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# Subsynchronous Control Interactions (SSCI) Studies using EMTP


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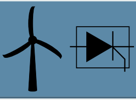
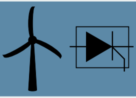
# Today's Topics:

1. Subsynchronous Oscillations (SSO)
2. Frequency-Domain Analysis using EMTP
3. Time-Domain Analysis using EMTP
4. Parametric Study of the Wind Speed
5. Parametric Study of the PLLs
6. GSC effects over SSCI
7. Conclusions

# Subsynchronous Oscillations (SSO)

# Introduction

| |  |  |  |
|---|---|---|---|
|  | --- | SSCI | SSR |
|  | SSCI | CI (Control interactions can be at any frequency) | SSTI |
|  | SSR | SSTI | --- |

1. SSCI: Subsynchronous Control Interaction
2. SSO: Subsynchronous Oscillations
3. SSR: Subsynchronous Resonance
4. SSTI: Subsynchronous Torsional Interaction

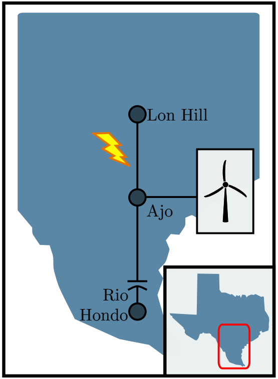
# Overview: SSCI

## Subsynchronous Control Interaction

- SSCI is a control interaction that can occur between any power electronic device (including Type 3 and 4 wind turbines) and a series capacitor
- Not a result of mechanical interactions
- Purely an electrical interaction
- Interaction between turbine control system and electrical network
- Prominent when Type 3 wind turbine generators connected radially through series capacitors

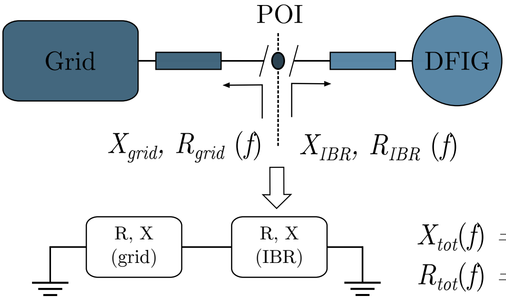
# Real World SSCI Events – Texas, 2009

1. Ground fault occurred on 345 kV Ajo-Lon Hill line
2. After fault clearing, type 3 WTG's radially connected to series compensated 345 kV line
3. Subsynchronous current oscillations in 20-30 Hz range started within 150 ms
4. Overvoltages damaged series capacitors and WTG crowbar circuits
5. Mitigated by reducing compensation on line



# Frequency-Domain Analysis using EMTP

# SSCI Screening Studies

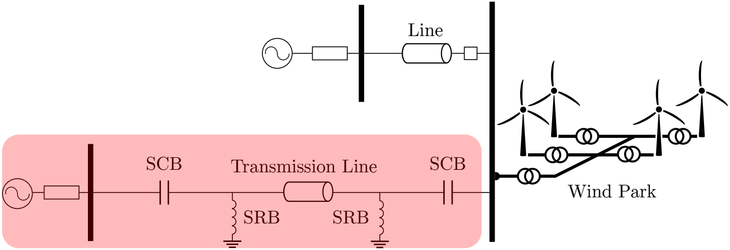


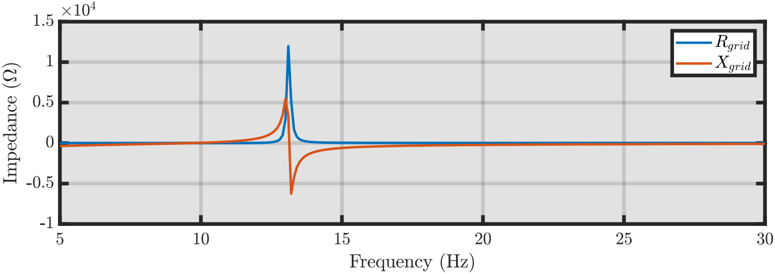

$$X_{tot}(f) = X_{grid}(f) + X_{IBR}(f)$$
$$R_{tot}(f) = R_{grid}(f) + R_{IBR}(f)$$

## Consists of four main steps:

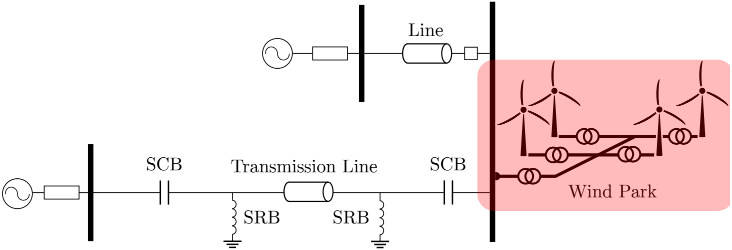
1. Grid-side scan ($R_{grid}$ and $X_{grid}$)
2. Converter-side scan ($R_{IBR}$ and $X_{IBR}$)
3. Combined scan ($R_{tot}$ and $X_{tot}$)
4. Time-domain verification

