Modeling of Large Wind Farm Systems for Dynamic and Harmonics Analysis

Part 2- Harmonics Analysis

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Agenda

- Modeling of different elements in a typical wind power plant (WPP) for harmonics analysis
- Potential parallel and series resonance problems
- Problems associated with harmonics and solutions
- Two case studies
- Conclusions

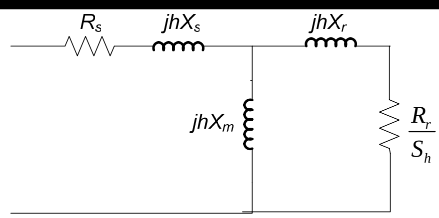
Harmonics Problem in a Wind Power Plant (WPP Why?

- The significant amount of capacitance in a typical wind farm
- Harmonics current injected from certain types of wind turbines
- Background harmonics voltage existing in the transmission networks
- These values will be always changing based on the operating scenario
- Resulting in a high potential for resonance problems to occur

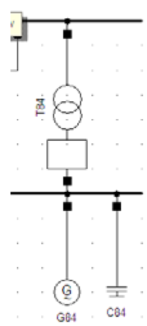
Harmonics Analysis Methods

- *Frequency Scan Analysis*
  - Plot of the magnitude of the driving point impedance at a certain bus versus harmonic order
  - Used to identify resonance frequencies
- *Harmonics Power Flow Analysis*
  - It can be performed in the frequency or the time domains
  - Used to calculate harmonic distortion indices such as voltage THD.

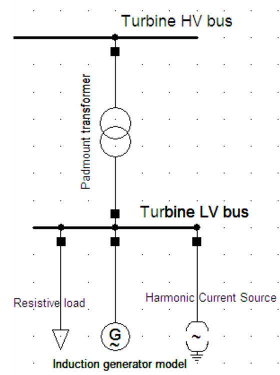
Modeling of Wind Turbine Generator



$$S_h = \begin{cases} 1 - \dfrac{n}{hn_s} & \text{for +ve sequence harmonics} \\ 1 + \dfrac{n}{hn_s} & \text{for -ve sequence harmonics} \end{cases}$$

