Design and Implementation of a Wireless High Voltage Power Line Sensor

Group 11:
Bill Song, Jordan Bartel, Sailen Kara, Thomas Neusitzer

Academic Supervisor: Dr. Gregory Bridges (University of Manitoba)
Industry Supervisor: Dr. Miodrag Kandic (Manitoba Hydro)
Presentation Outline

• Project Overview
• Design of Subsystems
• Subsystem Integration
• Testing and Results
• Conclusion
Motivation

- Manitoba Hydro’s digital recording ammeters have two concerns:
  - Battery life
  - Wired connection

  ➡  Energy harvesting
  ➡  Wireless communication
System Block Diagram

1. **Energy Harvesting System**
2. **Power Storage System**
3. **Data Acquisition System**
4. **Microcontroller**
5. **Wireless Communication System**
6. **Base Station**

Flow of Information:
- **High-Voltage Power Line**
- **Energy Harvesting System** to **Power Storage System**
- **Data Acquisition System** to **Microcontroller**
- **Microcontroller** to **Wireless Communication System**
- **Wireless Power Line Sensor** during optimal line conditions
Project Specifications

- Continuous power supply (0 to 600 A line current)
  - Mainly energy harvesting
  - Backup battery supply

- Records line parameters:
  - Current (0 to 600 A)
  - Sag angle (0 to 45°)
  - Temperature (-40 to 125 °C)

- Wireless transmission of parameters (100 m range)
Final Prototype

- EHS Current Clamps
- Power Supply Circuitry (EHS and PSS)
- DAQS Sag and Acceleration Sensors
- PSS Batteries
- DAQS Current Sensor
- Arduino Uno with Wireless SD Shield (DAQS and WCS)
- WCS Antenna
Presentation Progress

• Project Overview
• Design of Subsystems
• Subsystem Integration
• Testing and Results
• Conclusion
Energy Harvesting System

Design of Subsystems
Energy Harvesting System

- Harvests power through EM induction
- Rectifies AC input to provide a DC bus
- Regulates DC voltage to protect the Arduino

Design of Subsystems
Power Storage System

Diagram of the Power Storage System:
- Energy Harvesting System
- Data Acquisition System
- Microcontroller
- Wireless Communication System
- Base Station
- Power Storage System
- Wireless Power Line Sensor

Flow:
- Energy Harvesting System to Power Storage System
- Data Acquisition System to Microcontroller
- Microcontroller to Wireless Communication System
- Wireless Communication System to Base Station

During Optimal Line Conditions:
Power Storage System

- Stores excess harvested power
- Automatically stops charging when batteries are full
- Provides up to 13 hours of backup power
Data Acquisition System

- Energy Harvesting System
- Power Storage System
- Wireless Power Line Sensor
- Microcontroller
- Wireless Communication System
- Base Station
Data Acquisition System

- Records line parameters using external sensors

Diagram:
- Line Temperature Sensor
- Ambient Temperature Sensor
- Line Sag / Acceleration Sensor
- Line Current Sensor
- Rectifier
- 10-bit Analog to Digital Converter
- ATmega328 Microcontroller
- Arduino Uno

Design of Subsystems
Data Acquisition System

- External sensors capture:
  - Line current
  - Line and ambient temperatures
  - Sag angle
  - Acceleration due to external loads
Wireless Communication System

- Energy Harvesting System
- Data Acquisition System
- Power Storage System
- Microcontroller
- Wireless Communication System
- Base Station
- During Optimal Line Conditions

High-Voltage Power Line
Wireless Communication System

- Transmits sensor data to base station PC
Wireless Communication System

- XBee transceivers used

Achieved transmission range of 250 m
Presentation Progress

• Project Overview
• Design of Subsystems
• Subsystem Integration
• Testing and Results
• Conclusion
Subsystem Integration

- Integration phases:
  1. Hardware integration
  2. Power management interface
  3. Software integration
  4. Housing unit
Initial Block Diagram

- Energy Harvesting System
- Power Storage System
- Wireless Power Line Sensor
- Data Acquisition System
- Microcontroller
- Wireless Communication System
- Base Station

During Optimal Line Conditions

High-Voltage Power Line

Subsystem Integration
Final Block Diagram

Subsystem Integration
Hardware Integration

• DC bus maintained by switching between power sources
  • Battery power for line currents from 0 – 200 A
  • Harvested power from 200 – 600 A

• Passive switching implemented
  • Schottky diode connects batteries to DC bus
Power Management Interface

- Excess harvested energy dissipated as heat
  - Introduced supercapacitors to reduce this power loss

- Supercapacitors
  - Charged during high line currents
  - Discharged during data transmission at low currents
  - Reduces current draw from batteries
Software Integration