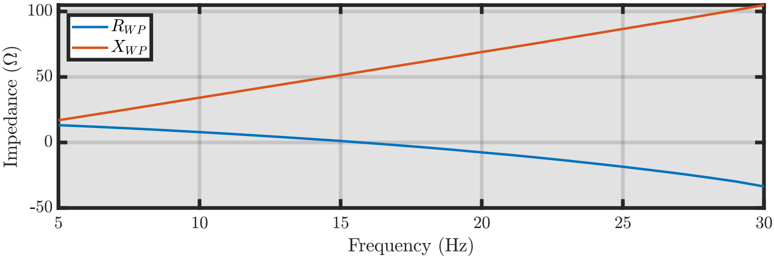
# Step I: Grid side Frequency Scan



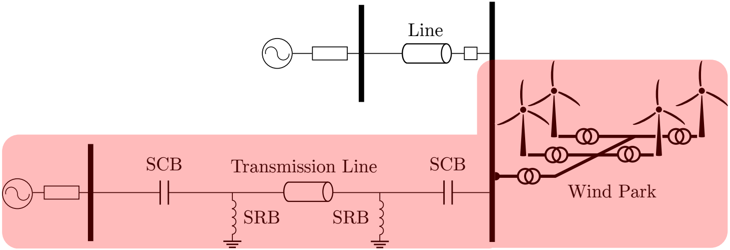



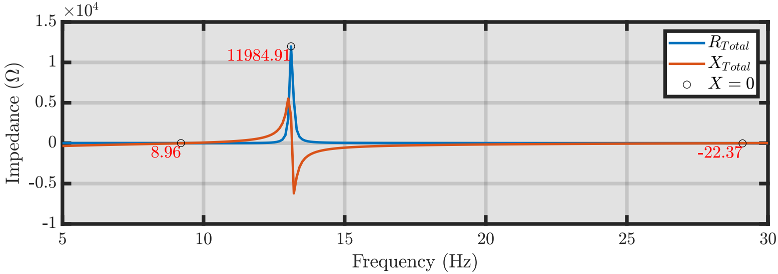
# Step II: Wind Park side Frequency Scan