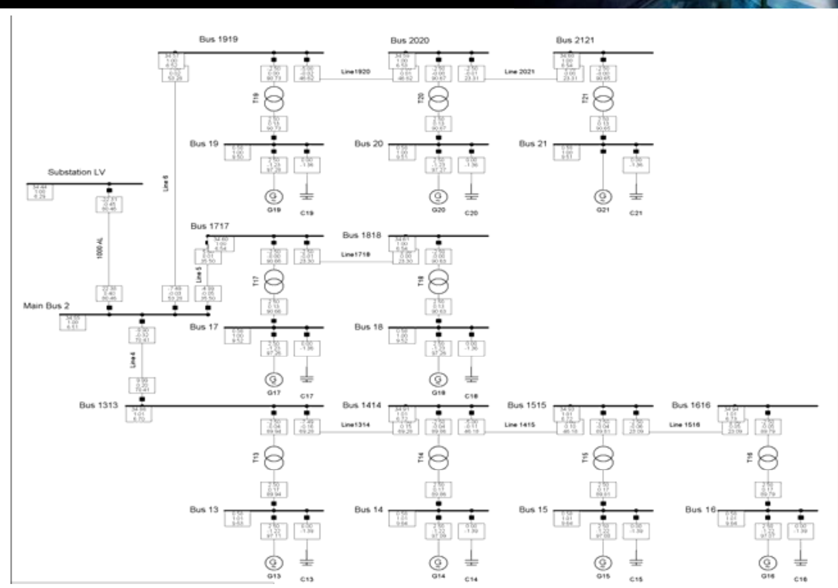


Types A & B

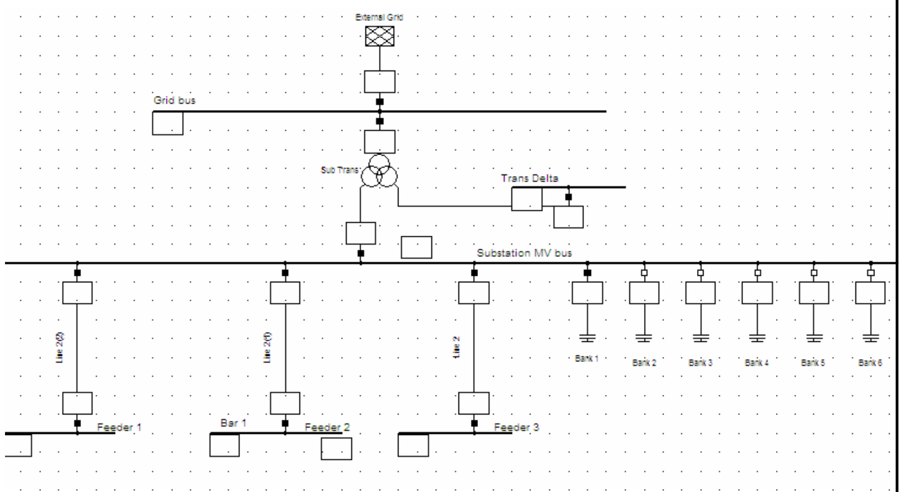


Types C & D

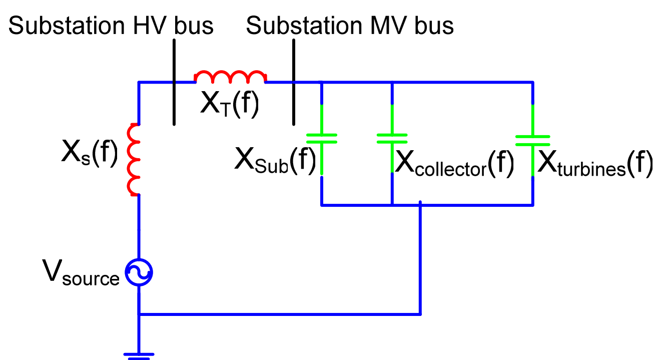
Typical Wind Power Plant (collector)



Typical Wind Power Plant (substation)



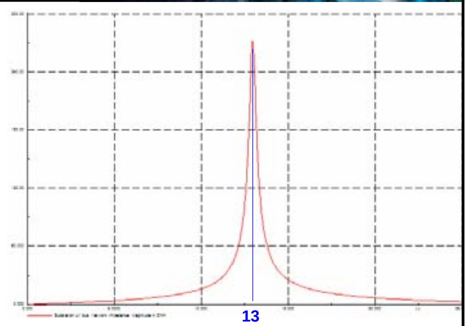
Simplified Model for WPP for Harmonics Analysis

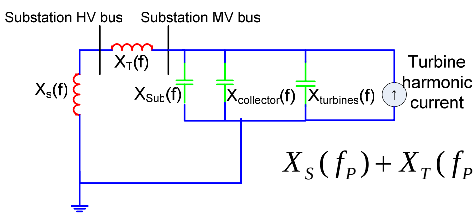


- $X_{Sub}(f)$: The total capacitance of substation capacitor banks
- $X_{turbine}(f)$: The total capacitance of turbines capacitor banks
- $X_{collector}(f)$: The total capacitance of collector system cables
- $X_T(f)$: The inductance of substation transformer
- $X_S(f)$: The equivalent inductance of the external grid

Parallel Resonance Problem

Parallel resonance frequency is (f_p) the frequency that has a high impedance value at frequency scans at the ***substation MV bus*** for certain operating scenarios



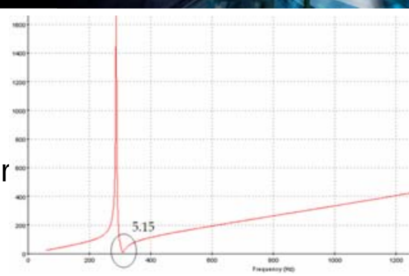


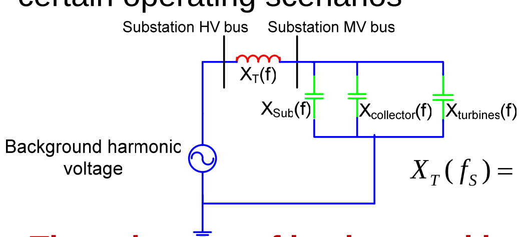
$$X_S(f_P) + X_T(f_P) = X_{sub}(f_P) + X_{collector}(f_P) + X_{turbines}(f_P)$$

