Ongoing List of Topics:

• URL: http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm
• Term Project - Due Friday (remote students can negotiate extension)
  • Local presentations: 12:45 - 2:45pm Wed; EERC B45
• Gen Protection - Ch. 8, Basic Protection issues (summary from prev lectures)
  • 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
  • Grounding Issues
  • Notes from adjunct faculty, example
  • Out-of-step issues - see also Kundur’s text
• An extreme example of stray voltage (neutral current return thru gnd paths)
• Motor Protection
  • Armature - similar strategies as with Synch Machines
  • Bearing Temp, vibration
  • Other issues - See Ch.11
• SCADA basics, transducers, scaling factors for relays and SCADA
Next/Last:
• Basic DSP relay algorithms – convert samples waveforms into phasor Vs and Is
• Real-time Communications for protection & control, IEC 61850
Motor Protection System

- Overloading - heat/thermal
- Vibration - Bearings
  - $3\Phi$ Tind = $K$
  - $1\Phi$ Tind ≠ $K$ (<5HP)
- Motor Starting, Motor Drives
  $\frac{V}{Hz}$
The SEL-710 Motor Protection Relay takes the next logical step in motor monitoring and control. While other motor relays assume a constant value for rotor resistance, the SEL-710 dynamically calculates motor slip and uses this information to precisely track motor temperature using the AccuTrack Thermal Model. Rotor resistance changes depending on slip and generates heat, especially during starting, when current and slip are highest. If your motor protection uses a constant rotor resistance for thermal protection, it could be off by a factor of three or more. By correctly calculating rotor temperature, the AccuTrack Thermal Model reduces the time between starts. It also gives the motor more time to reach its rated speed before tripping.

AccuTrack™ Thermal Model

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SCADA - Monitoring & Control

- Polling
- Interrupts

MTU

• Local Station

RTU

1 sec, 2 sec

RTU

System Control

...
RTU - I/O

**ANALOG:**
- Voltage
- Current
- Watts, Vars
- Temp
- Pressure
- etc.

**Status**
- 52a, 52b
  - open/close
  - off/on
  - local/remote

**Control/Output**
- Trip/Close, Pset
- On/off, LTG
EE 380 - H4.1 - Complete by Wednesday Feb 16th - This is another problem that applies your EE280 and EE380 skills to a very common Computer and Controls interfacing situation involving a Watt/Var transducer. We'll do the setup in class on Feb 14th.

This particular transducer measures 3-phase Watts and Vars (see the spec sheets on the following pages). This very common engineering application requires a blend of engineering skills in:

- **Power** - being able to calculate/measure 3-phase watt and var flows, as well as PF.
- **Interfacing** - correctly connecting CTs, VTs, and transducer to the 3-phase circuit being monitored, and connecting the transducer output to either a) the computer's DAQ card, or b) Programable Logic Controller (PLC), or c) System Control and Data Acquisition (SCADA) terminal.
- **Controls and Computer** - Calibrating the transducer and applying the correct output scaling factor to the control algorithm and software (i.e. computer DAQ card, PLC, SCADA, etc).

**Goal of this assignment:** Review and familiarize yourself with the measurement of 3-phase watts, vars and PF. Learn that there are 3 types of meters/transducers - 2-element, 2½-element, and 3-element. Gain experience in correctly connecting a transducer to the power circuit and to the computer, and correctly calculate the scaling factors needed by the software to correctly control the system. Failure to correctly connect and calibrate may not be as serious as the Mars Orbiter crash (failure to convert Newtons to Pounds resulted in loss of a $125M spacecraft and the entire project), but damage due to system misoperation, down time, expensive design errors, and loss of your next raise can result. On the other hand, successful completion leads to promotion.

**Background:** See the spec sheets on the following pages. Depending on whether the circuit supplying the load is 3-wire (3 phase wires but no neutral, for delta or ungrounded-Y loads), or 4-wire (3 phase wires plus neutral, for grounded-Y loads), you can apply one of the following 3 basic types of meters/transducers:

- 2-element - contains 2 single-phase wattmeters (for 3-wire or balanced 3-phase)
- 2½-element (2 voltage + 3 current) - 4-wire loads with balanced V but unbalanced I.
- 3-element - consists of 3 single-phase wattmeters - 4-wire loads, V and I both unbalanced.

(Over)
**Statement of Engineering Problem**: You are a power/controls engineer at a large manufacturing facility. Your boss assigns you to a project to monitor and improve the energy efficiency and power factor of a production line. The first step is to install a Watt-Var transducer and interface it to the facility’s energy management system. The 3-phase bus you are to measure from is 480-V, 4-wire, and has a 100-A maximum current.