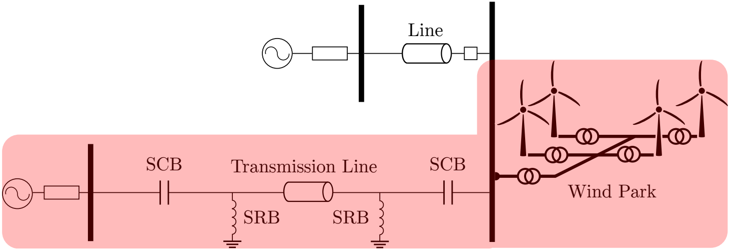
# Step III: Full Response

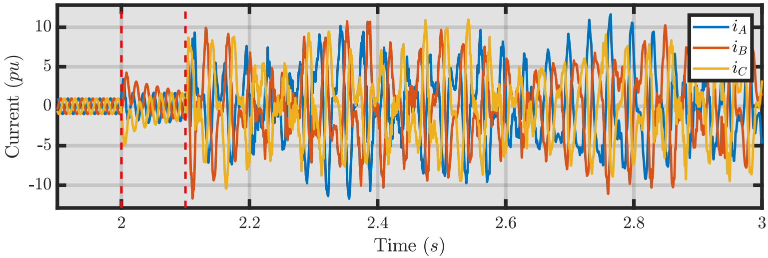


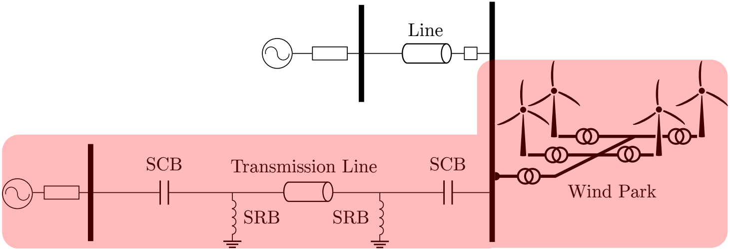
# Time-Domain Analysis using EMTP

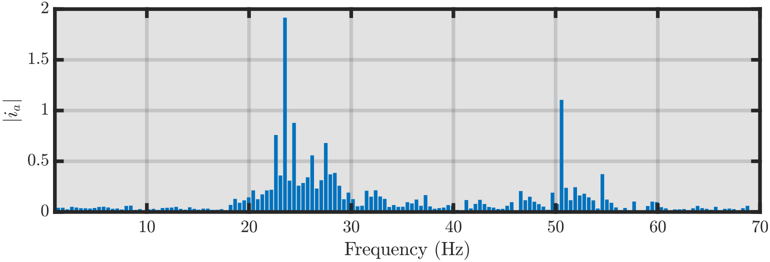
# Step IV: Time-Domain Verification



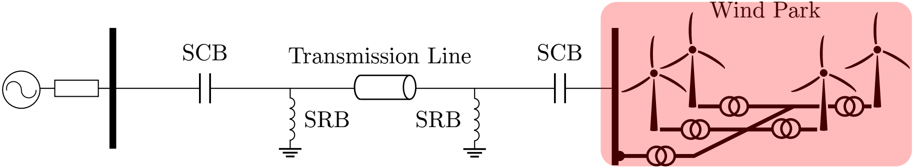
# Step IV: Fast Fourier Transform



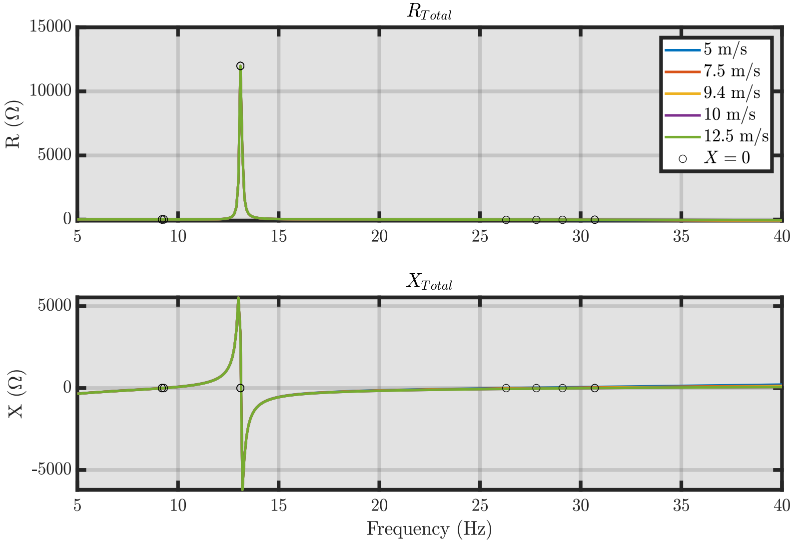
# Parametric Study of the Wind Speed

# Wind Speed Variation: Overview

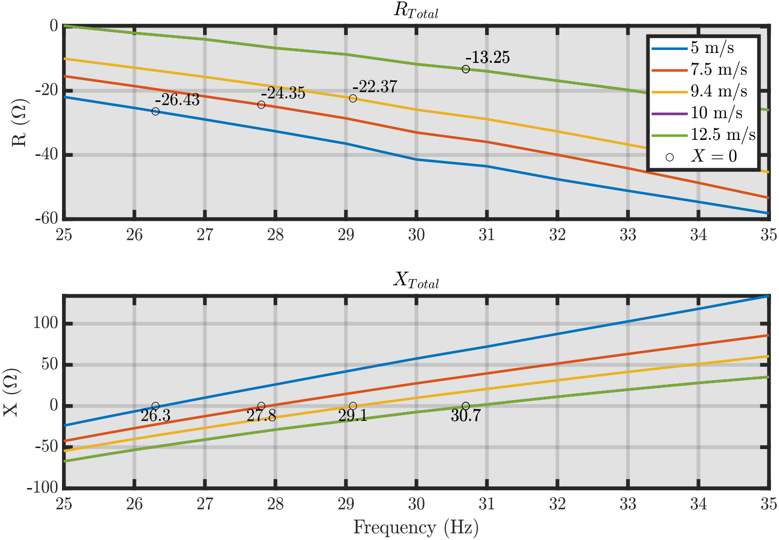



| Case | Wind Speed [m/s] | Active Power [pu] |
|---|---|---|
| 1 | 5 | 0.07 |
| 2 | 7.5 | 0.26 |
| 3 | 9.4 | 0.51 |
| 4 | 10 | 0.61 |
| 5 | 12.5 | 1.00 |

