port commands.

Making Electric Power Safer, More Reliable, and More Economical®

Functional Overview



- SELOGIC® Control Equations
- Event Reports
- Sequential Events Recorder (SER)
- Breaker Wear Monitor
- Station Battery Monitor
- Modbus®, ASCII, Fast SER, Binary, and Distributed Port Switch Communications
- Remote and Local Control Switches
- High-Accuracy Metering
- Off-Frequency Operation Time Accumulators
- Field Ground Detection*

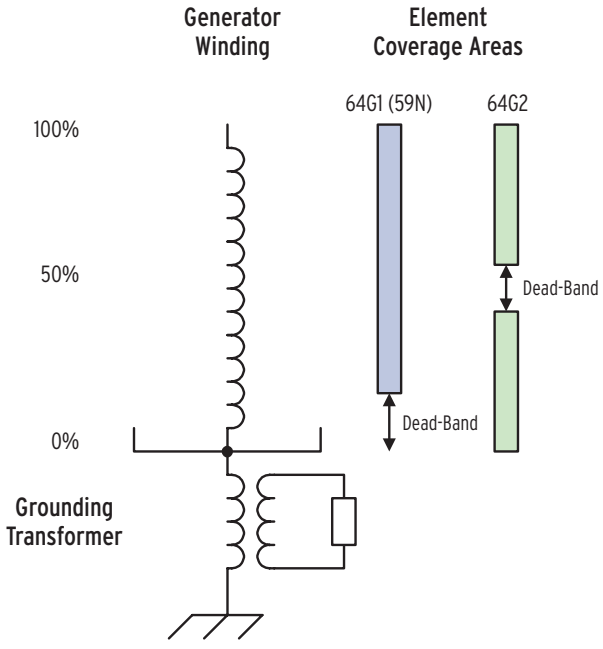
* *Optional Functions*

** *Provided When 87* Is Not Specified*

Complete Generator Fault Protection

Limit equipment damage and speed repairs with high-speed protection for all types of phase and ground faults. Current and voltage elements, combined with optional differential protection, make the SEL-300G suitable for all generator sizes and configurations.

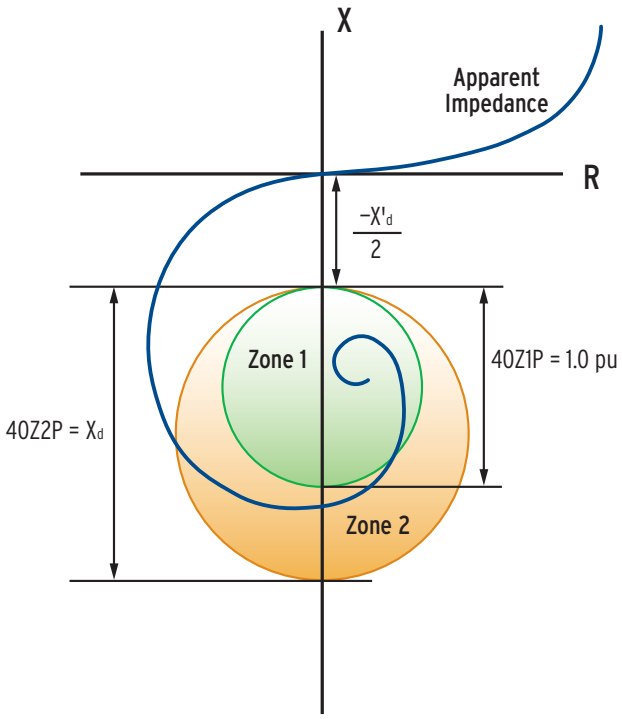
- Current and voltage elements protect large and small machines against damaging faults.
- Optional differential protection provides sensitive and fast protection for generators and unit transformers. Harmonic blocking provides security when transformers are in the generator differential zone.
- 100-percent stator ground fault protection uses fundamental and third-harmonic voltage signals.
- Continuously measure field-to-ground resistance using the SEL-2664 Field Ground Module. Accurately detect field ground faults whether the generator is operating, stopped, or de-energized.



100-percent stator ground fault protection.

Complete Generator Fault Protection (cont.)

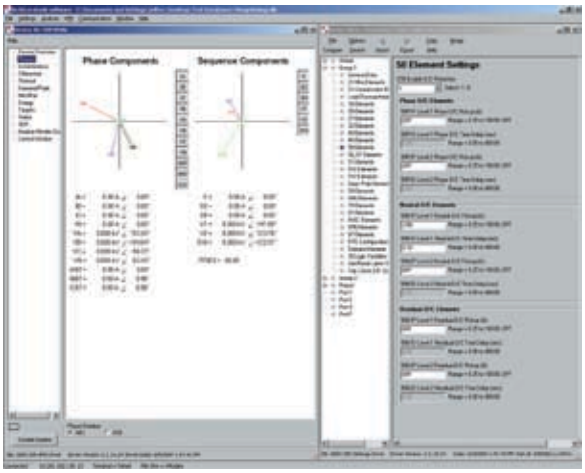
- Dual-element loss-of-field protection prevents rotor heating and system instability from abnormally low excitation.



Dual-element loss-of-field operating characteristic, negative Zone 2 offset.

Simplified Setup and Troubleshooting

- Use ACSELERATOR QuickSet to customize your generator protection. Set and edit relay configuration, settings, and logic.
- View the HMI screens in ACSELERATOR QuickSet to check wiring polarity and connections.



ACSELERATOR QuickSet HMI simplifies configuration and troubleshooting.

Event Analysis, Recording, and Alarming

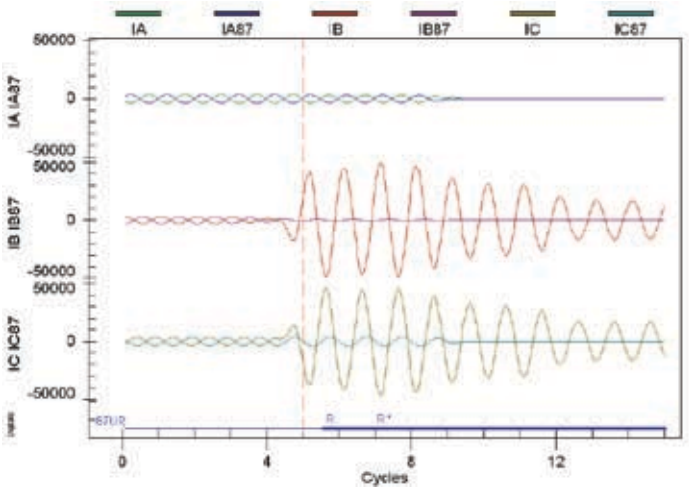
Speed repair and troubleshooting to reduce costs and get units back online. Identify root cause for emergency and triggered shutdown of generators and prime movers using detailed event reports. Program recordings of voltage and current waveforms with internal relay and external monitor points for an accurate record of operations and events.

- Improve operation analysis with a timed record of the last 512 operations of 96 different internal and external events.
- Use the built-in SER to verify startup and shutdown sequencing, routine and emergency operations, and timing of alarms.

```
GENERATOR        Date: 01/20/01        Time: 10:07:10.890
TERMINAL
FID=SEL-300G-X113V00H425XX4X-D980119          CID=88A9
#     DATE       TIME            ELEMENT            STATE
11    01/20/01   09:09:58.826    51N                Deasserted
10    01/20/01   09:09:58.826    50N1T              Deasserted
9     01/20/01   09:09:58.826    50N1               Deasserted
8     01/20/01   09:09:58.826    FAULT _ TRIP       RESET
7     01/20/01   09:09:58.826    FIELD _ BKR        OPENED
6     01/20/01   09:09:58.830    64G1               Deasserted
5     01/20/01   09:09:58.876    86 _ TRIP          RESET
4     01/20/01   09:09:58.876    PRIME _ MVR _ TR   RESET
3     01/20/01   09:09:58.876    FIELD _ BKR _ TR   RESET
2     01/20/01   09:09:58.876    GEN _ MAIN _ TR    RESET
1     01/20/01   09:10:00.828    INAV _ ENR _ SCHM  ARMED
```

Log important user-defined system activities using the SER.

- Receive instant alarm messages triggered by selectable relay events using SEL Fast SER messaging.
- Use the ACSELERATOR QuickSet Software Event Viewer or the more advanced ACSELERATOR Analytic Assistant SEL-5601 Software to clearly view and understand system faults. To aid in analysis, records can be up to 180 cycles long.



Using ACSELERATOR Analytic Assistant, clearly view and understand system faults like this phase-to-phase fault captured by the SEL-300G.

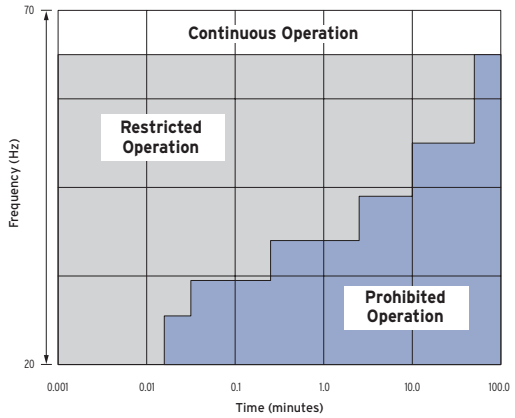
SEL-300G Generator Relay

System Backup Protection

- Use phase mho or compensator distance elements for secure system protection with stable reach looking through a delta-wye transformer.
- Apply voltage-restrained or voltage-controlled overcurrent relaying for reliable system fault response.

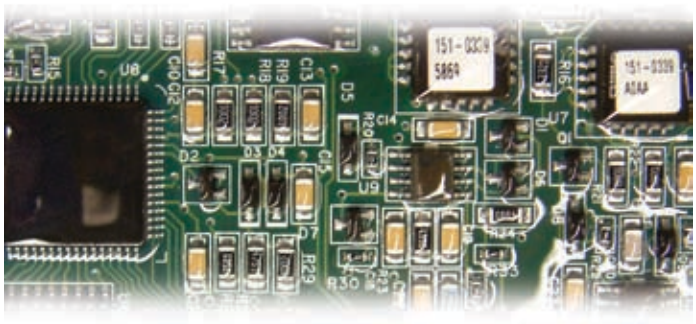
Abnormal Operation Protection

- Use the SEL-300G to measure and store accumulated off-nominal frequency data for proactive maintenance operations.
- Protect against damage from inadvertent energization. The SEL-300G instruction manual provides complete SELOGIC® control equation settings to activate protection when the generator is offline.



Prevent vibration or damage with flexible alarms for off-nominal frequency.

Conformal Coating



Make the world's most reliable relays even tougher. Add an extra level of protection to printed circuit boards with optional conformal coating.