When harmonic current with this frequency is produced by wind turbines, it will result in high harmonic voltage value at this frequency at this bus

Series Resonance Problem

Series resonance frequency (f_S) is the frequency that has a zero (very low) impedance value at frequency scans at the ***substation HV bus*** for certain operating scenarios





$$X_T(f_S) = X_{sub}(f_S) + X_{collector}(f_S) + X_{turbines}(f_S)$$

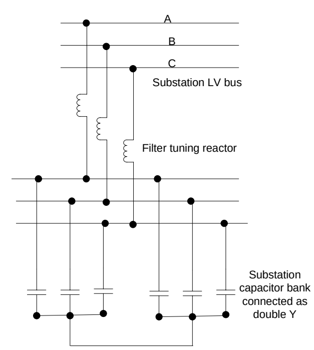
The existence of background harmonic voltage at this frequency results in the amplification of this background harmonic voltage at the substation MV bus for certain operating scenarios

Potential Problems due to Resonance

- The rms current in the substation capacitor banks could be higher than 135% of its rating current violating IEEE 18-2002 (standards for shunt power capacitors)
- Excessive voltage THD at the substation MV bus
- The harmonics current injected from the WPP at the PCC could violate IEEE-519-1992 (recommended practices and requirements for harmonic control in electrical power systems)

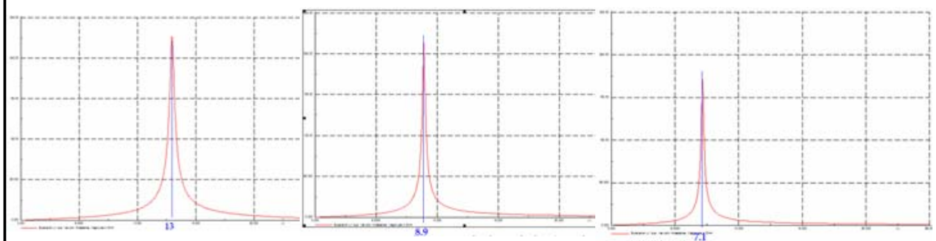
Solutions to Overcome Harmonic Problems

- In the design stages, the size of the substation capacitor banks can be adjusted to avoid the occurrence of resonance at certain frequencies
- The use of C type filters. These convert the substation capacitor bank into a shunt filter with damping.
- Series filters that are built by the addition of series reactors to the substation capacitor bank, so that the resulting impedance has series resonance that results in shifting substation resonance to a less problematic frequency.



First Case Study (Frequency Scans)

- A 200 MW wind farm consists of 100 2-MW DFIG turbines with 6 steps, 12 MVAR each of reactive power installed on the substation MV bus



Zero MVAR　　12 MVAR　　24 MVAR

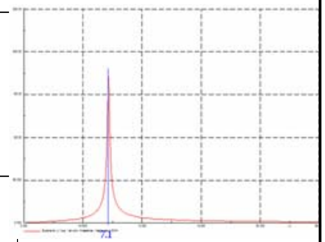
Frequency scans with different number of capacitor banks switched at the substation

First Case Study (Harmonics Power Flow Results)

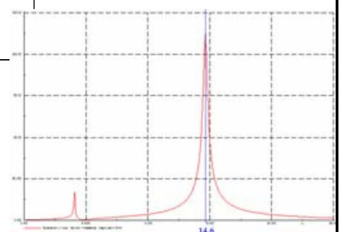
Reactive power support	34.5 kV bus			12 MVAR capacitor bank harmonic current as percentage of fundamental current
	Voltage pu	Individual voltage HD%	Voltage THD %	
0x12 MVAR	0.97 pu	V_5=0.84% V_7=2.09% V_{11}=1.43% **V_{13}=6.3%** V_{17}=0.22%	**6.86%**	-----
1x12 MVAR	0.98 pu	V_5=1.43% V_7=**6.03%** V_{11}=0.28% V_{13}=0.12% V_{17}=0.11%	**6.22%**	I_5= 6.7% I_7= 41% I_{11}= 3% I_{13}=1.5% I_{17} =1.8% I_{rms}=108%
2x12 MVAR	1.18 pu	V_5=3.12% **V_7=9.31%** V_{11}=0.18% V_{13}=0.08% V_{17}=0.07%	**10.1%**	I_5=15.5% **I_7= 65%** I_{11}= 2% I_{13}= 1.0% I_{17} = 1.0% I_{rms}=120%