# Wind Speed Variation: Results

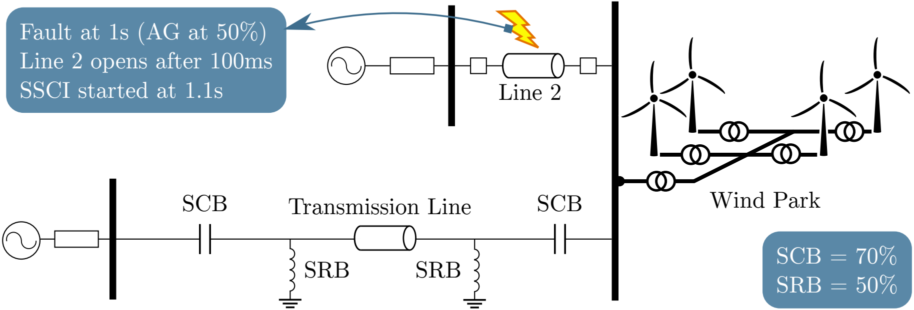


# Wind Speed Variation: Results



# Wind Speed: Time-Domain Study

Fault at 1s (AG at 50%)
Line 2 opens after 100ms
SSCI started at 1.1s

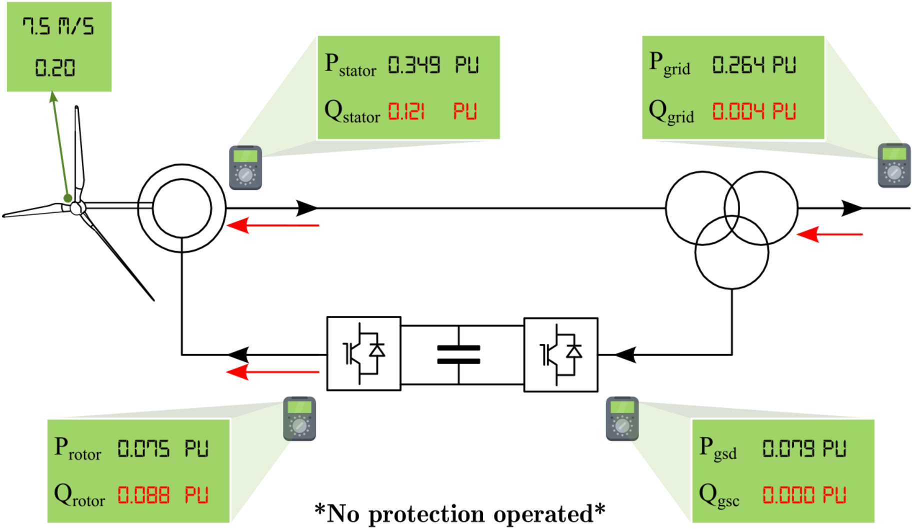



SCB = 70%
SRB = 50%

| Wind Speed [m/s] | slip | P [pu] | $f_{meas}$ [Hz] | $f_{scan}$ [Hz] |
|---|---|---|---|---|
| 7.5 | 0.20 | 0.26 | 27.15 | 27.8 |
| 9.4 | 0.00 | 0.53 | 29.07 | 29.10 |
| 12.5 | −0.25 | 1.00 | 30.96 | 30.70 |

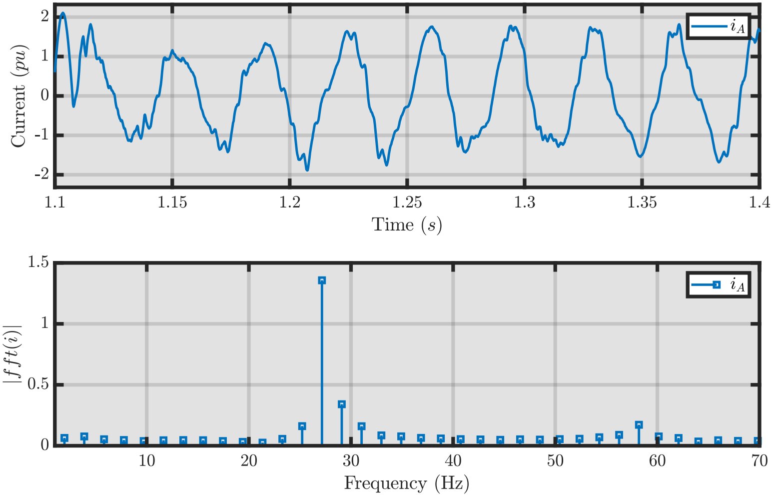
**After line 2 opens, WP is radially connected to the series compensated line**

# Subsynchronous Operation [7.5m/s]: Power Flow



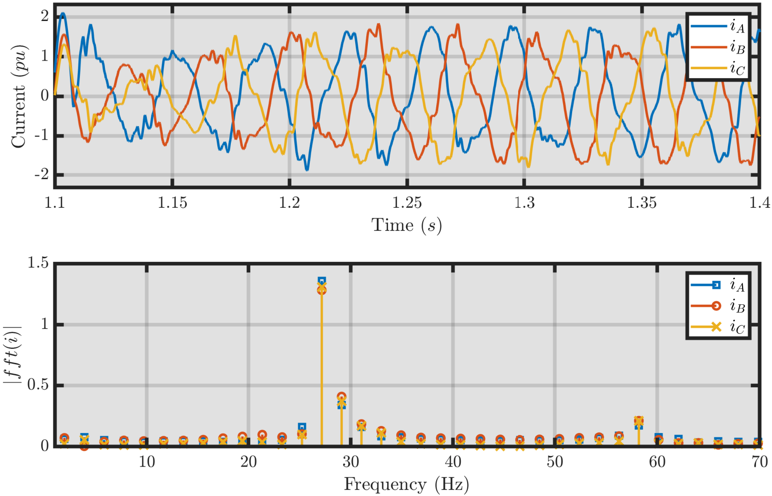

***No protection operated***

# Subsynchronous Operation [7.5m/s]: Currents




$f_{meas} = 27.15 \times f_{scan} = 27.8$ / window $= 500ms$

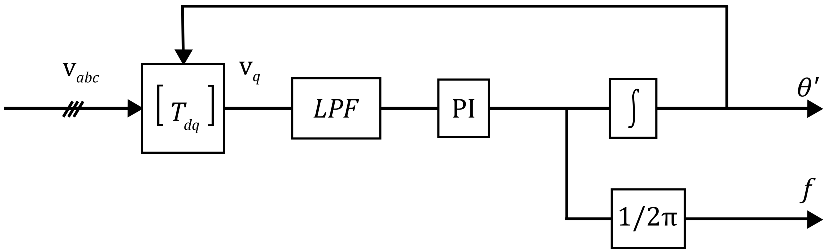
# Subsynchronous Operation [7.5m/s]: Currents