General Specifications

AC Voltage Input

80–208 V_{L-L} nominal for four-wire wye voltage input

80–140 V_{L-L} nominal for three-wire delta voltage input

300 V_{L-N} continuous limit for three-phase, four-wire wye connection

300 V_{L-L} continuous limit for three-phase, three-wire delta connection

365 Vac for 10 seconds

300 V continuous, V_{N-NN} neutral voltage input

300 V continuous, V_{S-NS} synch voltage input

Burden 0.13 VA @ 67 V; 0.45 VA @ 120 V; 0.80 VA @ 300 V

Power Supply Ratings

125/250 V 85–350 Vdc or 85–264 Vac

48/125 V 38–200 Vdc or 85–140 Vac

24/48 V 18–60 Vdc

25 W maximum for all supplies

AC Current Inputs

5 A nominal

15 A continuous, 500 A for 1 second, linear to 100 A symmetrical, 1250 A for 1 cycle

Burden 0.27 VA @ 5 A; 2.51 VA @ 15 A

1 A nominal

3 A continuous, 100 A for 1 second, linear to 20 A symmetrical, 250 A for 1 cycle

Burden 0.13 VA @ 1 A; 1.31 VA @ 3 A

Standard Control Input and Output Ranges

24, 48, 110, 125, or 250 Vdc

Standard configuration provides 6 inputs and 8 outputs, <5 ms pickup, <8 ms typical dropout time, 30 A make, 6 A continuous duty

Additional interface I/O board may be selected with standard inputs and high-current interrupting outputs

Operating Temperature

–40° to +85°C (–40° to +185°F)

(Note: LCD contrast impaired for temperatures below –20°C)

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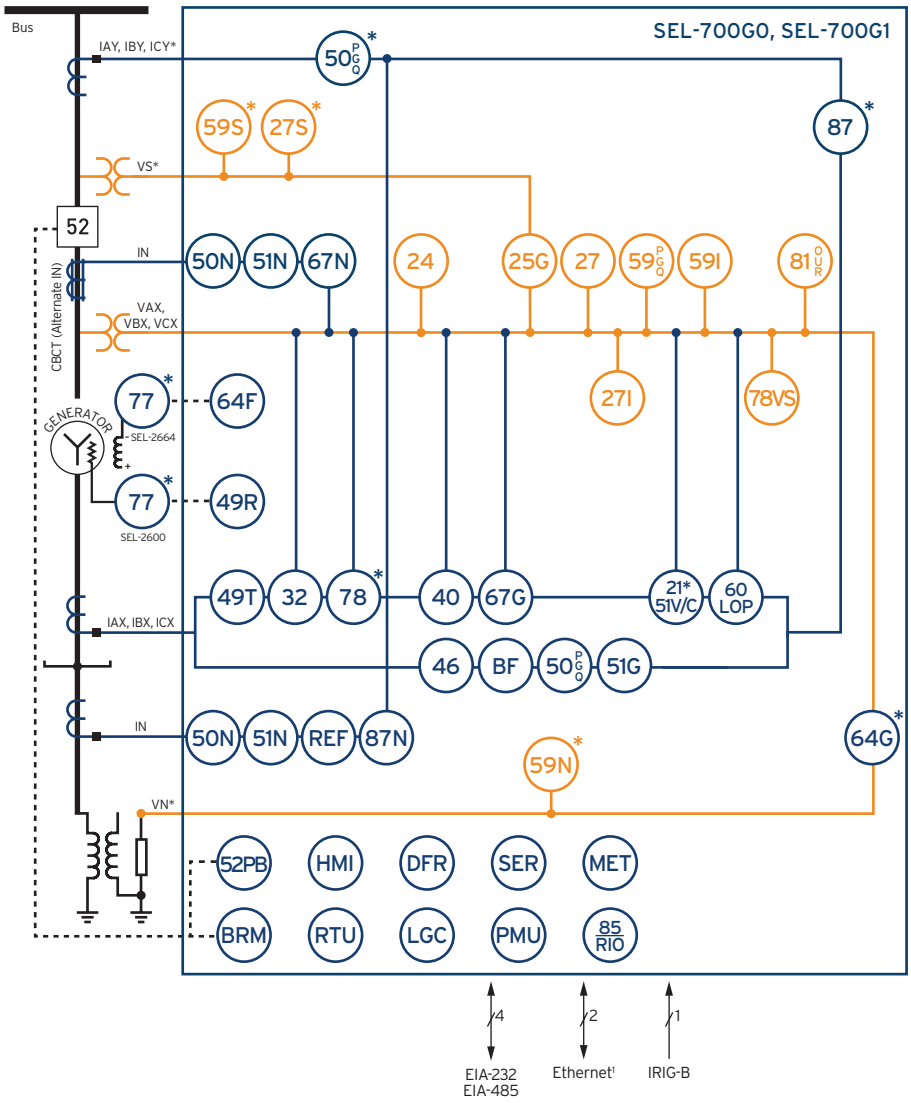
SEL-700G

Generator Protection Relay

Comprehensive protection for large, medium, and small generators

- Provide primary and backup generator protection with current, voltage, frequency, distance, power, and out-of-step elements.
- Achieve 100 percent stator ground detection with full winding coverage.
- Use the automatic synchronizer and event reports to analyze generator startup, shutdown, or system faults.
- Quickly configure, monitor, and control your system using the new touchscreen display.

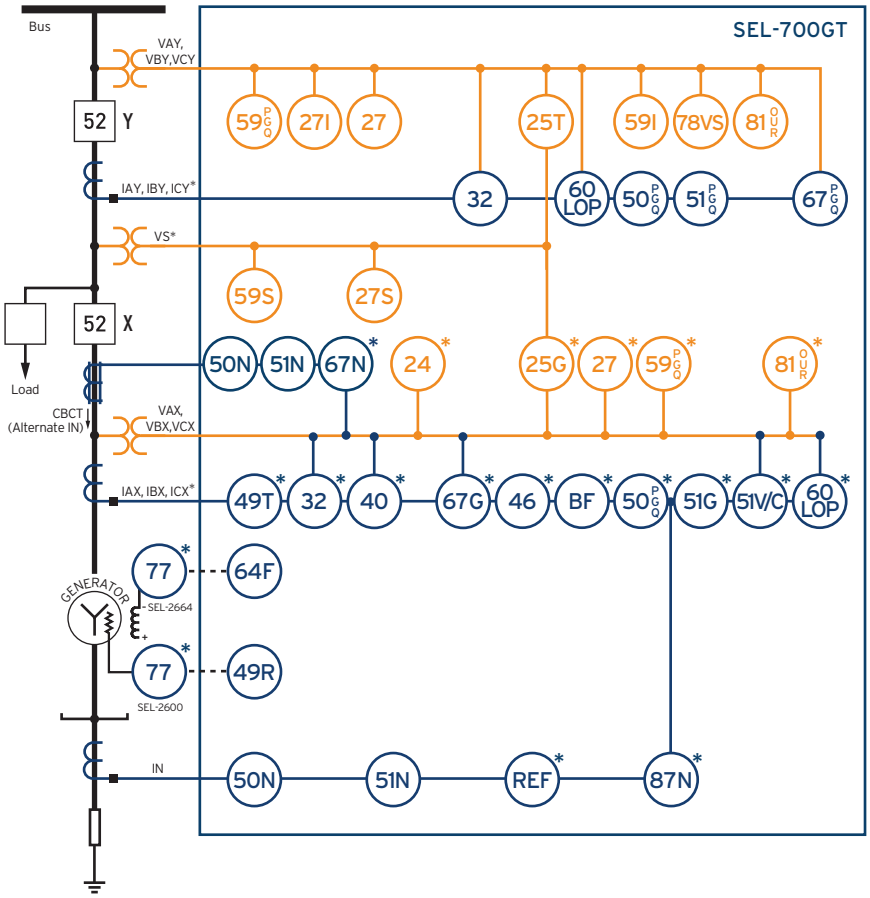
Functional Overview

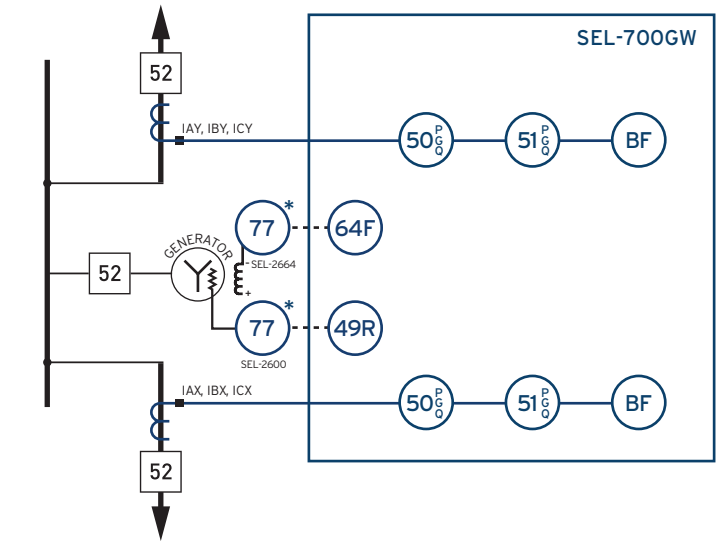


Model Comparison Table

You can customize the SEL-700G for specific applications by selecting preconfigured model options.

Model	Application
SEL-700G0 or SEL-700G0+	Basic generator protection
SEL-700G1 or SEL-700G1+	Full generator protection
SEL-700GT	Intertie protection
SEL-700GT+	Intertie and generator protection
SEL-700GW	Basic dual-feeder protection





ANSI Numbers/Acronyms and Functions	
21C/51VC	Compensator Distance, Voltage Restrained/ Controlled Time-Overcurrent
24	Volts/Hertz
25G	Synchronism Check
27	Undervoltage
27I	Inverse-Time Undervoltage
27S	Synchronism Undervoltage
32	Directional Power
40	Loss-of-Field
46	Current Unbalance
49R	Thermal Overload (Resistance Temperature Detector [RTD])
49T	Thermal Model
50N	Neutral Overcurrent
50 (P,G,Q)	Overcurrent (Phase, Ground, Neg. Seq.)
51 (P,G,Q)	Time-Overcurrent (Phase, Ground, Neg. Seq.)
51N	Neutral Time Overcurrent
59I	Inverse Time Overvoltage
59N (64G1)	Neutral Overvoltage
59S	Synchronism Overvoltage
59 (P,G,Q)	Overvoltage (Phase, Ground, Neg. Seq.)
60	Loss-of-Potential
64F	Field Ground
64G	100% Stator Ground
67 (P,G,Q)	Directional Overcurrent (Phase, Ground, Neg. Seq.)
67N	Directional Neutral Overcurrent
78	Out-of-Step
78VS	Vector Shift
81 (O,U,R)	Frequency (Over, Under, Rate)
87	Three-Phase Current Differential
87N	Neutral Current Differential
REF	Restricted Earth Fault
Additional Functions	
52PB	Pushbutton Trip/Close
85 RIO	SEL Mirrored Bits® Communications
BF	Breaker Failure
BRM	Breaker Wear Monitor
DFR	Event Reports
ENV	SEL-2600
HMI	Operator Interface
LDP	Load Data Profiling
LGC	SELogic® Control Equations
MET	High-Accuracy Metering
PMU	Synchrophasors
SER	Sequential Events Recorder (SER)
RTU	Remote Terminal Unit

*Optional Feature [1]Copper or Fiber-Optic

Key Features

Comprehensive Generator Protection

Connect the SEL-700G Generator Protection Relay across small, medium, or large generators for complete primary and backup protection. Adding the neutral voltage connection provides 100 percent stator ground protection, based on fundamental-frequency and third-harmonic neutral voltage measurements. Connecting the neutral current input provides protection for solidly grounded or resistance-grounded machines.

Automatic Synchronizer

Replace external generator control and synchronizer relays with the built-in automatic synchronizer function. The SEL-700G automatically synchronizes the frequency, voltage, and phase control of the generator with the power system. Generator start reports and the PC-based synchroscope allow you to monitor the generator synchronization. The built-in automatic synchronizer function is available on select SEL-700G models.

Breaker Wear Monitoring

Record accumulated breaker contact wear with the breaker monitor function, which uses the breaker manufacturer's specifications for defining operation limits. The internal monitor tracks the total number of close/open operations and integrates the interrupted current per phase. You can set an alarm to alert operators when measured and accumulated quantities approach maintenance thresholds. This information facilitates proactive breaker maintenance and replacement without underutilizing resources.

