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Chicago

Harmonic Distortion Control and reactive Power Compensation in a large Wind Mill Generation Plant

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Introduction

- Wind Power-One of the foremost renewable (Green Energy Sources)
- 94 GW of Wind Power Added till end of 2007 worldwide
- USA ranks second in the world in installed wind power capacity-installed capacity 65 GW as in 2013.

Introduction

- Largest wind turbine=8 MW and smaller less than 100 kW.
- DOE/NREL initiative is 20% land based and off-shore wind power generation =300 GW by 2030.

INTRODUCTION

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1. Wind Power Plants have stringent requirements for connections to utility
2. All configurations are not suitable to meet these requirements
3. Harmonics and Harmonic resonance is an important consideration
4. Reactive Power compensation is required.
5. Transient stability and low-voltage ride through is a consideration
6. Fault voltage ride through capability is a consideration

INTRODUCTION

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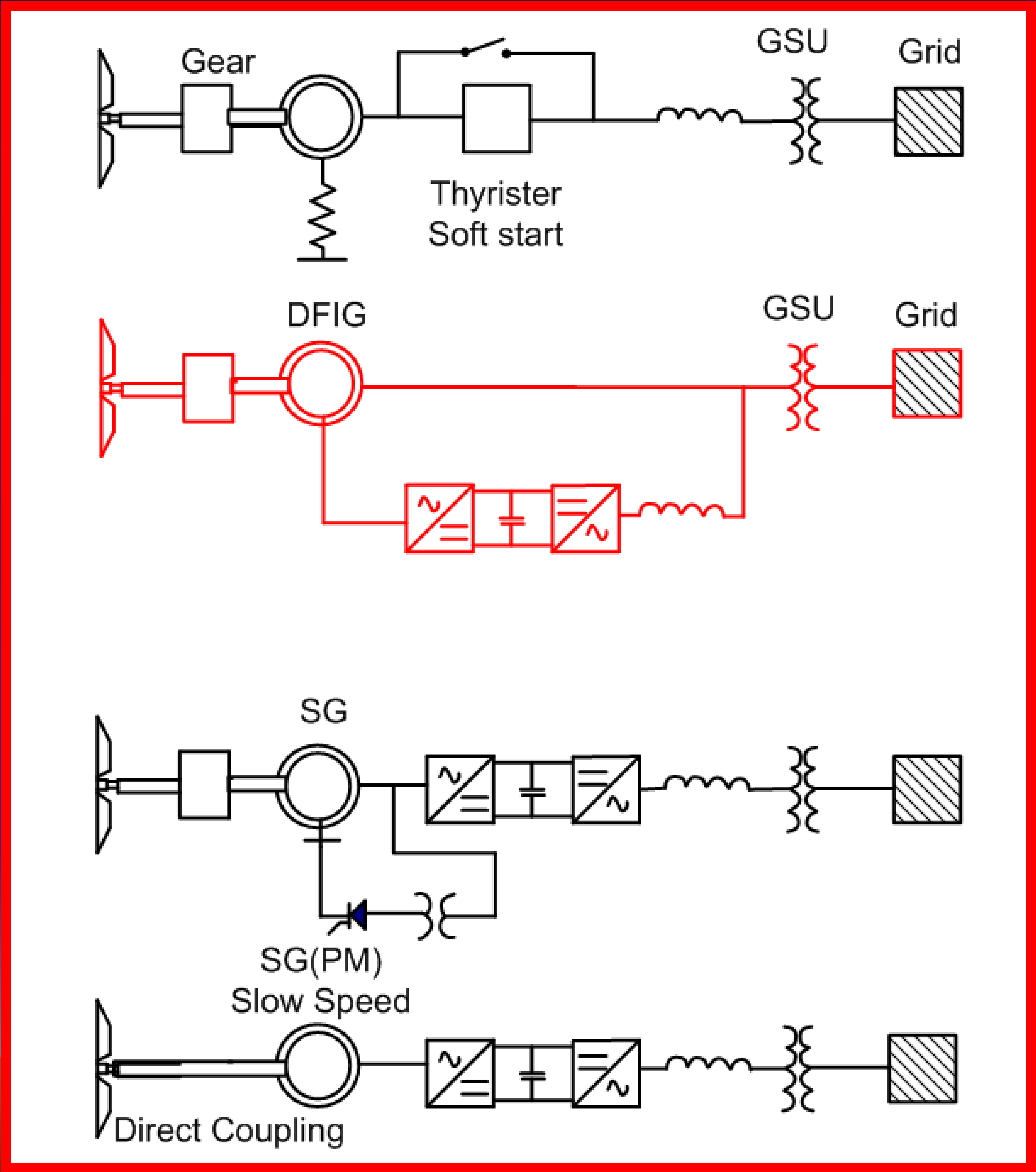
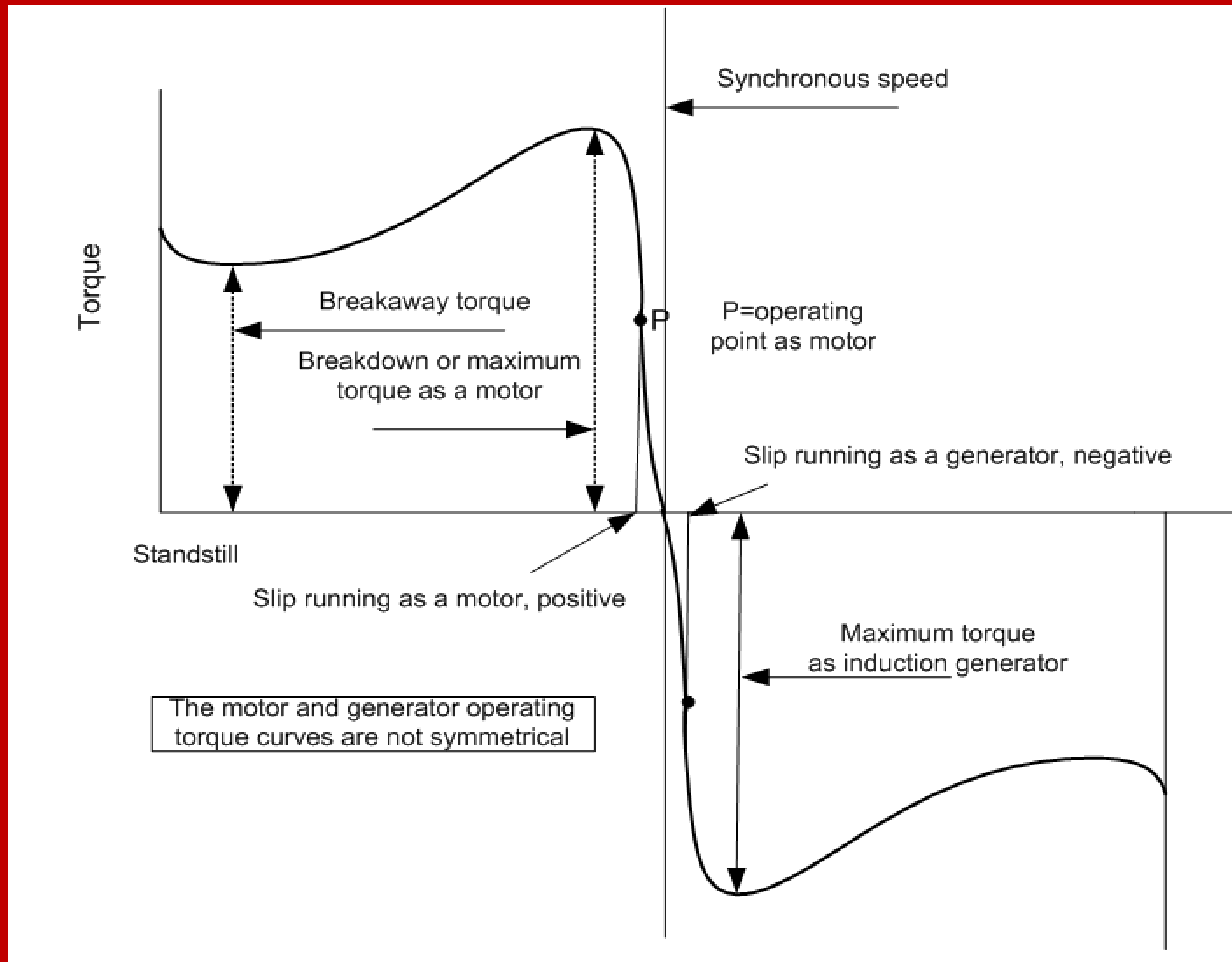
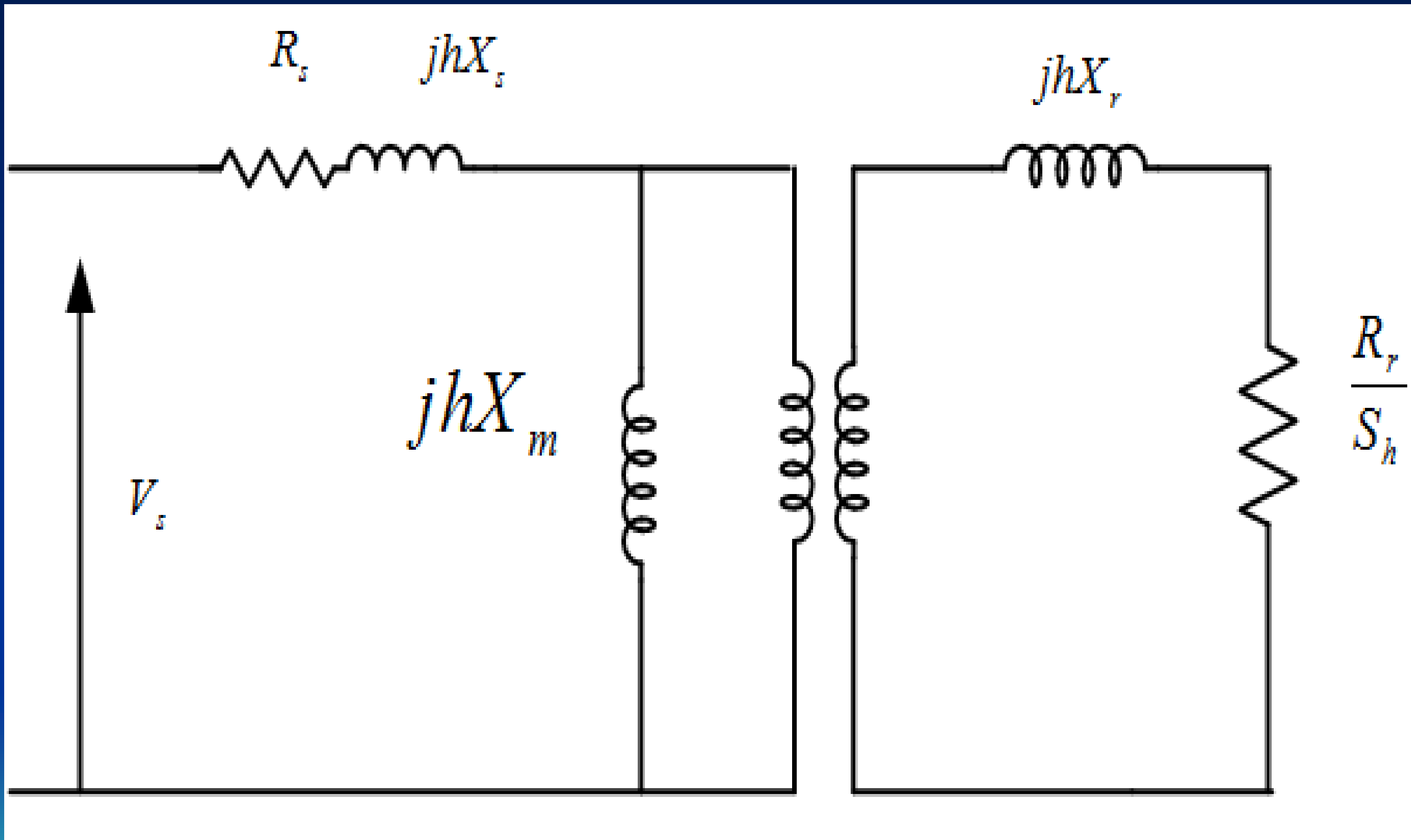
1. The paper presents reactive power compensation, harmonic analysis study, and passive and active reactive power compensation in a 100 MW wind generation plant with
AMBIENT HARMONICS