$f_{meas} = 27.15 \times f_{scan} = 27.8$ / window $= 500ms$

# Parametric Study of the PLLs

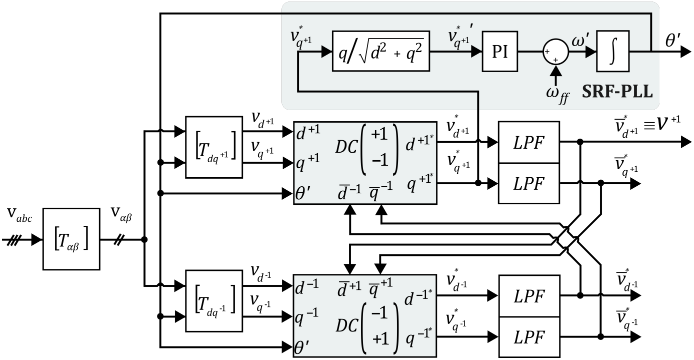
# PLL 1 - Conventional Design




## Studied Parameters:

1. Proportional gain $K_p = 33$
2. Integral gain $K_i = 100$

# PLL 2 - Decoupled Double Synchronous Reference

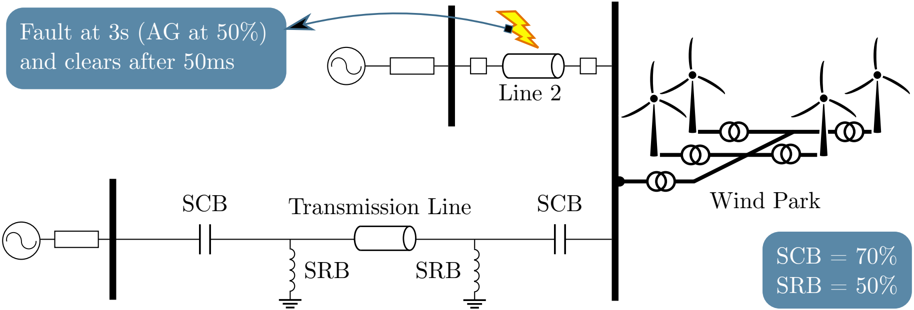



## Studied Parameters:

1. Proportional gain $K_p = 33$
2. Integral gain $K_i = 100$

DDSR = Decoupled Double Synchronous Reference

# Power System




## Parameters:

- 500kV, 400km Transmission Line
- Type 3 WTG, $400 \times 1.66 = 666.8$ MVA, 9.4 m/s
- Two PLLs and different values for $K_p$ and $K_i$

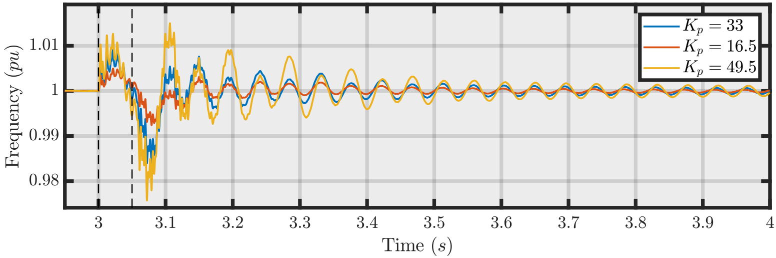
# Parametric Study of the PLLs

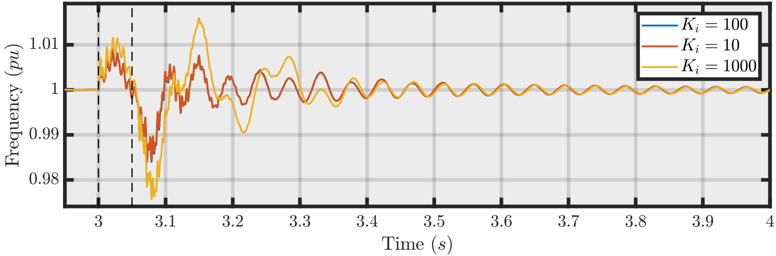
## Summary:

- Conventional PLL vs DDSR PLL
- $K_p \rightarrow$ +/- 50% $\rightarrow$ 16.5, 33, and 49.5
- $K_i \rightarrow \times 10$ and $\times 0.1 \rightarrow$ 10, 100, and 1000