Easy Communications

Choose from single or dual copper or fiber-optic Ethernet ports, serial communications, and several protocols, including Mirrored Bits communications, IEC 61850 Edition 2, IEC 60870-5-103, and the Parallel Redundancy Protocol (PRP). Multiple Modbus® TCP or Modbus serial sessions are available for custom configuration of your application. You can also use DNP3 serial or DNP3 LAN/WAN protocols.

Current Differential Protection

Apply sensitive percentage-restrained current differential elements and an unrestrained element, along with synchronism-check and volts-per-hertz elements, across the entire unit to protect both the generator and the step-up transformer. Optional current differential elements detect stator faults using a secure, sensitive current differential function. Power transformer and CT connection compensation allows you to include the unit step-up transformer in the generator differential zone.

Synchrophasor Data

Apply SEL synchrophasors (IEEE C37.118) to turn state estimation into state measurement and to provide early warning of potential system instability. The SEL-700G phasor measurement accuracy meets the IEEE C37.118-2005 Level 1 requirement.

Islanding Protection

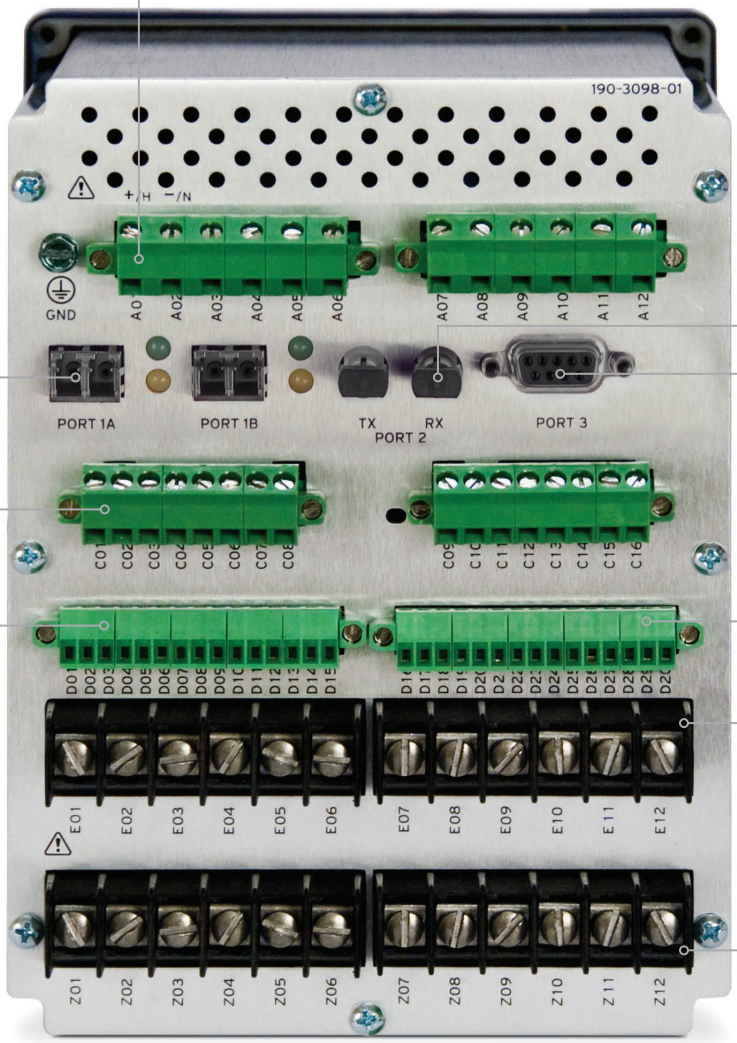
Detect islanding conditions using the vector shift function. The vector shift function provides another element of protection for distributed generators connected to the utility network. It operates within three cycles—fast enough to prevent out-of-synchronization reclosing with the network feeders to avoid generator damage.

Product Overview

Power supply options include 24–48 Vdc or 110–250 Vdc/110–240 Vac.

A wide variety of communications protocols and media provide flexibility to communicate with other devices and control systems.

Positions for optional expansion cards.



Fiber-optic serial port.

Mirrored Bits communications.

Optional RTD inputs.

Voltage and current inputs.

Touchscreen Overview

The 5-inch diagonal color display with a resolution of 800 × 480 offers direct navigation via a capacitive touchscreen.

Full keyboard facilitates easy adjustment of settings.

Folders and applications provide quick access to bay screens, metering and monitoring data, reports, settings, and more.

The home pushbutton allows users to easily return to the default home screen.

Front-panel available in English or Spanish.

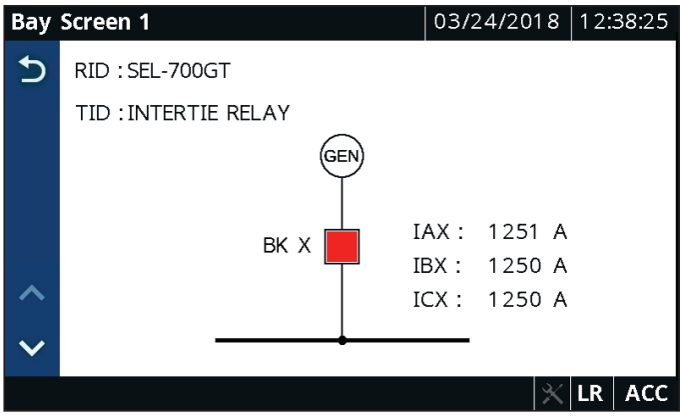
Touchscreen Display Features and Functions

The SEL-700G Relay's 5-inch, 800 × 480 color touchscreen display provides a one-line diagram mimic display for bay control and monitoring. You can view metered quantities, phasor diagrams, relay settings, event summaries, target statuses, and SER data.

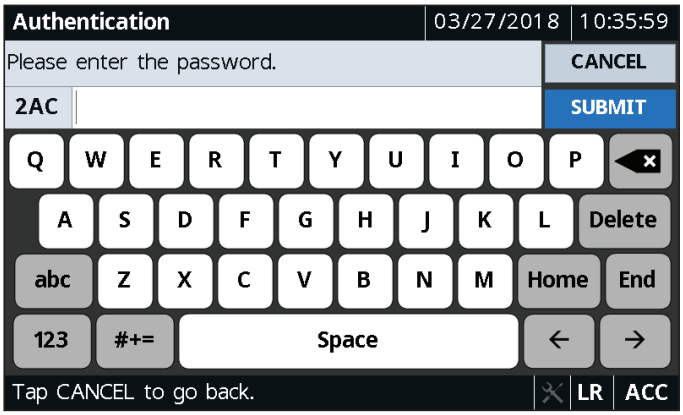
Bay Screens and Bay Control

Select from predefined bay screens, or configure your own bay screens using the ACSELERATOR® Bay Screen Builder SEL-5036 Software and ACSELERATOR QuickSet® SEL-5030 Software. With the bay screen, you can control as many as two breakers, monitor as many as eight disconnect switches, and view analog and digital data in a contextual display.

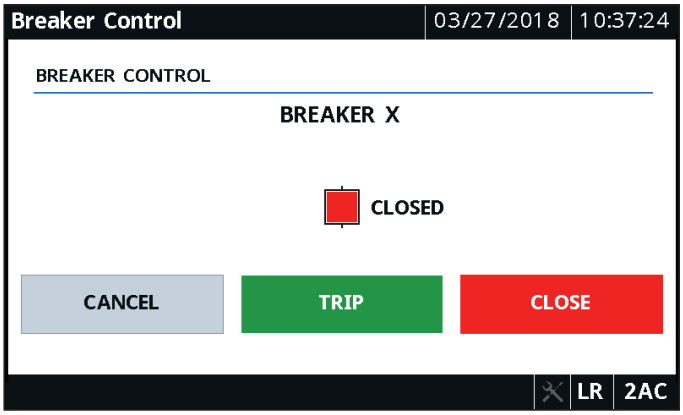
To control a breaker, simply tap the Bay Screens application on the home screen and then the breaker you want to control.



Next, enter your Level 2 password and tap Submit. The onscreen keyboard allows you to quickly and easily enter passwords, search for Relay Word bits, and enter settings whenever necessary.

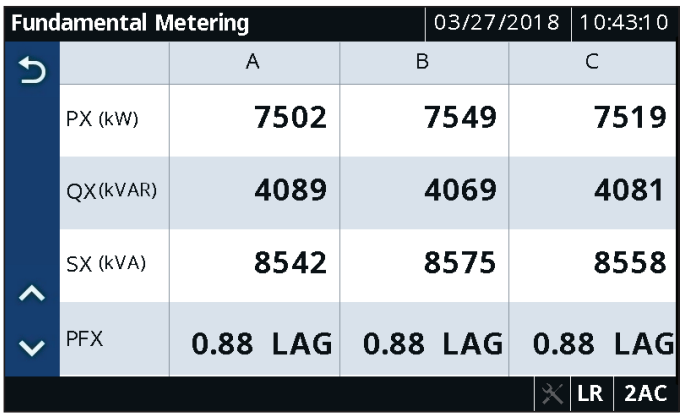


Finally, tap Trip or Close to control the breaker. When asked to confirm the action before the operation is completed, choose Yes or No.



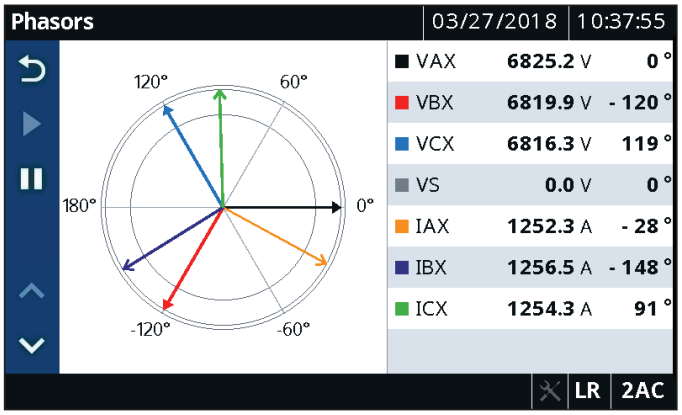
Meter Fundamentals

View the real, reactive, and apparent power of each phase in your system, and monitor the power factor information to determine if the phase current leads or lags the phase voltage.



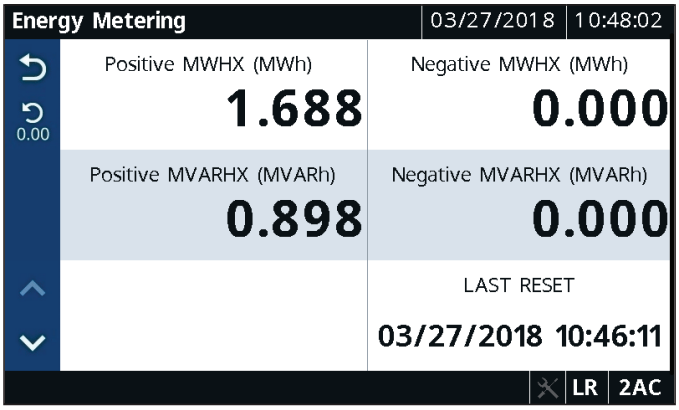
Meter Phasors

View a graphical and textual representation of the real-time voltages and currents in a power system during balanced and unbalanced conditions. By analyzing the phasors, you can determine power system conditions.