2. DFIG Models and characteristics.


Gear
GSU
Grid
Thyrister
Soft start
DFIG
GSU
Grid
SG
SG(PM)
Slow Speed
Direct Coupling


Synchronous speed
Torque
Breakaway torque
P
P=operating
point as motor
Breakdown or maximum
torque as a motor
Slip running as a generator, negative
Standstill
Slip running as a motor, positive
Maximum torque
as induction generator
The motor and generator operating
torque curves are not symmetrical

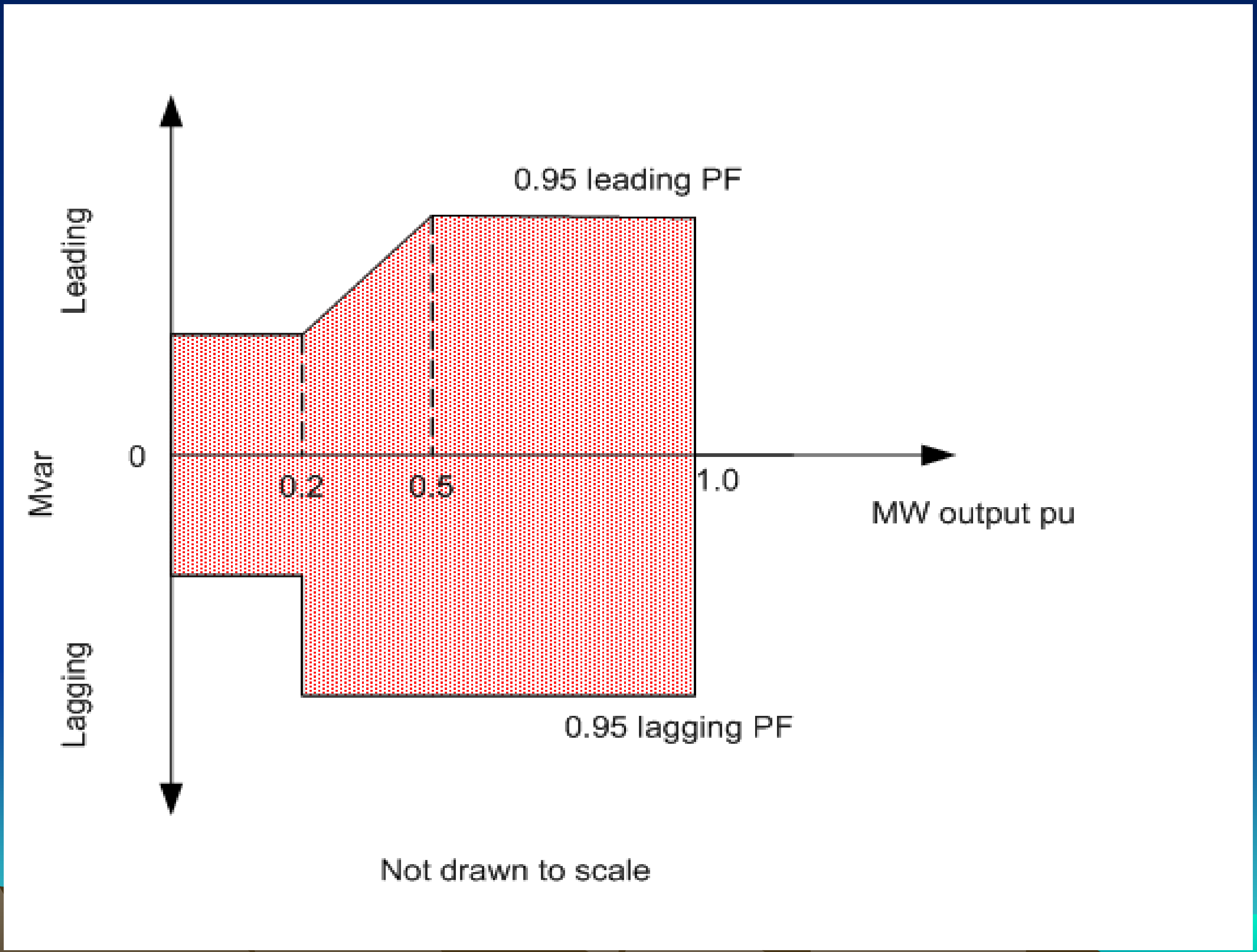

R_s
jhX_s
jhX_r
jhX_m
V_s
$\frac{R_r}{S_h}$

$$Q = \frac{-b}{2a}V_1^2 + \frac{\sqrt{(b^2 - 4ac)V_1^4 + 4aPV_1^2}}{2a}$$

Reactive power Required by DFIG

$$Q = \frac{-b}{2a}V_1^2 + \frac{\sqrt{(b^2 - 4ac)V_1^4 + 4aPV_1^2}}{2a}$$

Operational requirements for Connection to Utility source



First set of studies

- Reactive power cpmpensation
- Fault levels and short-circuit Analysis
- Variations in active power generation in course of a day, month to month
- Peak and lowest raw electricity that will be generated.

Modeling for Harmonic Studies

NOT DISCUSSED, see References provided.

The power system components must be correctly modeled , for higher frequencies.

As an example consider model of long cables.