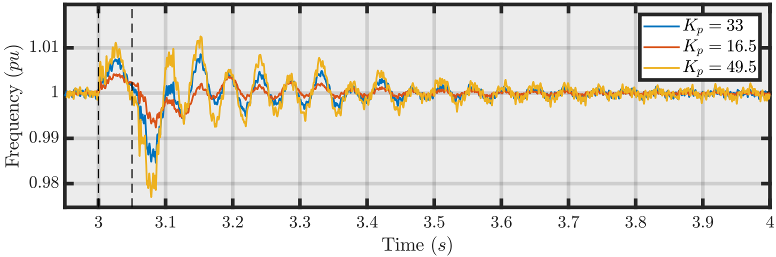
| Study | PLL | Description | Simulations |
|---|---|---|---|
| I | Conventional | AG fault | 5 |
| II | DDSR | AG fault | 5 |
| III | Conventional | SSCI | 3 |
| IV | DDSR | SSCI | 3 |

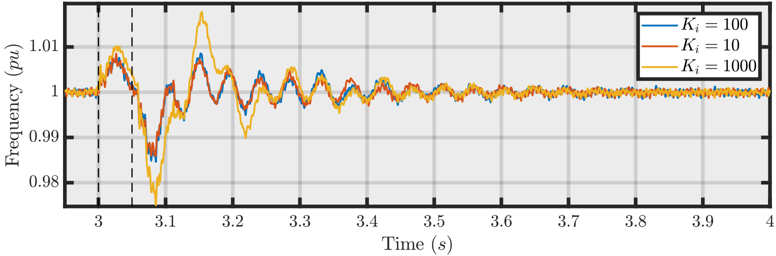
# Conventional PLL - Response after Disturbance