Meter Energy

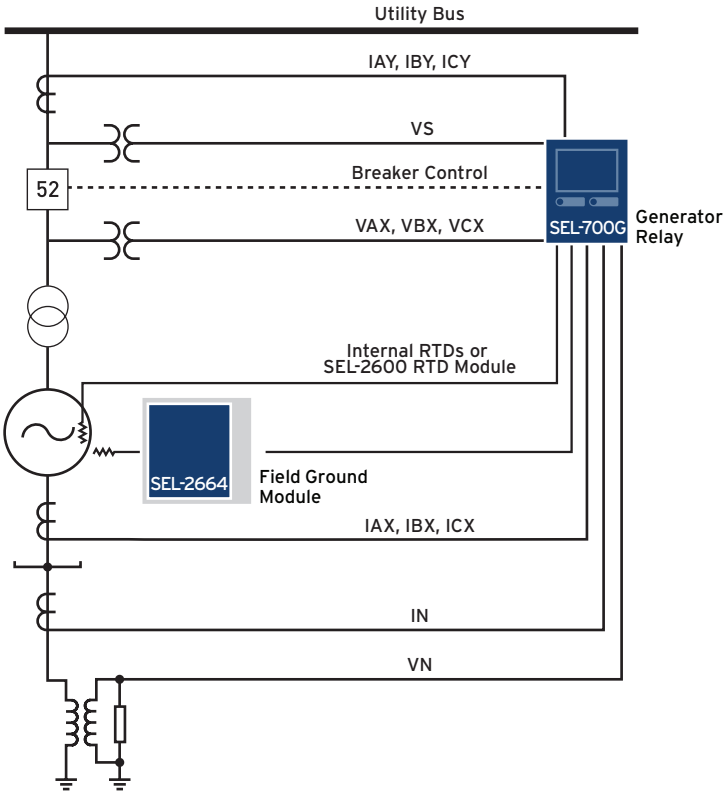
Display the real, reactive, and apparent energy metering quantities imported and exported by your system. You can reset the energy values via the display and record the time and date of reset. The metered quantities accurately account for the power system energy flow, whether your system is a net energy producer or consumer.



Applications

Eliminate the complexity and cost of standalone synchronizer packages. The SEL-700G provides a comprehensive protection and synchronization solution for synchronous generators. Integrating the synchronization capability into the generator protection relay provides the most cost-effective and reliable solution.

The optional SEL-2664 Field Ground Module accurately detects field ground faults whether the generator is operating, stopped, or de-energized.

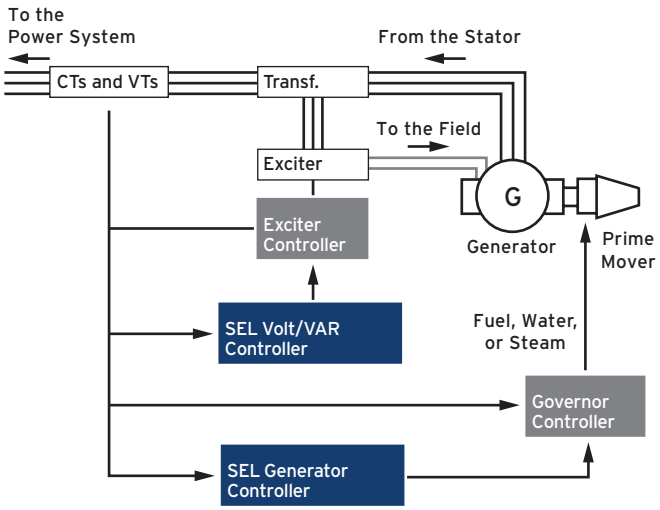


Unit Protection

Apply sensitive percentage-restrained current differential elements and an unrestrained element, along with synchronism-check and volts-per-hertz elements, across the entire unit to protect both the generator and the step-up transformer. Harmonic blocking elements protect the unit transformer bushing and end windings while maintaining security for inrush and through-fault conditions.

Stator/Field Ground Protection

Adding the neutral voltage connection provides 100 percent stator ground protection for most machines, based on fundamental-frequency and third-harmonic neutral-voltage measurements. Connecting the neutral current input provides protection for solidly grounded or resistance-grounded machines. State-of-the-art voltage injection provided by the SEL-2664 Module allows you to monitor field ground insulation resistance. You can protect generators from damage by responding to low field ground insulation resistance warnings.



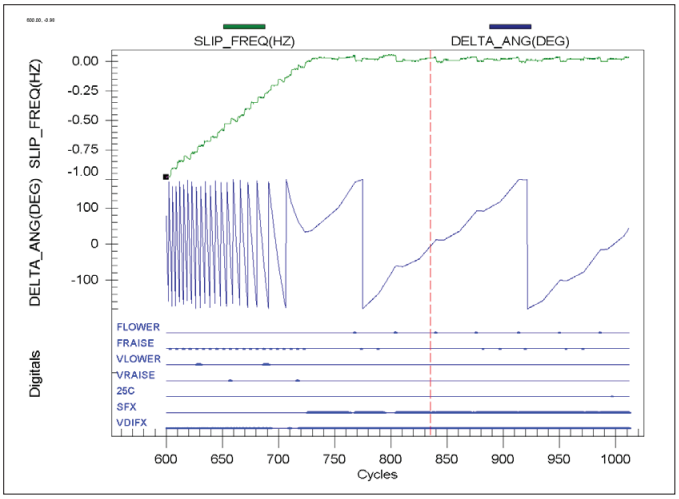
Automatic Generator Control

SEL's generation control system regulates generator power outputs and manages utility interties to maximize system stability, minimize electrical disturbances, and mitigate load-shedding requirements. The SEL-700G in combination with the SEL POWERMAX® Power Management and Control System can balance generation loading, control tie line power flow, and maintain bus voltage.

The automatic MVAR and voltage control system maintains MVAR flows on interties and system bus voltages by controlling load tap changers, generator field and large synchronous motor exciters, synchronous and static condensers, and capacitor banks.

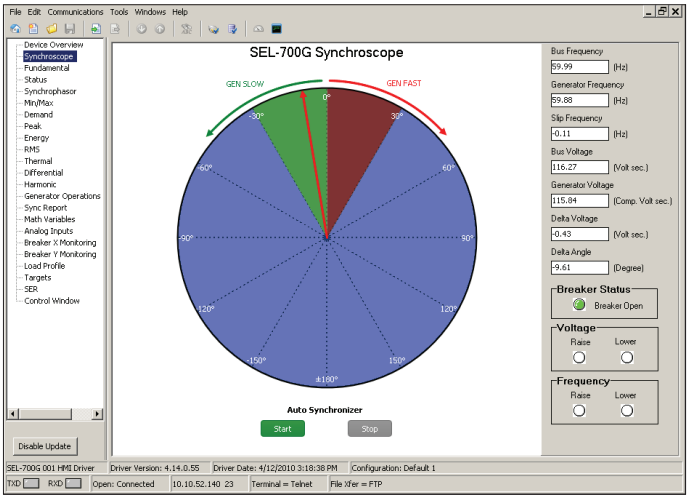
Metering and Reporting

View generator automatic synchronizer, SER, and 180-cycle oscillographic event reports in COMTRADE and CEV formats to analyze generator startup, shutdown, or system faults. The SEL-700G measures electrical, thermal, and generator run-time quantities and allows you to retrieve COMTRADE files via Ethernet FTP or IEC 61850 MMS.



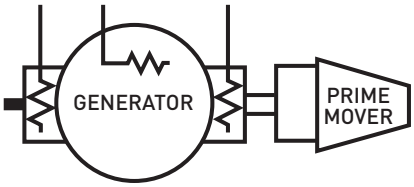
Autosynchronization

Use the additional, built-in automatic synchronizer function to automatically synchronize the frequency, voltage, and phase angle of the generator and connect to the power system. This eliminates the need for expensive external synchronizing equipment.



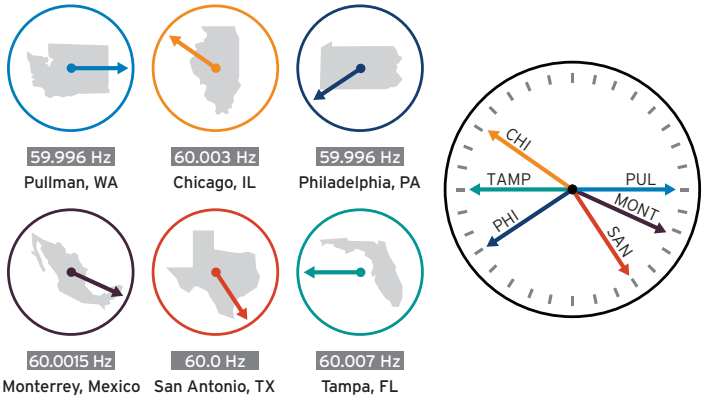
RTD-Based Thermal Protection

Acquire thermal data for alarm, monitoring, and trip functions in the SEL-700G with a 10 RTD input card or an external 12 RTD SEL-2600 RTD Module.



Synchrophasor Measurement

Combine the SEL-700G with an SEL IRIG-B time source to measure the system angle in real time with a timing accuracy of ±10 µs. You can measure instantaneous voltage and current phase angles in real time to improve system operation with synchrophasor information.



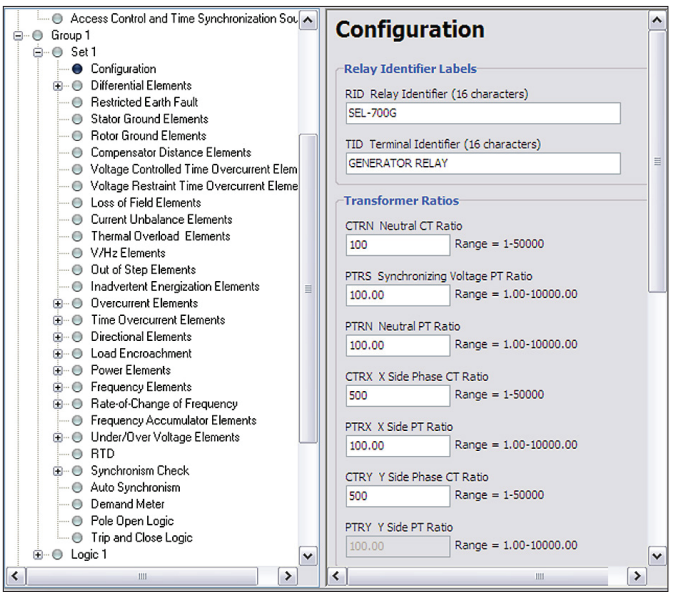
View of system angle at multiple locations.

Easy to Set and Use

Use QuickSet Software to Set, Monitor, and Control the SEL-700G

With QuickSet, you can:

- Communicate with the SEL-700G through any ASCII terminal, or use the QuickSet graphical user interface.
- Develop settings offline with a menu-driven interface and completely documented help screens. You can speed up installation by copying existing settings files and modifying application-specific items.
- Simplify the settings procedure with rules-based architecture to automatically check interrelated settings. Out-of-range or conflicting settings are highlighted for correction.
- Use the ACSELERATOR HMI synchroscope to view the real-time synchronization process.
- Initiate the generator synchronization process using an HMI pushbutton.



Use ACSELERATOR Software to Retrieve and Display Event Reports Recorded by the SEL-700G

With ACSELERATOR software, you can:

- Display event report oscillograms. You can view each report as a plot of magnitude versus time and select analog and digital points to build a custom display.
- Display phase and symmetrical component phasors. Displaying the phasor view of electrical data helps you better understand asymmetrical, three-phase faults. You can build a custom plot using per-phase and symmetrical component sequence currents and voltages.
- Retrieve event reports using serial or Ethernet communications links.