First Case Study (Harmonics Power Flow Results after adding Series Reactors

Reactive Power support	34.5 kV bus			12 MVAR capacitor bank harmonic current as percentage of fundamental current
	Voltage pu	Individual voltage HD%	Voltage THD %	
1x12 MVAR	0.98 pu	V_5=0.43% V_7=0.37% V_{11}=0.46% V_{13}=1.5% V_{17}=0.37%	1.97%	I_5=3.6% I_7= 2.0% I_{11}=1.0% I_{13}=0.85% I_{17} =0.5% I_{rms}=101%
2x12 MVAR	0.99 pu	V_5=0.41% V_7=0.36% V_{11}=0.48% V_{13}=0.54% V_{17}=0.47%	1.23%	I_5=2.0% I_7= 2.0% I_{11}=1.1% I_{13}= 1.0% I_{17} = 0.6% I_{rms}=101%



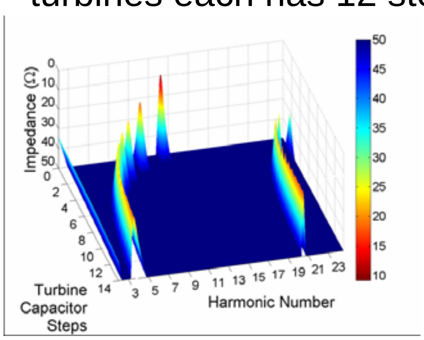
Before reactor addition



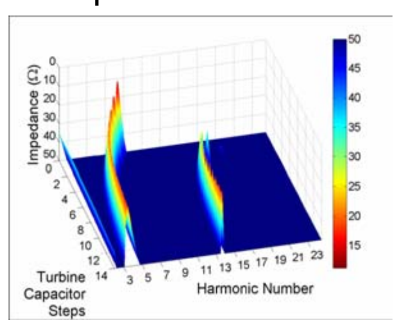
After reactor addition

Second Case Study (Frequency Scans)

- A 150 MW wind farm consists of 100 1.5-MW Type A turbines each has 12 steps of capacitor banks



Zero MVAR at the substation

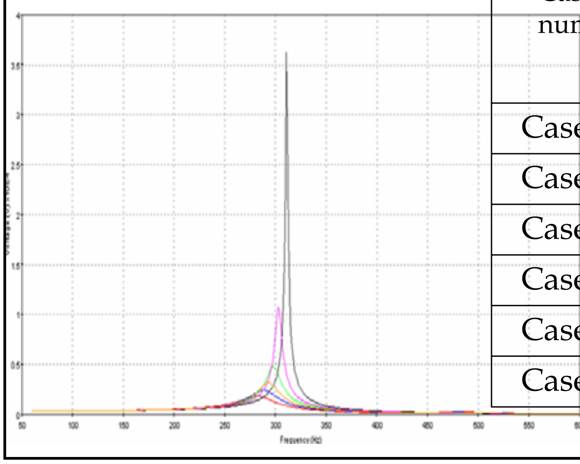


One substation capacitor bank switched

Frequency scans with different number of turbine and substation capacitor banks

Second Case Study (Harmonic power flow)

Apply 1% background harmonic voltage at substation HV bus and monitor the harmonic voltage at the substation MV bus for the operating scenarios with series resonance around the 5th harmonic



Case number	Fifth harmonic voltage at the 34.5 kV bus
Case 1	11.5%
Case 2	26.7%
Case 3	15.8%
Case 4	9.06%
Case 5	6.31%
Case 6	4.16%

Conclusions

- Harmonics analysis is a vital part in the pre-construction design stages of new wind power plants
- Frequency scans and harmonic power flow are performed on an accurate frequency dependent models of the wind power plant .
- Background harmonics measurement is necessary to determine the potential of its amplification due to series resonance
- Harmonic contents of line current at different loading levels should be supplied by turbine manufacturers to determine the potential of parallel resonance
- Different filtering solutions should be examined

Questions?