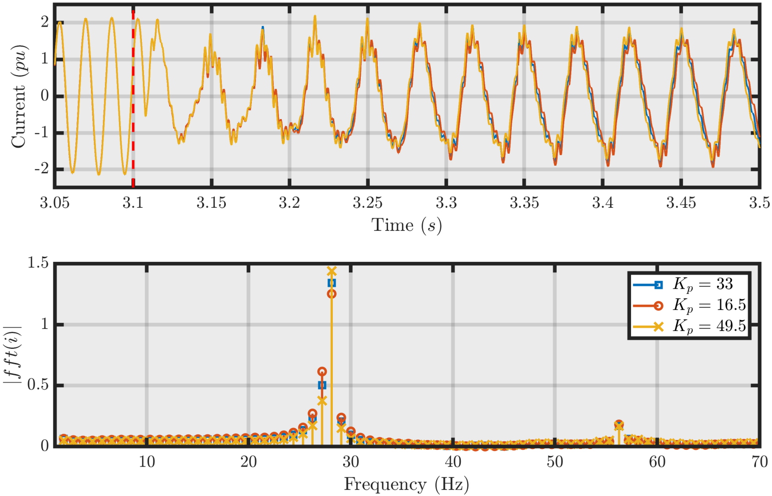



# DDSR PLL - Response after disturbance



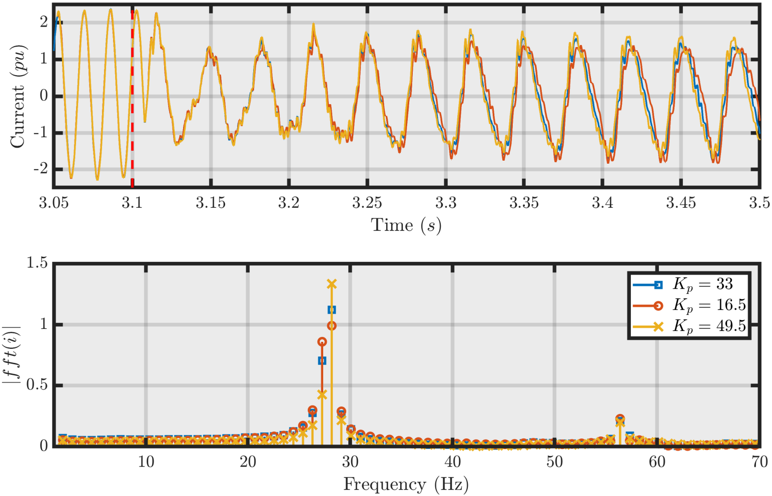



# SSCI: Conventional vs × DDSR




Conventional

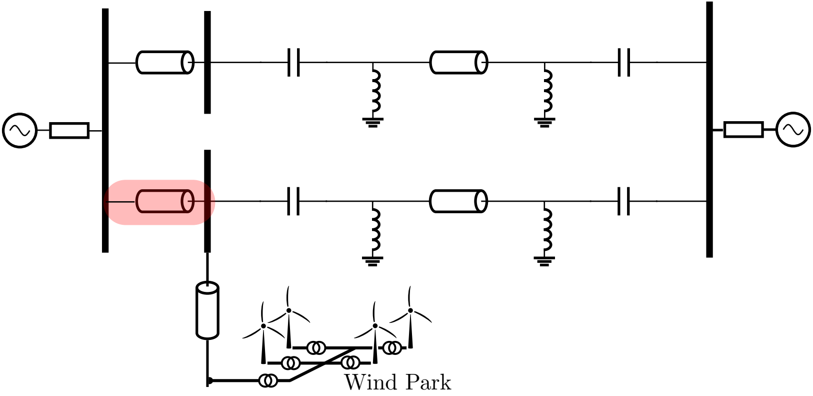
# SSCI: Conventional vs × DDSR




DDSR

# GSC effects over SSCI

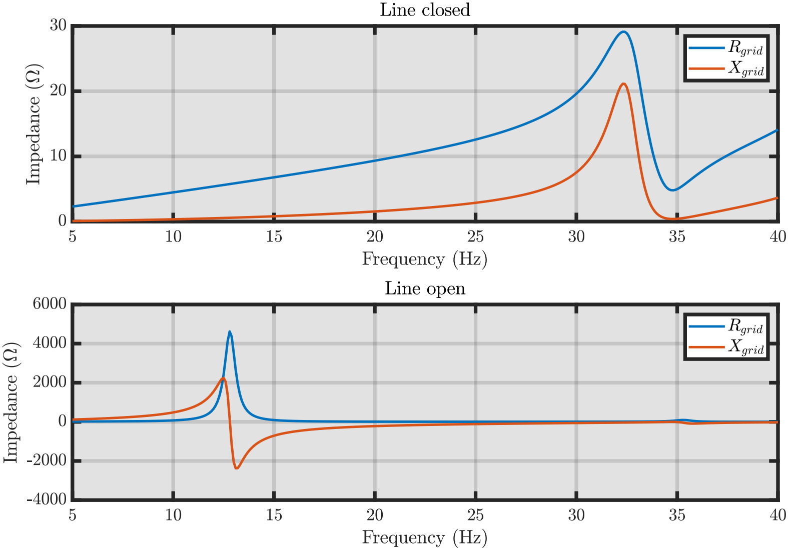
# Step IV: Transient Analysis



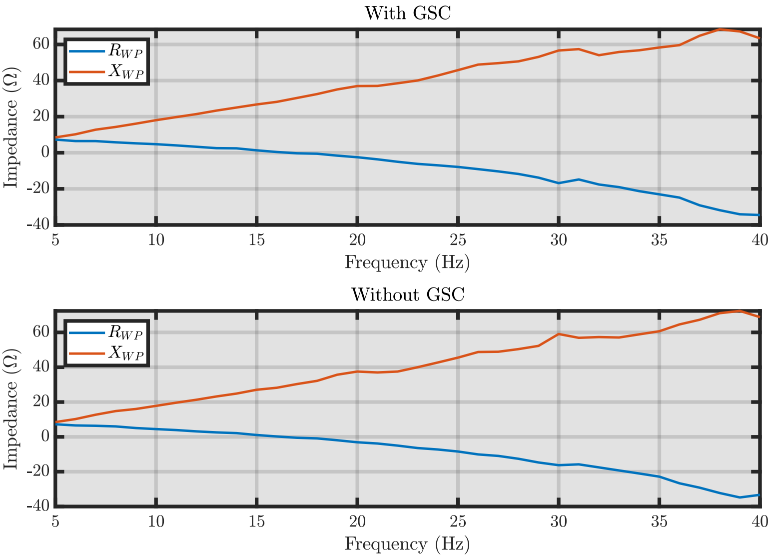

**Parameters:**

- $400 \times 1.66 = 666.8$ MVA, $v = 8.95$ m/s, slip $= 0.05$
- Line opens at 2.2s