Retrofit Replacement Kits

Easily replace existing generator protection with the SEL-700G and the applicable mounting kit. These kits provide everything needed to replace many existing generator relays with the SEL-700G.

No cutting or drilling is required when you use the optional mounting kits. Replacement of existing protection is quick and easy.

SEL-700G Options

Current and Voltage Input Cards	Model
3 currents, 1 neutral current, 3 voltages (Slot Z)	SEL-700G0
3 currents, 1 neutral current, 3 voltages (Slot Z) and 1 voltage (battery or synchronism check) (Slot E)	SEL-700G0+
3 currents, 1 neutral current, 3 voltages (Slot Z) and 3 currents (Slot E)	SEL-700G1
3 currents, 1 neutral current, 3 voltages (Slot Z) and 3 currents, 1 voltage (battery or synchronism check) (Slot E)	SEL-700G1+
1 neutral current (Slot Z) and 3 currents, 1 voltage (synchronism check), 3 voltages (Slot E)	SEL-700GT
3 currents, 1 neutral current, 3 voltages (Slot Z) and 3 currents, 1 voltage (synchronism check), 3 voltages (Slot E)	SEL-700GT+
3 currents (Slot Z) and 3 voltages (Slot E)	SEL-700GW

Optional Communications and I/O Cards
Serial communications card (EIA-232/-485)
3 digital inputs (DI)/4 digital outputs (DO)/1 4–20 mA analog output (AO)
4 DI/4 DO
8 DO
8 DI
14 DI
4 DI/3 DO (2 Form C, 1 Form B)
4 analog inputs (AI)/4 AO
10 RTD inputs

SEL-700G Specifications

General	
Displays	2-line × 16-character LCD 5-inch color touchscreen display, 800 × 480 pixels
AC Current Inputs	5 A or 1 A phase and 5 A or 1 A neutral
AC Voltage Inputs	300 Vac continuous, 600 Vac for 10 seconds
Output Contacts	The relay supports Form A, B, and C outputs.
Optoisolated Control Inputs	DC/AC control signals: 250, 220, 125, 110, 48, or 24 V As many as 26 inputs are allowed in ambient temperatures of 85°C (185°F) or less. As many as 34 inputs are allowed in ambient temperatures of 75°C (167°F) or less. As many as 44 inputs are allowed in ambient temperatures of 65°C (149°F) or less.
Frequency and Phase Rotation	System frequency: 50, 60 Hz Phase rotation: ABC, ACB Frequency tracking: 15—70 Hz (requires ac voltage inputs)
Autosynchronizing	Frequency matching: ±0.1% plus ±4.2 ms at 60 Hz Voltage matching: VAY, VBY, VCY, VABY, VBCY, BCAY, or angle from VAY or VABY
Communications Protocols	SEL (Fast Meter, Fast Operate, and Fast SER), Modbus TCP, Modbus RTU, DNP3, FTP, TCP/IP, IRIG-B, Telnet, the Simple Network Time Protocol (SNTP), IEC 61850 Edition 2, IEC 60870-5-103, Parallel Redundancy Protocol (PRP) for dual-Ethernet models, MIRRORED BITS communications, and IEEE C37.118 (synchrophasors).
Language Support	English and Spanish
Power Supply	**110—250 Vdc or 110—240 Vac** Input voltage range: 85—275 Vdc or 85—264 Vac **24—48 Vdc** Input voltage range: 19.2—60 Vdc
Operating Temperature	—40° to +85°C (—40° to +185°F) Note: Front-panel display contrast is impaired for temperatures below —20°C (—4°F) and above +70°C (+158°F).

Gross, 2nd Ed.

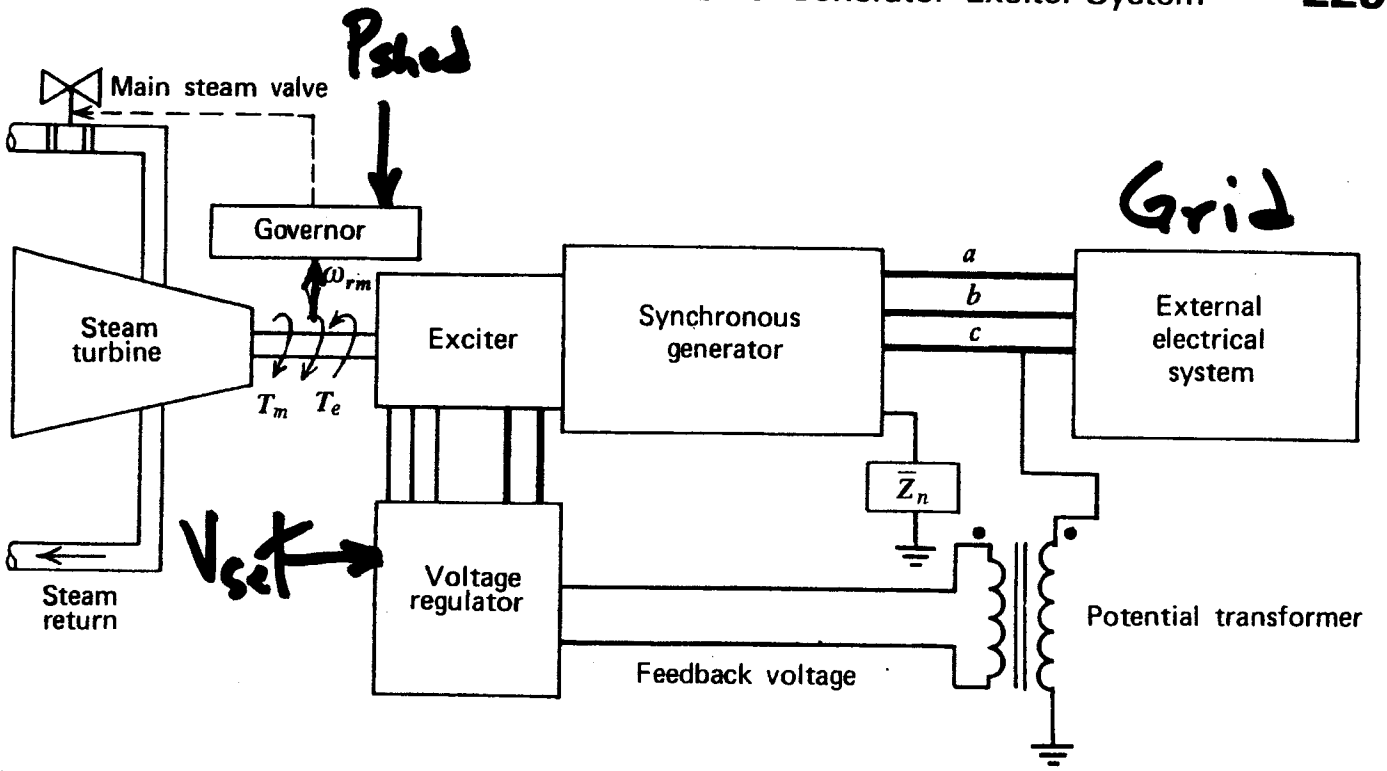


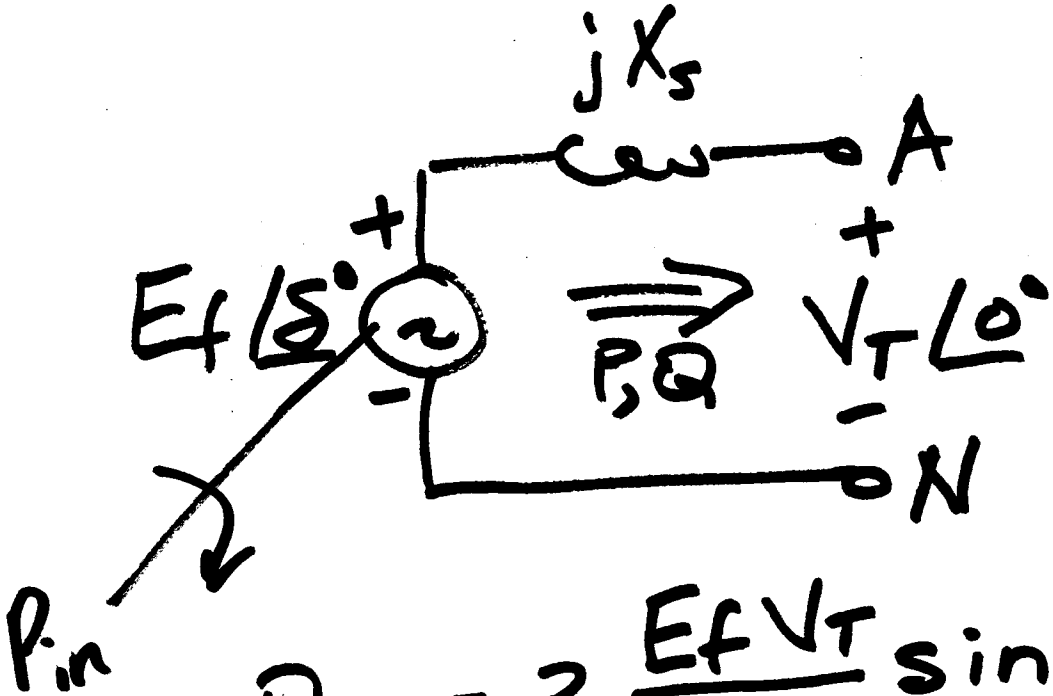
Figure 6.10. Turbine–generator–exciter system.

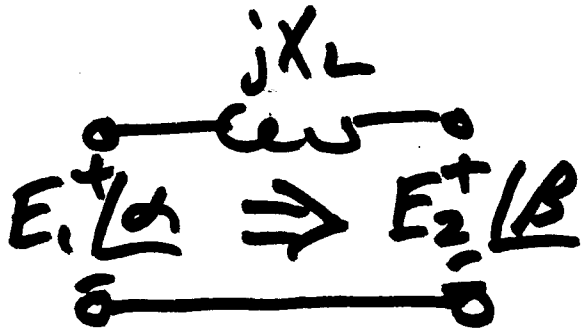
ble dc source,

c field current
ctly the stator

epresented in
controlled by

Two basic control actions are therefore apparent. The power converted from mechanical to electrical form (P_e) is controlled by the steam value setting, and the terminal voltage is controlled by the regulator setting. We wish to examine this system analytically without getting overwhelmed by the intricacies of any of its particular components. We also postpone the more complex problem of transient performance until Chapter 12; that is, we have the option of adjusting the steam valve or regulator setting but can calculate steady-state conditions only at each setting.