You are to use a pre-made transducer panel (as shown in class). CTs are connected for 100:5 ratio, and the transducer is XLWV34-2KBA2-2 (see attached spec sheet). It is a 3-element device, connection diagram shown on attached Figure 48-K. The basic specs of the transducer are:

- Three L-N voltage elements, rated 480 V nominal, maximum of 600 V continuous.
- Three current elements, rated 5 A nominal, maximum of 10 A continuous.
- Calibration: 1 mA DC output = 6000 W on Watt output, or 6000 Var on Var output.
- A loading resistor converts the 0-1 mA DC output to a 0-10 V DC voltage which is then input to a meter or to the A/D converter of a DAQ card, PLC, or SCADA. (Note that this loading resistor is standardly a “wire-wound” precision 10 KΩ resistor, but any resistor from 0-10 KΩ will work with the transducer).

a) Sketch the AC system connections, showing the 3-phase source and load, the CTs, and the lines connecting the source and load. What is the maximum Watts and Vars that can flow thru this 480-V 100-A circuit?

b) Add the transducer’s voltage and current elements to your sketch. Show terminal numbers so your electrician can properly connect them. Polarity is important, else you may be measuring power flows in the wrong direction.

c) Sketch the connections for the transducer’s 2 outputs: Watt and Var. Connect a 10-KΩ load resistor on each output.

d) The transducer outputs go into 2 input channels of a DAQ card, with each channel having a 0-10 V DC range. What DC voltage appears at the Watt channel when the 480-Volt 100-A load is operating at unity PF? From this, calculate the correct scaling factor for the control and monitoring software (i.e. how many Watts does 1 Volt correspond to? How many Vars does 1 Volt correspond to?)

e) **Bonus**: If we want to make use of the complete dynamic range of the 10-V A/D input of the DAQ card, what precision resistance value should we specify (instead of the 10-KΩ resistor that is standardly used)?

f) **Finally**: Anything else we’re forgetting? Remember! This transducer requires a separate 120-V AC power supply, so you need to run a 120-Volt circuit over to it to power it.
EXCELTRONIC™ WATT/VAR TRANSDUCERS
packaged in one case
XLWV-A2 Series

Accuracy ± 0.2% of Reading

DESCRIPTION
The EXCELTRONIC Model XLW Transducers are the perfect combination of Scientific Columbus’ XL Watt Transducers and XLV Var Transducers. Model for model, the XLW will do everything the individual XL and XLV will do, but in half the panel space, with half the wiring, and at almost half the cost.

The XLW Series has the percent of reading specifications comparable to the EXCELTRONIC XL and XLV Series. It uses the patented ± 0.1% accuracy circuits of Scientific Columbus’ Digilogic products, the top of the line from the Power Instrumentation People. By using mass-produced, multi-function integrated circuits, Scientific Columbus has been able to manufacture these units inexpensively. The EXCELTRONIC line of Watt/Var Transducers offers the opportunity to make a system twice as accurate and many times more compatible with high accuracy computers for a very small additional investment.

Data now traceable to the National Bureau of Standards shows that the EXCELTRONIC line of Watt/Var Transducers gives better long-term stability than any other transducers made today. The transformer ratios never change and a very special zener diode is carefully selected for its temperature stability to assure 0.1%/year stability, non-cumulative. Aging of parts does not affect long-term stability. Zero drift has been eliminated completely. No zero adjustment is ever needed.

The EXCELTRONIC XLW mounting and connection drawings are identical to those always used by Scientific Columbus. There is no need to change established specification drawings.

THEORY OF OPERATION
The Model XLW Watt/Var Transducer uses a common power supply but time shares the single set per element input potential and current transformers. Because of this unique feature, the burden on the user’s transformers remains the same as when only one watt or var transducer is used individually. The function switching speed is 1344 HZ ± 5%. Since the output of each watt and var circuit appears on their associated output terminals 1344 times per second, only a small filter is used to reduce peak ripple to the <0.5% of ROI level. Essentially, each output is a dc signal directly proportional to instantaneous watts and vars.

