New Microprocessor Based Relay to Monitor and Protect Power Systems Against Sub-Harmonics

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Outline

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• Event Analysis
• Microprocessor based relay hardware architecture
• Sub harmonic detection process
• Principle of sub harmonic detection
• Operations/Minute detector
• Results and discussions
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Introduction

• Wind power based generation is growing rapidly throughout the world
• Since wind farms are generally located far away from the load centers – series compensation is used for economical reasons
• Sub Synchronous Resonance (SSR) is a well known phenomena in series compensated system and many mitigation techniques exist
Introduction..

• Sub harmonic oscillations due to wind generation interaction (controls/system) impose new challenges to today’s electrical grid.

• A new event on Xcel Energy grid with wind generator interaction with the series compensated transmission system lead to the innovation of a microprocessor based sub harmonic relay
Introduction...

- Sub harmonics is defined as the harmonic frequency below the system frequency (60 Hz or 50 Hz)
- Natural frequency of series compensated transmission system is defined by

\[ f_n = f_{sys} \sqrt{\frac{X_c}{X_{TOT}}} \]

Where,

- \( f_n \) = natural frequency (Hz)
- \( f_{sys} \) = system frequency (60 Hz or 50 Hz)
- \( X_c \) = series capacitor reactance
- \( X_{TOT} \) = sum of all the system inductive reactance (transmission line, transformer, generator sub transient reactance)

Note:

For compensation between 20% to 80%, \( f_n < 60 \) Hz which is sub synchronous frequency
Introduction....

System electrical dynamics

Generator electromagnetic dynamics

\[ C \rightarrow R_s \rightarrow L_s \rightarrow L_r \rightarrow R_r \rightarrow 1 - \frac{s_e}{s_e} R_r \]

\[ se = \frac{f_n - f_{sys}}{f_n} \]

Electrical self excitation or Induction generator effect (IGE)
Introduction…..

• SSCI –Sub Synchronous Control Instability
  – Interaction Between Power Electronics Devices (Wind Turbine, HVDC, SVC etc.) and Series Compensated Transmission System.
Introduction......

System electrical dynamics

Current

Generator electromagnetic dynamics

Voltage

Turbine mechanical dynamics

Electromagnetic torque

Shaft speed

Torsional interaction

Capacitor fault induced voltage

Current

Generator electromagnetic dynamics

Mechanical torque

Turbine mechanical dynamics

Mechanical torque amplifications
1- Breaker 1 & 2 opened for regular system switching procedure

2- CT1, CT2, and W start feeding radially through series capacitor

3- Tripped the CT generator unit

CT1, CT2 - Combustion turbine generators
W - Wind generators – as a single unit

Line 1 345 kV
345 kV
45 MVA

15 MW (20% of total generation)
Event Analysis

High speed recording of 3 phase currents captured by the DFR

9 Hz & 13 Hz dominant sub harmonics
Event Analysis

Slow speed (swing) recording of one of the phase
Relay Architecture

- Digital Inputs: 48/125/250VDC
- Outputs: Relay Output Contacts
- Analog Inputs with ADCs: 1A/5A Current, Voltage
- IRIG-B: Reference Clock

- Power Supply: 48-250VDC, 90-230VAC
- Local Power Rails

- DSP
- Glue Logic
- uP (RTOS)

- Display/Keypad
- Communication: Ethernet, Serial, USB, Modem
Relay Architecture ..
Sub Harmonic Detection
Logic Diagram
Sub Harmonic Detection

Trip or Alarm: \[ = \max (f_2, f_3, f_4, f_5, f_6, f_7) > L_{set} \]
Operations/Minute Detection

Subharmonic Level (%)

Time (minutes)

- $T_{\text{delay}}$
- $T_{\text{act}} < T_{\text{delay}}$

Set Threshold Level

Subharmonic signal level

- 30 operations/minute
Results and discussions

• RTDS (Real Time Digital Simulator)
• COMTRADE Playback
  – Nominal sub harmonic detector
  – Fundamental sub harmonic detector
  – Total sub harmonic detector
  – Operations / minute detector
Test Oscillography Files

Nominal sub-harmonic detector – 5 Hz
Test Oscillography Files

TSHD detector – 5 Hz
Test Oscillography Files

Fundamental sub-harmonic detector – 25 Hz
Test Oscillography Files

Operation/minute detector – 5 Hz and 5 operations/minute
Results and discussions

Current 1

Detector 1
- Name: Current 1 Detect 1
- Pickup Delay: 10 s
- Minimum Frequency: 5 Hz
- Maximum Frequency: 5 Hz
- Nominal Ratio: Enabled, Setting: 10 %
- Fundamental Ratio: Enabled, Setting: 20 %
- Total Sub-Harmonic Distortion: Enabled, Setting: 10 %
- Operations/Minute Setting: Enabled, Setting: 2 operations/minute

Detector 2
- Name: Current 1 Detect 2
- Pickup Delay: 10 s
- Minimum Frequency: 10 Hz
- Maximum Frequency: 10 Hz
- Nominal Ratio: Enabled, Setting: 20 %
- Fundamental Ratio: Enabled, Setting: 20 %
- Total Sub-Harmonic Distortion: Enabled, Setting: 100 %
- Operations/Minute Setting: Enabled, Setting: 60 operations/minute
Conclusions

• The event captured at the Xcel Energy Utility lead to the development of a new microprocessor based sub harmonic protection technique.

• With the increase use of wind generators feeding HV and EHV utility networks, it is necessary to ensure that sub harmonic oscillations are monitored, and that the electrical grid is protected from any resulting detrimental effects.
Conclusions ..

• The performance of the sub-harmonic protection technique was successfully tested using a Real Time Digital Simulator (RTDS)

• The tests demonstrated that the solution is capable of performing reliably the following functions:
  – Nominal sub-harmonic detection
  – Fundamental sub-harmonic detection
  – Total sub-harmonic detection
  – Operations/Minute detection