$$P_{OUT} = 3\frac{E_f V_T}{X_s}\sin\delta$$

$$Q_{OUT} = 3\left[\frac{E_f V_T}{X_s}\cos\delta - \frac{V_T^2}{X_s}\right]$$

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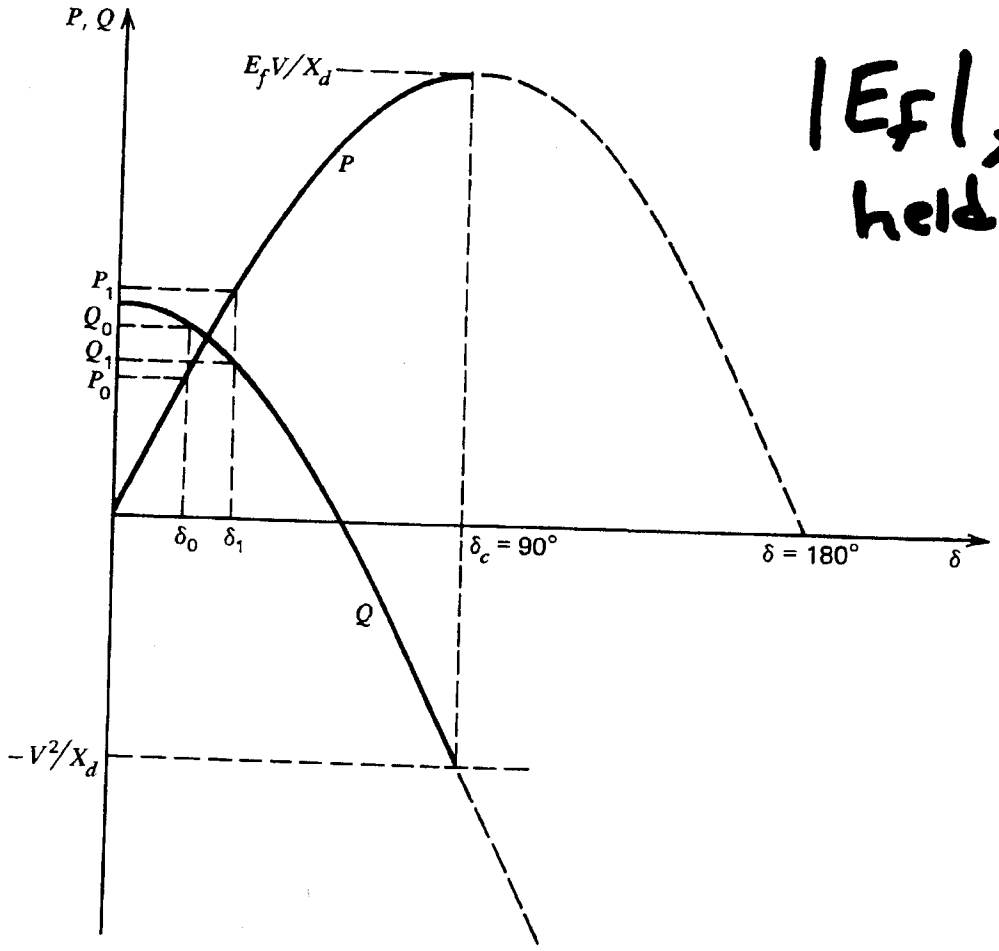


$|E_f|, |V_t|$ held const.

Figure 6.12. P and Q variation with delta.

power angles ($\sim 20°$). The conclusion is clear; there is a strong interrelation between the steam valve setting, real power flow, and δ.

Now, consider the second control action, namely, changing the voltage regulator setting. Suppose E_f increases. If we examine equations (6.22) and assume V, X_d, and P are constant, we observe that the P, Q relationships are modified to become P' and Q', as shown in Figure 6.13. Note that Q increase from Q_0 to Q_1. The angle δ also decreases slightly. We observe a strong interrelationship between regulator setting, reactive power flow, and E_f. Example 6.3 should help our understanding.

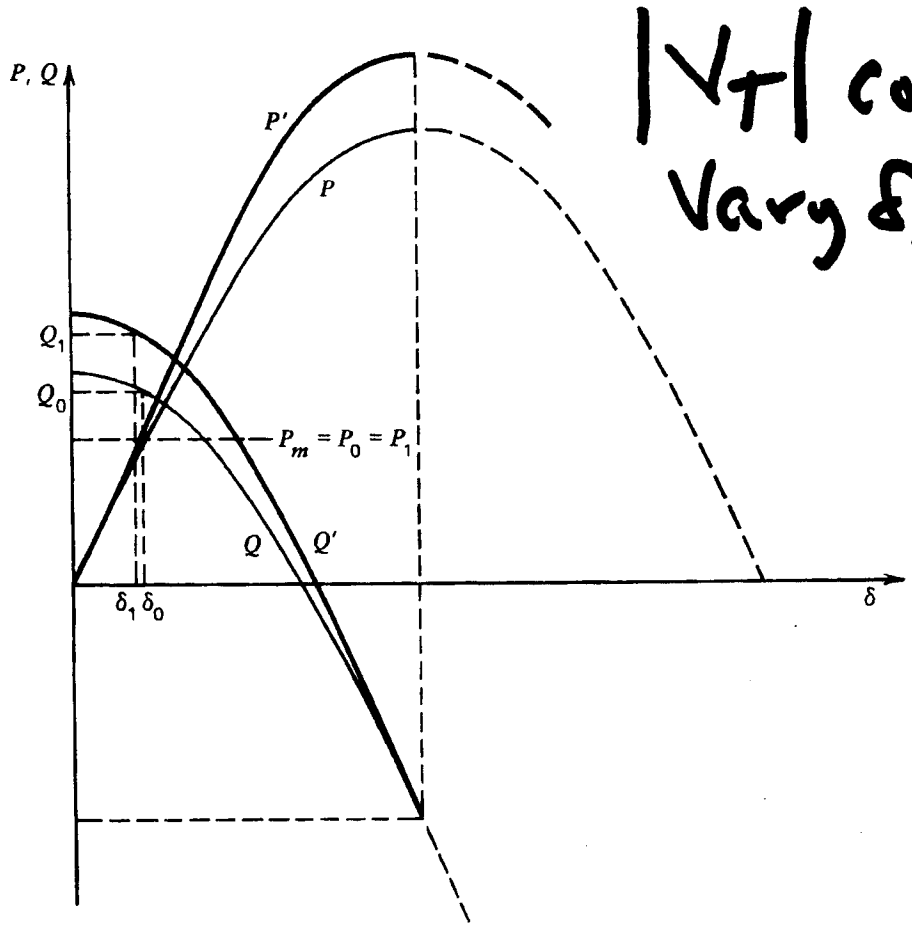


Figure 6.13. P and Q variation with E_f.

Solution

Let us use the subscript 0 to denote initial values and 1 to denote adjusted values

(a) $\bar{V} = 1\underline{/0^\circ}$

$$\psi_0 = \cos^{-1}(0.8) = 36.9^\circ$$

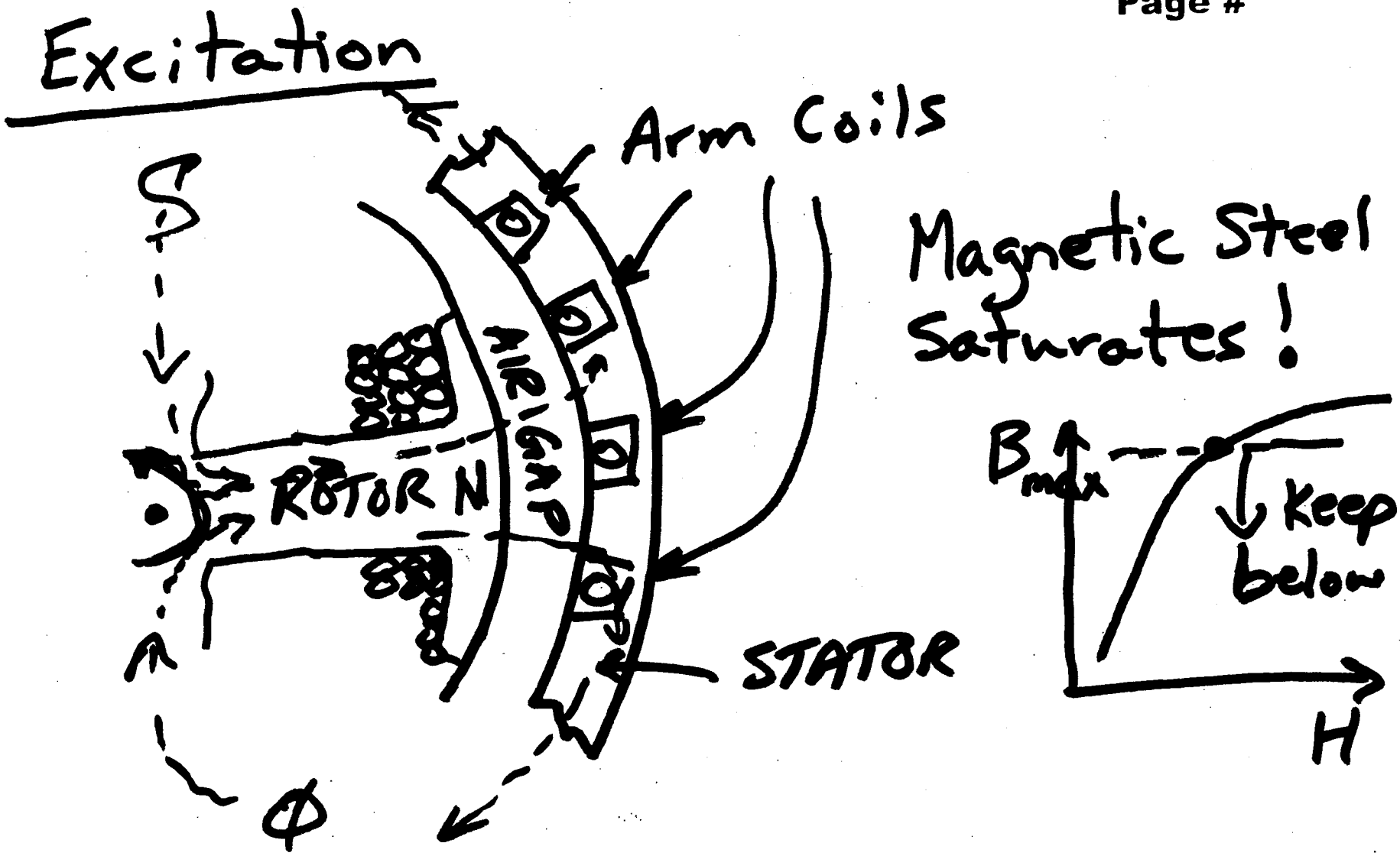
$$\therefore \quad \bar{I}_0 = 1\underline{/-36.9^\circ} = 0.8 - j0.6$$

$$\bar{E}_{f0} = jX_d\bar{I}_0 + \bar{V}$$

$$= j0.7(0.8 - j0.6) + 1$$

$$= 1.42 + j0.56$$

$$= 1.53\underline{/21.5^\circ}$$



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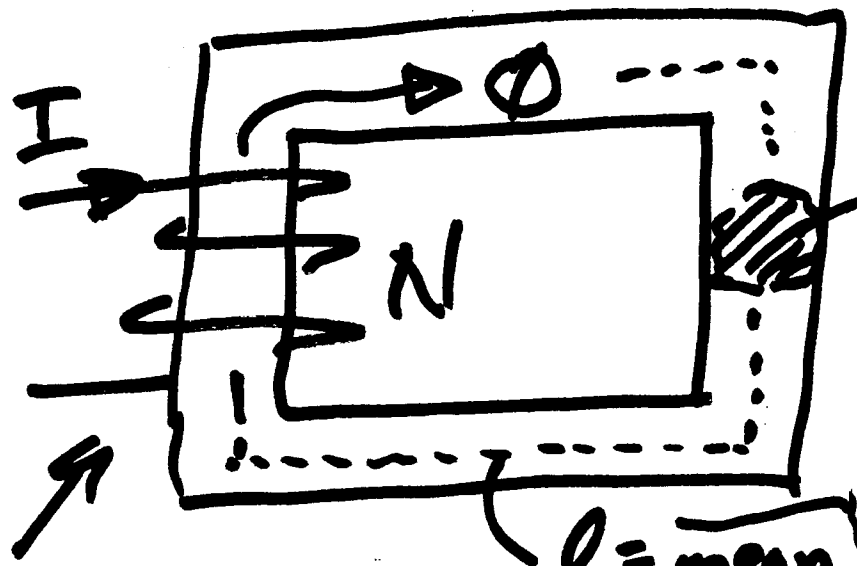