SPECIFICATIONS

<table>
<thead>
<tr>
<th>Model</th>
<th>Element</th>
<th>Voltage</th>
<th>Load</th>
<th>Connection</th>
<th>Cal. Watts ± Vars</th>
<th>Effective Range Watts or Vars</th>
</tr>
</thead>
<tbody>
<tr>
<td>XLWV5C5A2</td>
<td>1</td>
<td>Balanced</td>
<td>Balanced</td>
<td>Single Phase</td>
<td>500</td>
<td>0-1000</td>
</tr>
<tr>
<td>XLWV5C5A2</td>
<td>1½</td>
<td>Balanced</td>
<td>Balanced</td>
<td>3 Phase 3 Wire</td>
<td>1000</td>
<td>0-2000</td>
</tr>
<tr>
<td>XLWV31K5A2</td>
<td>2</td>
<td>Unrestricted</td>
<td>Unrestricted</td>
<td>3 Phase 3 Wire</td>
<td>1000</td>
<td>0-2000</td>
</tr>
<tr>
<td>XLWV34K5A2</td>
<td>2½</td>
<td>Balanced</td>
<td>Unrestricted</td>
<td>3 Phase 4 Wire</td>
<td>1500</td>
<td>0-3000</td>
</tr>
<tr>
<td>XLWV34K5A2</td>
<td>3</td>
<td>Unrestricted</td>
<td>Unrestricted</td>
<td>3 Phase 4 Wire</td>
<td>1500</td>
<td>0-3000</td>
</tr>
</tbody>
</table>

Potential Input Nominal 120 V
Potential Input Range 0-150 V
Potential Overload 175 V
Potential Burden Element 0.05 VA at 120 V

Current Input Nominal 5A
Current Range 0-10A
Overload Continuous 15A
Overload 10 sec 50A
Overload 1 sec 400A
Burden Element 0.10 VA at 5A

Watt or VAR Input Range See Table above (Effective Range)

Rated Output (RO) ± 1 mA dc Watts ± 1 mA dc Vars

* Accuracy WATTS ± 0.02% Reading + 0.01% RO
    VARS ± 0.02% Reading + 0.02% RO

Load Resistance, R Compliance 11.0 Volts Min. (see overrange note pages 5 & 6)

Output Ripple Peak < 0.5% of RO
Response Time (to 99%) < 400 ms.

Frequency 60 Hz
Power Factor Any
Options Shown on page 46
Temperature Range −20°C to +60°C
Temperature Influence ± 0.005%/°C Watt
    ± 0.009%/°C Var
Operating Humidity 0-95%
Stability (per year) ± 0.1% RO Max. Watt
    ± 0.2% RO Max. Var
Dielectric Test 1800 Vrms
Isolation Complete Input/Output/pwr. supply/case
Surge Withstand Capability Withstands IEEE Std. 472 SWC Test

Size See Outline Dimensions page 47
Style IV Case
Calibration Adjust ± 2% Min.
Zero Adjust None ever required
Power Supply 85-135 Vac, 60 Hz, 2.5 VA Burden Max at 120V

* Includes the worst combined effects of voltage, current power factor & load changes.

THE POWER INSTRUMENTATION PEOPLE

E Scientific Columbus
An Estelle Line Company

TYPE 1 PRODUCT

3794917, 3971979, 3975682, 3976942 and 4055804 Other Pat. Pending
*NOTICE*: 120 V AC External Amplifier Power, when required, is supplied to terminals as follows:

**Terminals**

<table>
<thead>
<tr>
<th>Terminals</th>
<th>Terminals</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 &amp; 12</td>
<td>6A &amp; 12A</td>
</tr>
<tr>
<td>Conn:</td>
<td>Conn:</td>
</tr>
<tr>
<td>48-A</td>
<td>48-D (2½ ele)</td>
</tr>
<tr>
<td>48-B</td>
<td>48-E</td>
</tr>
<tr>
<td>48-C</td>
<td>48-F</td>
</tr>
<tr>
<td>48-D (2 ele)</td>
<td>48-J</td>
</tr>
<tr>
<td>48-G</td>
<td>48-K</td>
</tr>
<tr>
<td>48-H</td>
<td>48-I</td>
</tr>
</tbody>
</table>

*Line* L1 L2 L3 N  *Load*
3-Phase P, Q Measurement

2-Element

\[
P_T = V_{12}I_1 \cos \left( \sqrt{3}I_1 - \sqrt{3}I_3 \right) + V_{32}I_3 \cos \left( \sqrt{3}I_2 - \sqrt{3}I_3 \right)
\]

\(\text{No NEUTRAL}\)

2 1/2-Element - Balanced Vs, Unbalanced Is

\[
P_{\text{TOTAL}} = V_1 I_1 \cos \left( \sqrt{3}I_1 - \sqrt{3}I_2 \right) + V_2 I_2 \cos \left( \sqrt{3}I_2 - \sqrt{3}I_3 \right) + V_3 I_3 \cos \left( \sqrt{3}I_3 - \sqrt{3}I_1 \right)
\]

Note: \(V_2\) synthesized as \(-V_1 - V_3\)

3-Element - Unbalanced Vs & Is
Generation 4

- "Smart Grid"
- IEC 61850
- Embedded Processors
- Intranet (Cybersecurity)
- NERC CIP Stds.