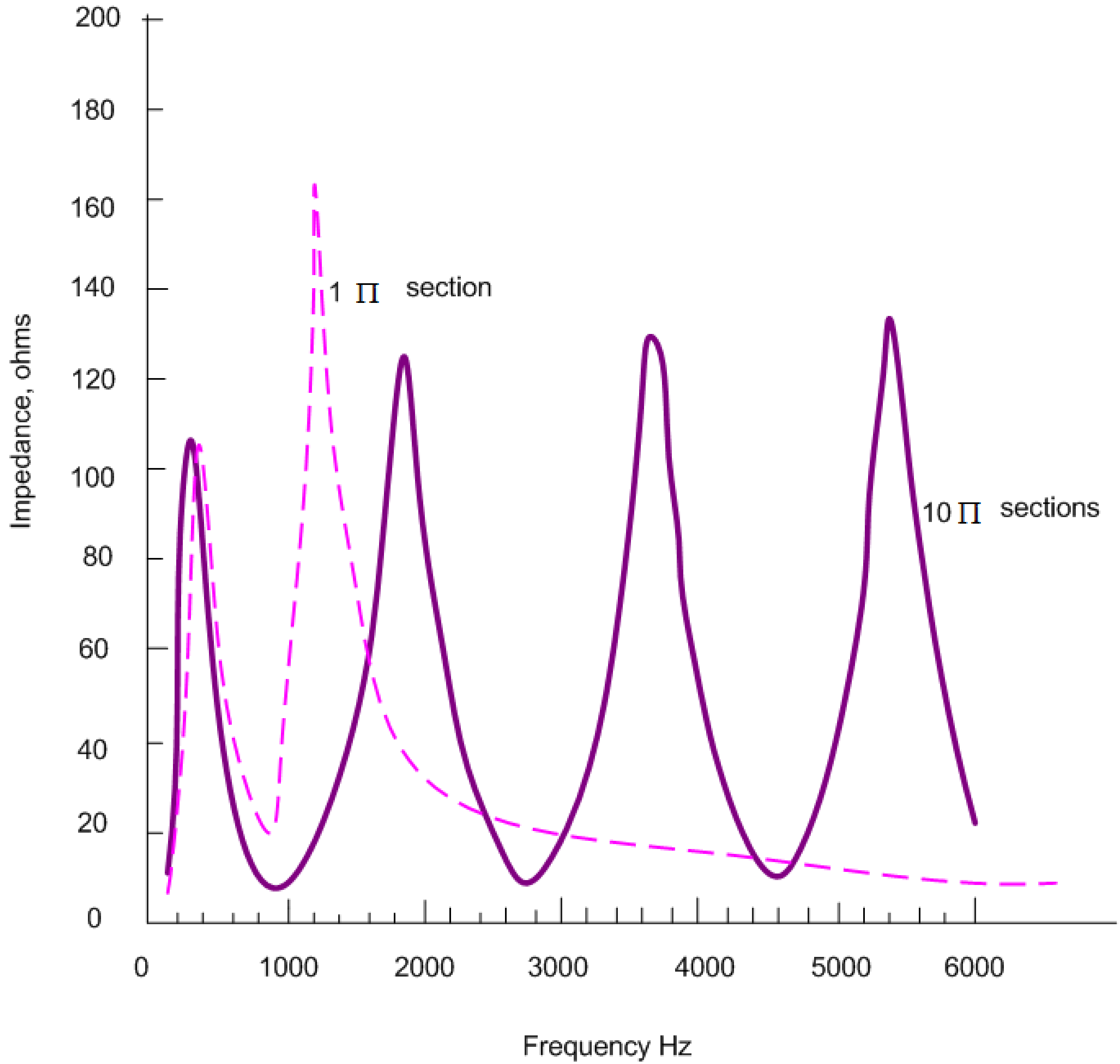
Modeling for Harmonic Studies

Consider 34.5 kV cable 1 mile long.

Use two models

1. One single PIE model
2. 10 PIE models in series

Observe different simulation results.