A = area of cross-section

Φ = Flux, Wb

$B = \frac{\Phi}{A}$ $\frac{Wb}{m^2}$ or T

ℓ = mean path length

MMF = NI = $\mathcal{F}$

H = Mag Field Intensity

= MMF/ℓ

Ampere's Law:

MMF = NI = Hℓ

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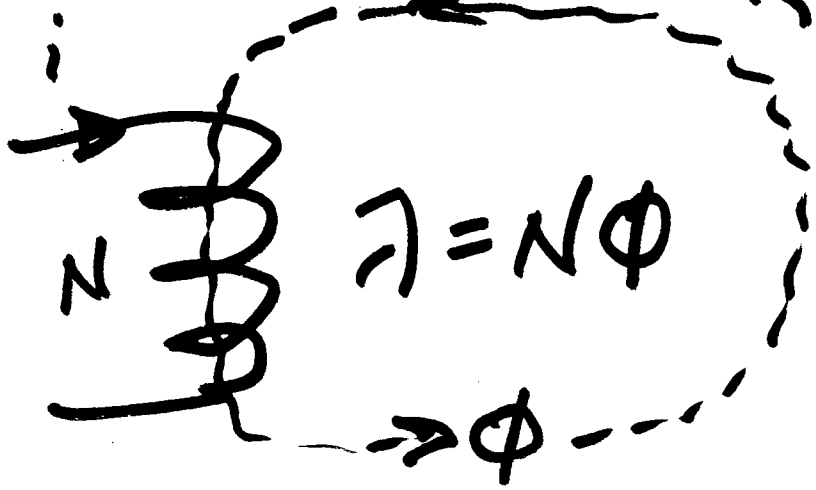
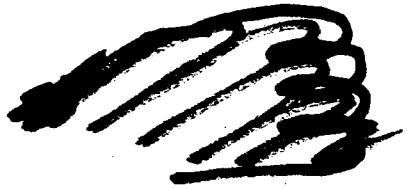
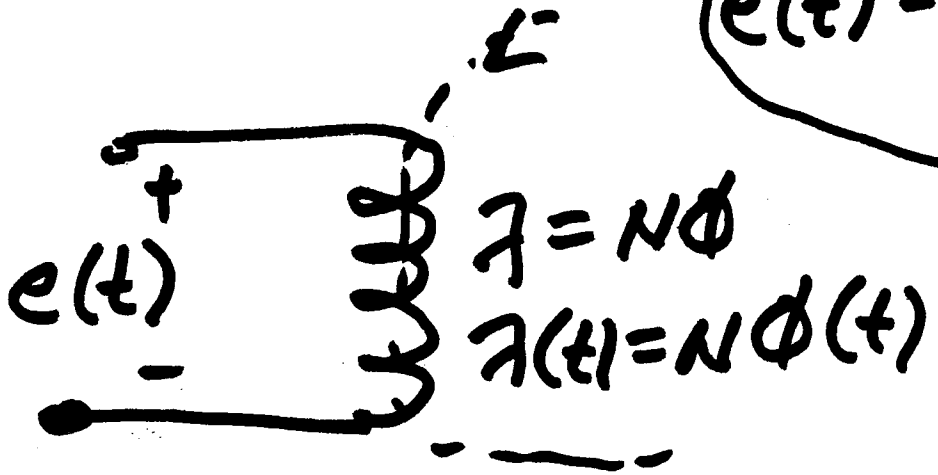
$$L = \frac{\lambda}{i} = \frac{N\phi}{i} \cdots \frac{N^2}{R}$$



$$e(t) = \frac{d\lambda(t)}{dt}$$

Lenz' Law





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$$e(t) = \frac{d\lambda(t)}{dt}$$

$$\lambda = N\phi$$

$$= NBA$$

$$e(t) = \frac{d}{dt}(NBA)$$

$$= NA\frac{dB(t)}{dt}$$

$$B(t) = B_{max}\sin\omega t$$

$$\frac{dB(t)}{dt} = \omega B_{max}\cos\omega t$$

$$e(t) = \omega NAB_m\cos\omega t$$

$$E_p = \omega NAB_M$$

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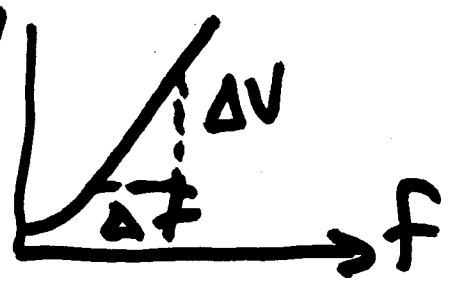
$$E_p = \sqrt{2}\,E_{RMS} = \omega N A B_M$$

$$E_{RMS} = \frac{2\pi f}{\sqrt{2}} N A B_M$$

$$\circledast \quad E_{RMS} = 4.44 f N A B_M$$

$$\Rightarrow \quad \underline{\underline{B_M \propto \frac{E_{RMS}}{f}}}$$

Motor Drives



Note: Monitor Volts/Hz ratio. Keep $B \leq B_M$.

> 120°C - damage insul.

Note: Written Pole Motor Above Curie Temp ? °F ≈ 950

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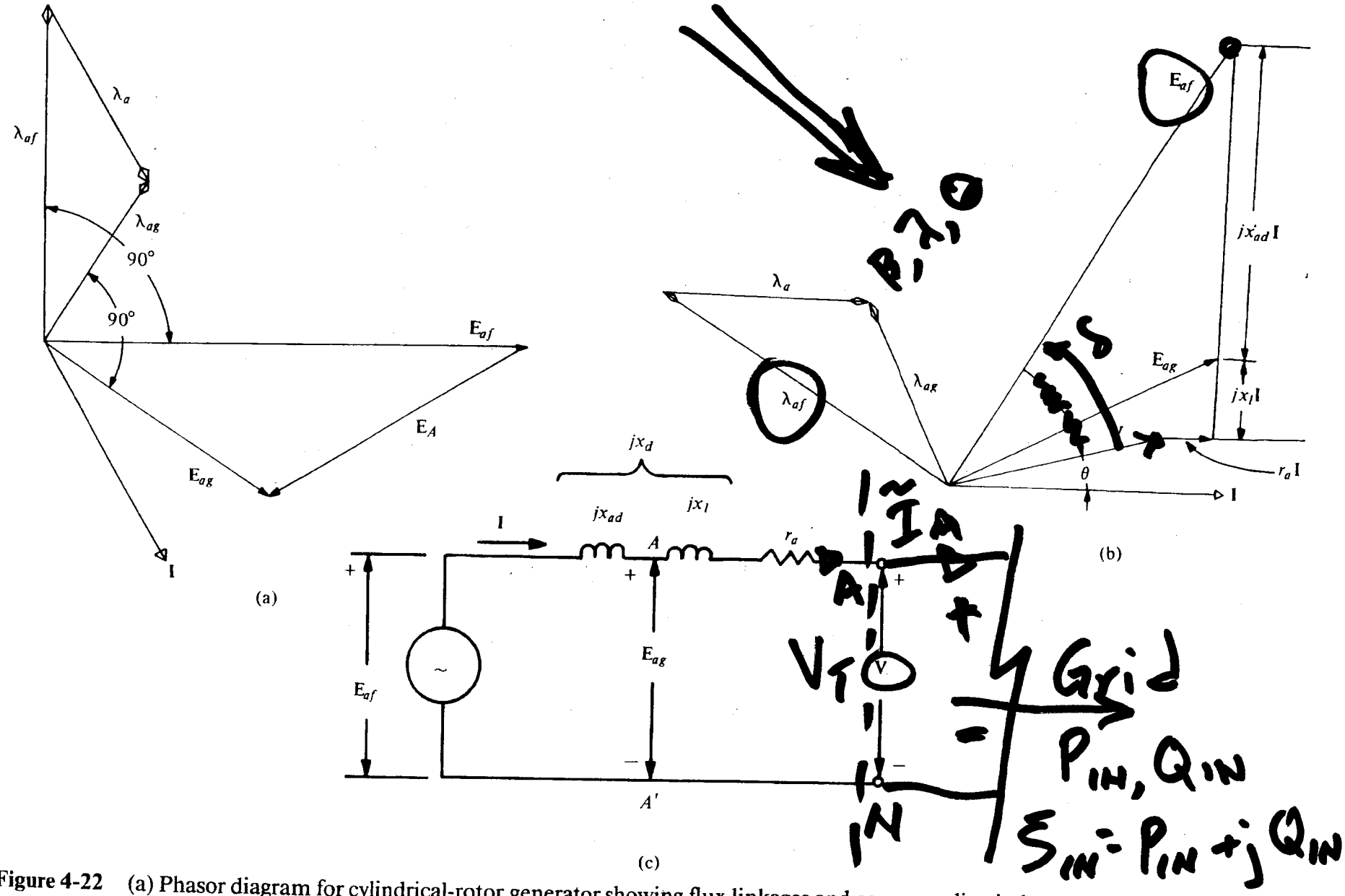
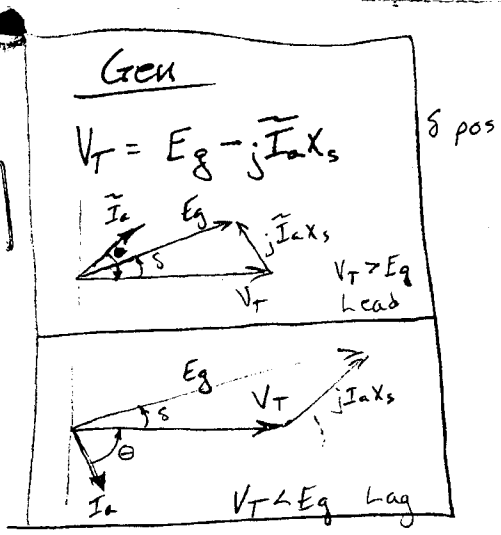
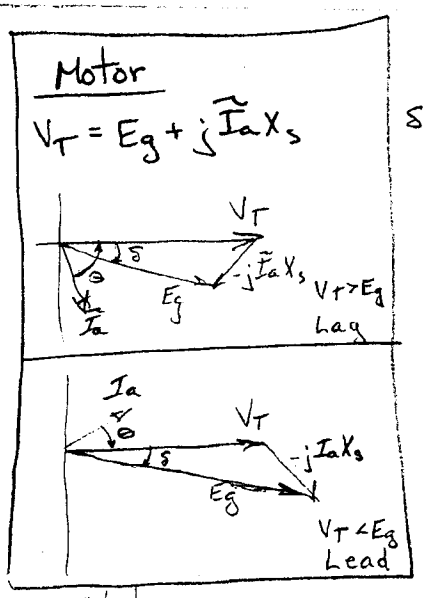


Figure 4-22 (a) Phasor diagram for cylindrical-rotor generator showing flux linkages and corresponding induced voltages. (b) Phasor dia; including leakage impedance voltage drop. (c) Equivalent circuit.