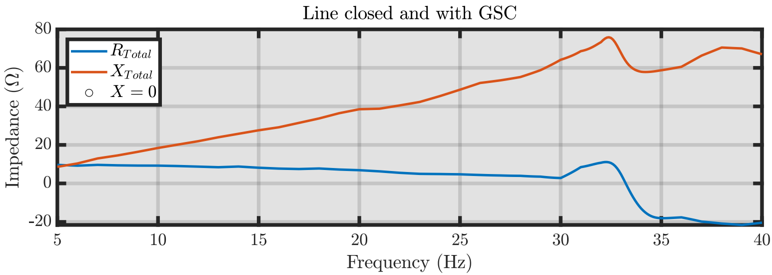
# Step I: Grid side Frequency Scan

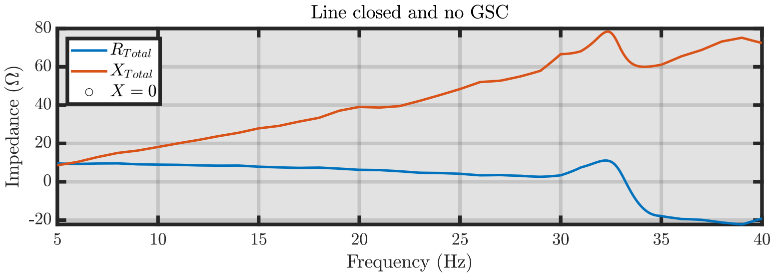


# Step II: Wind Park side Frequency Scan

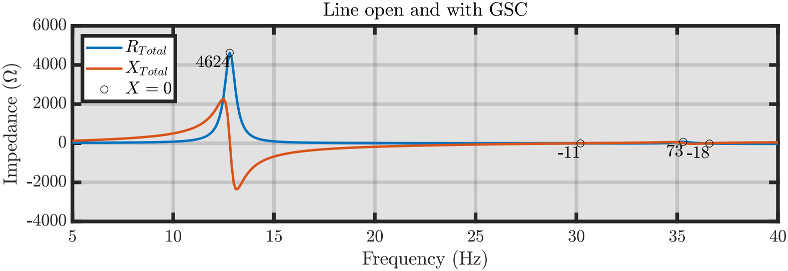


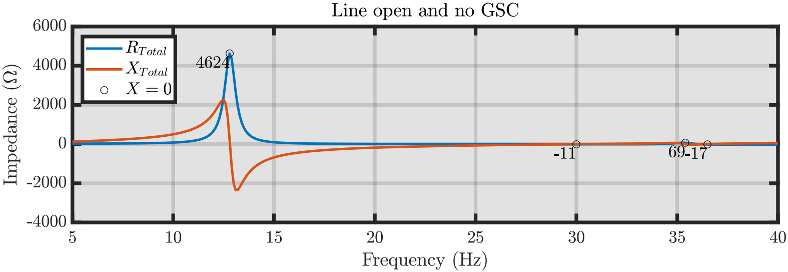
# Step III: Full Response



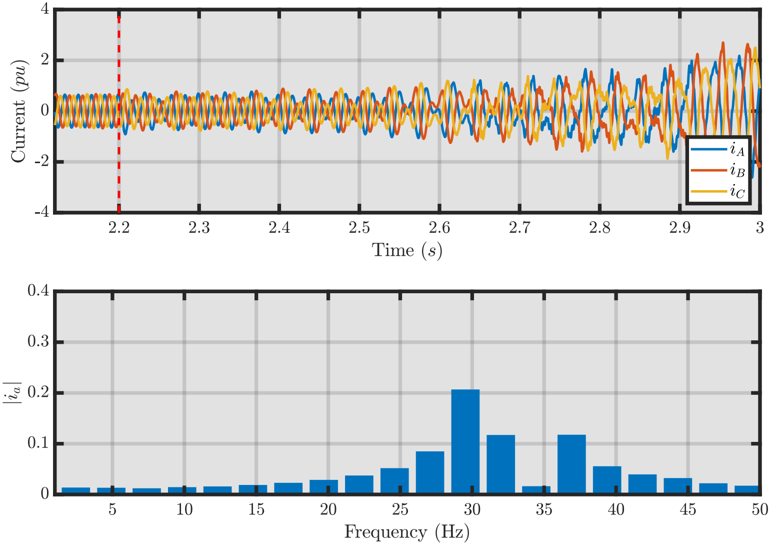



# Step III: Full Response

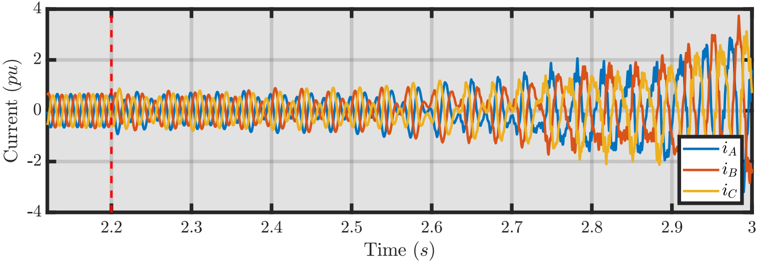


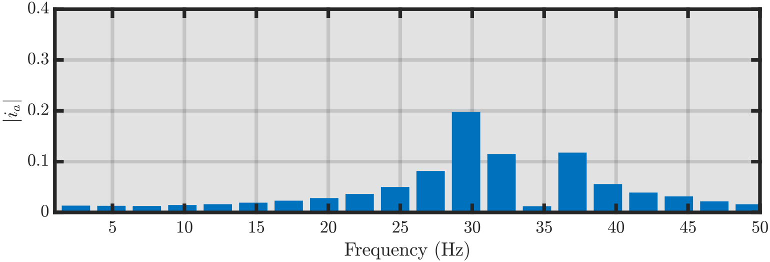



# Case 1: With the GSC



# Case 2: Without the GSC



# Conclusions

# Takeaways:

## Screening Studies Using EMTP

1. Slower wind speeds ⇒ Higher SSCI current

## PLLs: Conventional × DDSR

1. PI parameters will affect transient response
2. PLL 1 and 2 result in slightly different SSCI responses
3. A poorly tuned PI will the affects the SSCI frequency

## GSC influence over SSCI

1. GSC has small influence over SSCI
2. The Frequency response of the wind park is almost identical
3. Little influence over the resonant frequencies
4. Identical transient response for 400 ms

# Thank you!
# Any questions?

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