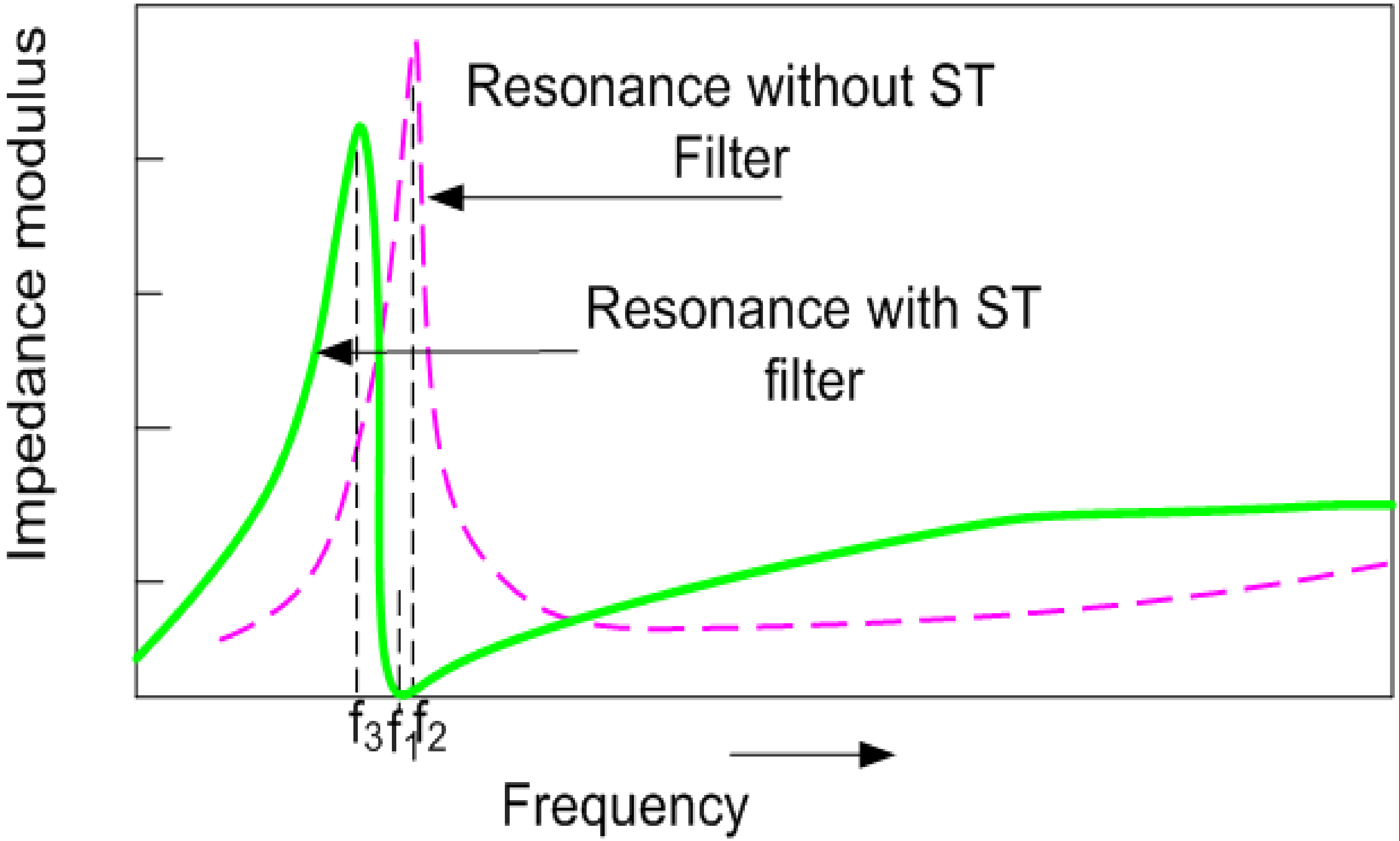
200
180
160
140
120
100
80
60
40
20
0
Impedance, ohms
1 Π section
10 Π sections
0
1000
2000
3000
4000
5000
6000
Frequency Hz