DON'T CONFUSE LEAD'S & LAG'S WITH P's & Q's

	GEN	MOTOR
OVEREXCITED	$V_T < E_g$, δ pos I_a Lags V_T Vars Generated into system	$V_T < E_g$, δ neg I_a Leads V_T Vars Generated into system
Underexcited	$V_T > E_g$, δ pos I_a Leads V_T Vars consumed from system	$V_T > E_g$, δ neg I_a Lags V_T Vars consumed from system





UNDEREXCITED
consume Vars
$V_T > E_g$

OVEREXCITED
Generate Vars
$V_T < E_g$

$|E_g| \cos\delta = V_T$
["normal" excitation]

Loads:

	Gen	Motor
Overexcited	Vars Flow out	Vars flow out
Underexcited	Vars Flow in	Vars flow in

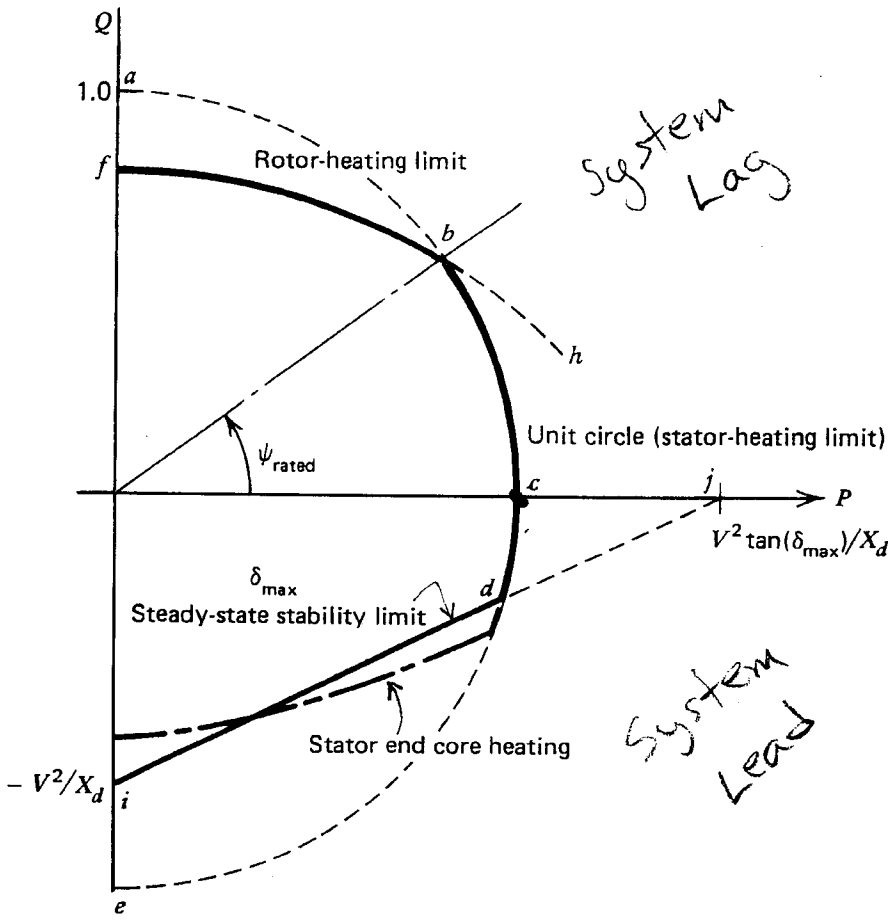


Figure 6.15. Generator-operating limits.

Solution

Unity-power-factor: $\bar{I} = 1 + j0$

$$\bar{E}_f = jX_d\bar{I} + \bar{V}$$

$$= j1.2(1) + 1 = 1.56\underline{/50.2^\circ}$$

$$\therefore \quad E_f = 1.56$$

Zero-power-factor lagging: $\bar{I} = 0 - j1$

$$\bar{E}_f = jX_d\bar{I} + \bar{V}$$

$$= j1.2(-j) + 1 = 2.20\underline{/0^\circ}$$

$$\therefore \quad E_f = 2.20$$

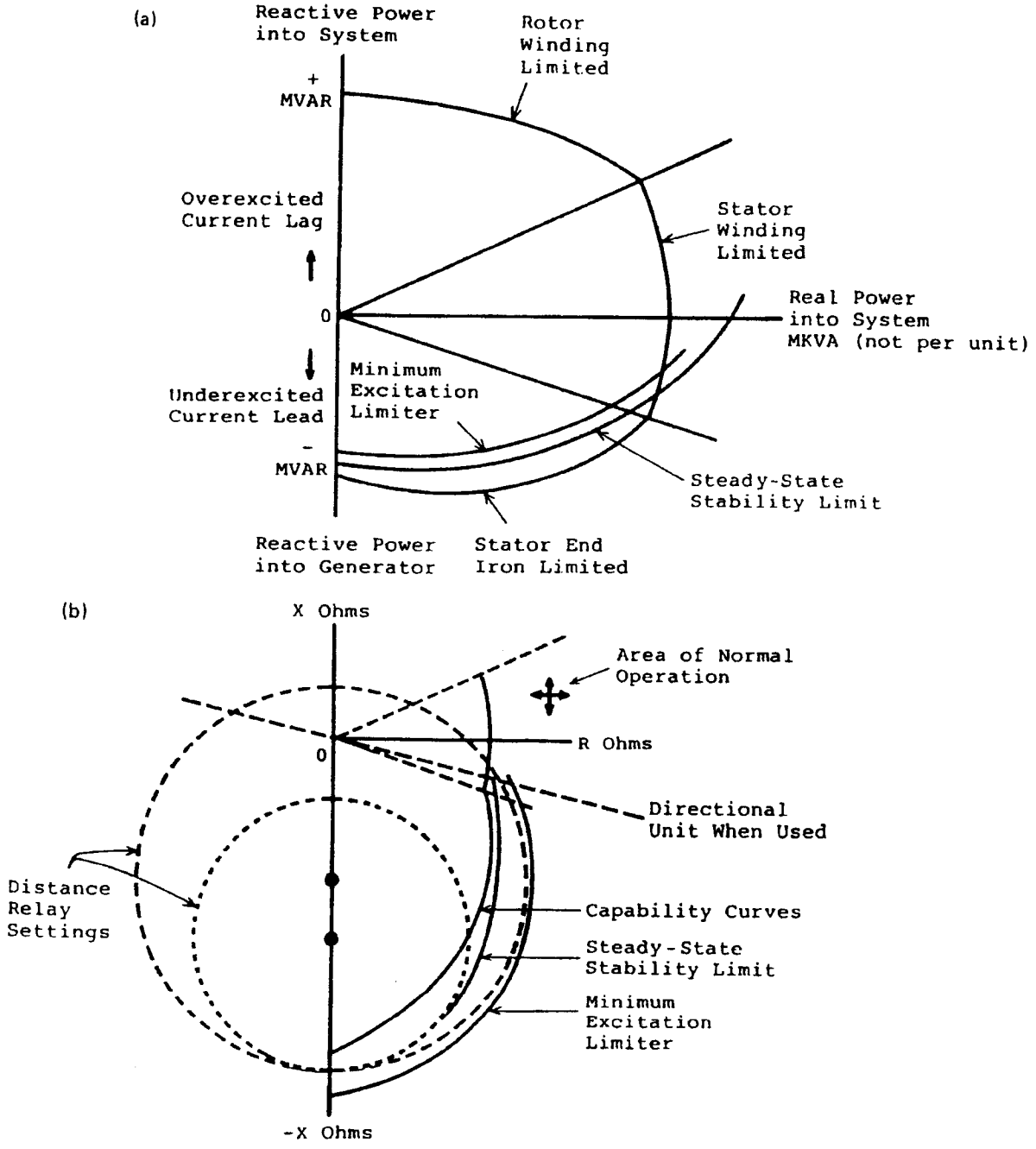
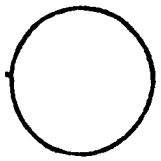


FIGURE 8.17 Typical power capability and stability curves for a generator and their conversion to an $R-X$ diagram for (40) relay protection application: (a) capability and stability curves on power axes; (b) power curves transferred to $R-X$ axes with distance-type relay protection.

Equivalent System



$X_1 = X_2 = 4\%$

$X_o = 12\%$

on 100 MVA, 345kV

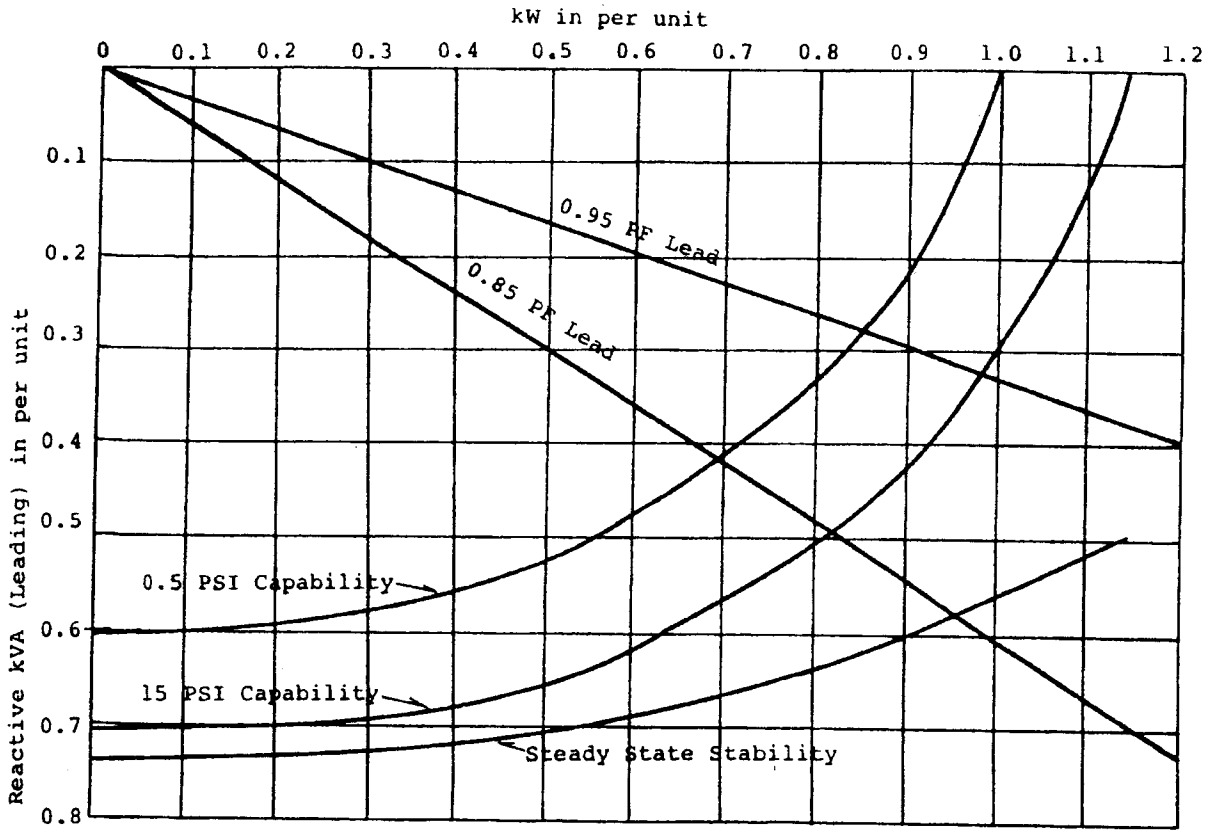


FIGURE P8.3

s.

ne-to-ground

er.

or a fault be-

ection. Com-

enerator relay

d. For the relay mho circle selected in part c, determine the per unit offset (distance of the circle center from the R-X origin) and the per-unit circle radius. Translate these values to relay ohms for