Ongoing List of Topics:

- URL: http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm
- Term Project - Follow timeline, see posting on web page
- Homework - one last homework..
- 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
SYNCH GENERATORS

Effect of System (or Load) Power Factor:

System Consumes
USAR

LAGGING

OVER-EXCITED
($|\tilde{E}_A|$ is > rated voltage)

UNITY

LEADING

UNDER-EXCITED
($|\tilde{E}_A|$ < rated voltage)
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®
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.

**Functional Overview**

**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.

- 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 B7* Is Not Specified

**Generator Winding**

<table>
<thead>
<tr>
<th>64G1 (59N)</th>
<th>64G2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead-Band</td>
<td>Dead-Band</td>
</tr>
</tbody>
</table>

**Element Coverage Areas**

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.

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.
- Log important user-defined system activities using the SER.

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.
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 SELLco® control equation settings to activate protection when the generator is offline.

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

General Specifications

AC Voltage Input
- 80-208 VL-L nominal for four-wire wye voltage input
- 80-140 VL-L nominal for three-wire delta voltage input
- 300 VL-N continuous limit for three-phase, four-wire wye connection
- 300 VL-L continuous limit for three-phase, three-wire delta connection
- 365 Vac for 10 seconds
- 300 V continuous, V<sub>n</sub> neutral voltage input
- 300 V continuous, V<sub>S</sub>-V<sub>N</sub> 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)

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.
ble dc source,

Figure 6.10. Turbine-genera\-tor-exciter system.

Two basic control actions are therefore apparent. The power converted from mechanical to electrical form ($P_e$) is controlled by the steam valve 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 controlled by
\[ P_{out} = 3 \frac{E_f V_T}{X_s} \sin \delta \]

\[ Q_{out} = 3 \left[ \frac{E_f V_T}{X_s} \cos \delta - \frac{V_T^2}{X_s} \right] \]
power angles ($\sim 20^\circ$). The conclusion is clear; there is a strong interrelation between the steam valve setting, real power flow, and $\delta$.

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 $\delta$ 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) $V = 1/0^\circ$

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

$\therefore \quad I_0 = 1/36.9^\circ = 0.8 - j0.6$

$E_{f0} = jX_d I_0 + V$

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

$= 1.42 + j0.56$

$= 1.53/21.5^\circ$
\( A = \text{area of cross-section} \)

\( \Phi = \text{Flux, Wb} \)

\( B = \frac{\Phi}{A} \text{ Wb/m}^2 \) or T

\( I = \text{mean path length} \)

\( \text{MMF} = NI = F \)

\( H = \text{Mag Field Intensity} = \text{MMF} / I \)

Ampere's Law:

\( \text{MMF} = NI = HL \)
\[ L = \frac{\dot{I}}{i} = \frac{N\Phi}{i} \ldots \frac{N^2}{R} \]

\[ \phi = N\Phi \]

\[ e(t) = \frac{d\phi(t)}{dt} \]

**Lenz's Law**

\[ e(t) \]

\[ \phi(t) = N\Phi(t) \]

**EE 5210 - Power Systems Protection**  
**Spring 2001**

Instructor: Bruce Mork  
Phone (906) 487-2857  
Email: bamork@mtu.edu
\[ e(t) = \frac{d}{dt} \frac{d A(t)}{dt} \]
\[ e(t) = \frac{d}{dt} (NBA) \]
\[ = NA \frac{d B(t)}{dt} \]
\[ B(t) = B_{max} \sin \omega t \]
\[ \frac{dB(t)}{dt} = \omega B_{max} \cos \omega t \]
\[ e(t) = wNABm \cos \omega t \]
\[ E_p = wNAABm \]
\[ E_p = \sqrt{2} \cdot E_{rms} = \omega N A B_m \]

\[ E_{rms} = \frac{2 \pi f}{\sqrt{2}} \cdot N A B_m \]

\[ \text{Note: Monitor Volts/Hz ratio. Keep } B \leq B_m. \]

\[ \text{Note: Written Pole Motor Above Curie Temp? } \]

\[ > 120^\circ C - \text{damage insul.} \]

\[ \text{Motor Drives } \]

\[ \sqrt{\frac{E_{rms}}{f}} \]

\[ \text{EE 5210 - Power Systems Protection } \text{ Spring 2001 } \approx 950^\circ F \]
### Table: Generator vs. Motor

<table>
<thead>
<tr>
<th>Condition</th>
<th>Generator</th>
<th>Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overexcited</strong></td>
<td>$V_T &lt; E_g$, $S$ pos</td>
<td>$V_T &lt; E_g$, $S$ neg</td>
</tr>
<tr>
<td>$I_a$ Lags $V_T$</td>
<td>Vars Generated into system</td>
<td>$I_a$ Leads $V_T$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vars Generated into system</td>
</tr>
<tr>
<td><strong>Underexcited</strong></td>
<td>$V_T &gt; E_g$, $S$ pos</td>
<td>$V_T &gt; E_g$, $S$ neg</td>
</tr>
<tr>
<td>$I_a$ Leads $V_T$</td>
<td>Vars consumed from system</td>
<td>$I_a$ Lags $V_T$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vars consumed from system</td>
</tr>
</tbody>
</table>

### Equations

- **Generator**
  - $V_T = E_g - jI_aX_s$  
  - $I_a = E_g / V_T$
  - $V_T > E_g$ Lead
  - $V_T < E_g$ Lag

- **Motor**
  - $V_T = E_g + jI_aX_s$
  - $I_a = E_g / V_T$
  - $V_T > E_g$ Lead
  - $V_T < E_g$ Lag

### Diagrams

- **Generator Diagram**:
  - Overexcited: Vars Flow out
  - Underexcited: Vars Flow in

- **Motor Diagram**:
  - Overexcited: Vars Flow out
  - Underexcited: Vars Flow in

### Notes

- $E_g \cos S = V_T$
- Normal excitation
Solution

Unity-power-factor: \( T = 1 + j0 \)

\[ \bar{E}_f = j X_d T + \bar{V} \]

\[ = j1.2(1) + 1 = \frac{1.56}{50.2^\circ} \]

\[ \therefore E_f = 1.56 \]

Zero-power-factor lagging: \( T = 0 - j1 \)

\[ \bar{E}_f = j X_d T + \bar{V} \]

\[ = j1.2(-j) + 1 = \frac{2.20}{0^\circ} \]

\[ \therefore E_f = 2.20 \]
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.
Figure P8.3

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