• Photorelay switches controlled by Arduino
  • Based on line current and state of supercapacitors

• XBee antenna interfaced directly to Arduino
  • Data passed from SD card to antenna using SPI

• Five minute power save mode implemented
  • All microcontroller peripherals disabled
  • Current draw ~ 6 μA
Housing Unit

- Constructed a simple case to hold prototype
- Lightweight, made of plastic
  - No significant stress on line
- Hinges to clamp around the line
- Antenna and ambient temperature sensor exposed to external environment
Final Prototype

- EHS Current Clamps
- Power Supply Circuitry (EHS and PSS)
- DAQS Sag and Acceleration Sensors
- PSS Batteries
- DAQS Current Sensor
- Arduino Uno with Wireless SD Shield (DAQS and WCS)
- WCS Antenna
Presentation Progress

• Project Overview
• Design of Subsystems
• Subsystem Integration
• Testing and Results
• Conclusion
Test Performed

- Three main tests were performed to

1. Ensure the Arduino is powered at all line currents
2. Determine accuracy of sensors
3. Verify transmission range
Test Apparatus

Sensor Prototype

Conductor

Variac Transformer

Current Transformer
DC Bus Voltage

Bus voltage tested by increasing the load (adding additional subsystems)
Line Current

- Rectified current waveforms captured for line currents from 0 – 600 A
  - 526 A waveform shown
  - Average measurement error of 1% for 0 to 600 A
• Sensors tested for cold, room and hot temperatures
  • Tested outside in -25 °C
  • Tested in oven up to 125 °C
  • Average measurement error of 1° C
Line Sag Angle

- Angle measured from 0 to 90°
- Average measurement error of 1°
Wireless Transmission

- Successful data transmission at distance of 250 m
- Received power level 30 dBm above MDS
## Specifications Summary

<table>
<thead>
<tr>
<th>Specification</th>
<th>Target Level</th>
<th>Achieved Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy harvesting range</td>
<td>200 – 600 A</td>
<td>200 – 600 A</td>
</tr>
<tr>
<td>Battery discharge time</td>
<td>4 hours</td>
<td>13 hours</td>
</tr>
<tr>
<td>Line current sensing</td>
<td>0 – 600 A</td>
<td>0 – 600 A ± 1.11%</td>
</tr>
<tr>
<td>Line temperature sensing</td>
<td>-40 – 125 °C</td>
<td>-40 – 125 °C ± 1 °C</td>
</tr>
<tr>
<td>Line sag angle sensing</td>
<td>0 – 45° from horizontal</td>
<td>0 – 90° ± 1° from horizontal</td>
</tr>
<tr>
<td>Ambient temperature sensing</td>
<td>N/A</td>
<td>-40 – 125 °C ± 1 °C</td>
</tr>
<tr>
<td>Line acceleration sensing</td>
<td>N/A</td>
<td>0 – 1.5g</td>
</tr>
<tr>
<td>Wireless range</td>
<td>100 m</td>
<td>250 m</td>
</tr>
</tbody>
</table>
Presentation Progress

- Project Overview
- Design of Subsystems
- Subsystem Integration
- Testing and Results
- Conclusion
Original Motivation

- Address concerns with DRAs
  - Limited battery life
  - Wired connection to recover data
- Minimize risk to technicians when removing DRAs
Our Solution – Battery Life

• Energy harvesting solution with power storage back up

• DC Bus Test verified prototype is powered from 0 to 600 A
Our Solution – Wired Connection

- Wireless communication system
- Transmit distance of 250 m
- Received data:
  - Line current
  - Line and ambient temperature
  - Sag angle
  - Acceleration
## Specifications Summary

<table>
<thead>
<tr>
<th>Specification</th>
<th>Achieved Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy harvesting range</td>
<td>Met</td>
</tr>
<tr>
<td>Battery discharge time</td>
<td>Exceeded</td>
</tr>
<tr>
<td>Line current sensing</td>
<td>Met</td>
</tr>
<tr>
<td>Line temperature sensing</td>
<td>Met</td>
</tr>
<tr>
<td>Line sag angle sensing</td>
<td>Exceeded</td>
</tr>
<tr>
<td>Ambient temperature sensing</td>
<td>Additional Feature</td>
</tr>
<tr>
<td>Line acceleration sensing</td>
<td>Additional Feature</td>
</tr>
<tr>
<td>Wireless range</td>
<td>Exceeded</td>
</tr>
<tr>
<td>Cost</td>
<td>$420</td>
</tr>
</tbody>
</table>
Thank You
Question Period

Questions are guaranteed in life; Answers aren't.