Harmonic control and reactive power compensation

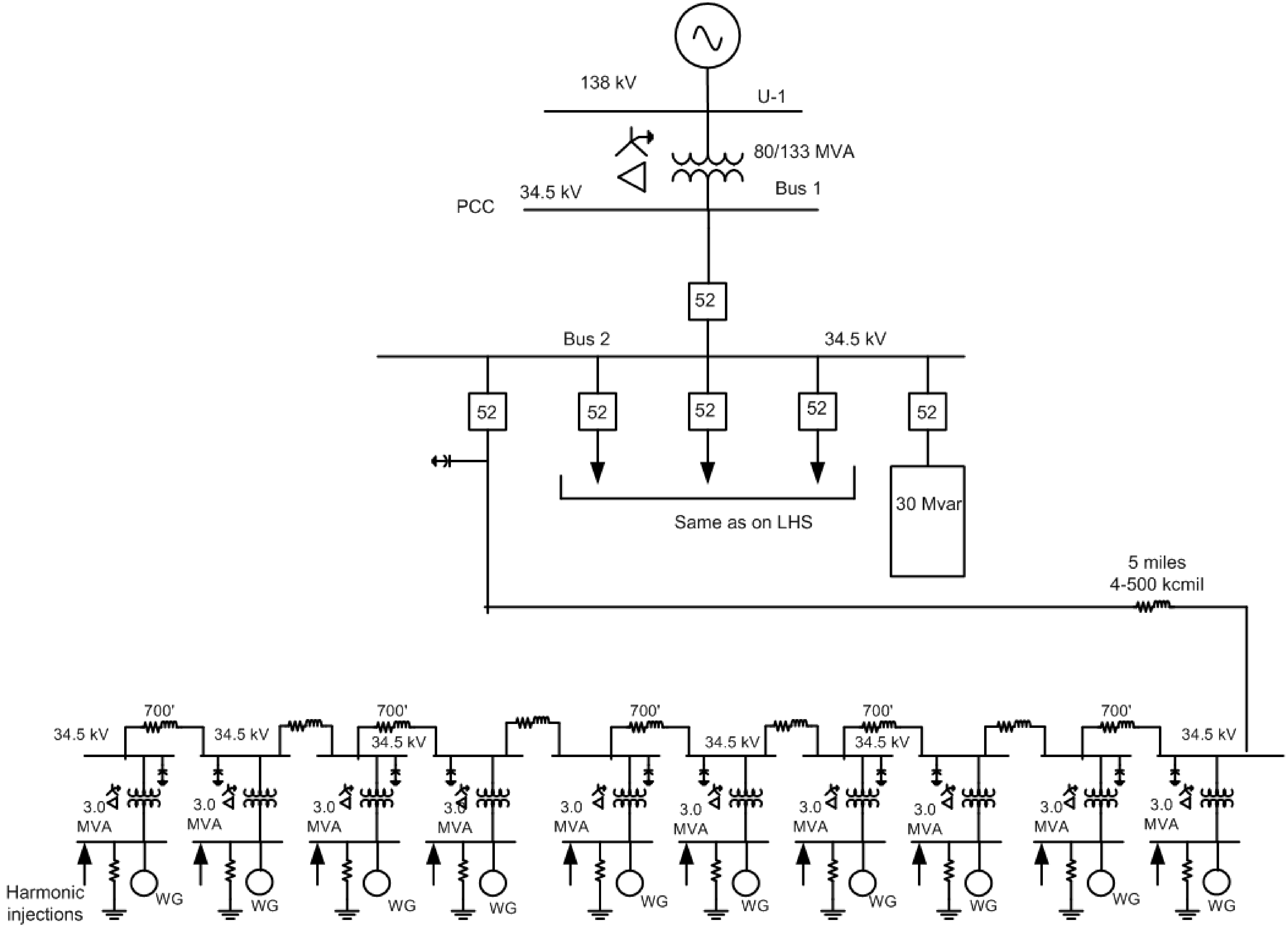
- Reactive power compensation and harmonic control can be simultaneously provided
- ST filters
- Type C filters
- Damped filters-first second and third order
- TCR
- TSC
- STATCOM

Harmonic control and reactive power compensation

- Filter Technologies not discussed in the paper.
- Consider for example ST filters, which are very efficient, but have the limitation that the resonance frequency shifts to a lower value



Impedance modulus
Resonance without ST
Filter
Resonance with ST
filter
f3 f1 f2
Frequency



138 kV
U-1
80/133 MVA
34.5 kV
PCC
Bus 1
52
Bus 2
34.5 kV
Same as on LHS
30 Mvar
5 miles
4-500 kcmil
700'
34.5 kV
3.0
MVA
WG
Harmonic
injections

Ambient Harmonics

- 5^{th}=3%
- 7^{th}=2.0%
- 11^{th}=1.5%
- 13^{th}=1.0%
- 17^{th}=0.5%
- (Ambient Harmonic Distortion at Utility source=4.06%)

Study Steps

- 30 Mvar reactive power compensation is required.
- Establish harmonics without 30 Mvar shunt capacitor banks
- Ascertain harmonic resonance with 30 Mvar capacitor bank
- Provide filters for mitiagation to meet IEEE 519 limits.

Harmonics from DFIG

- Very Important that harmonic emission from DFIG is correctly modeled.
- Obtain data from manufacturer-preferably.

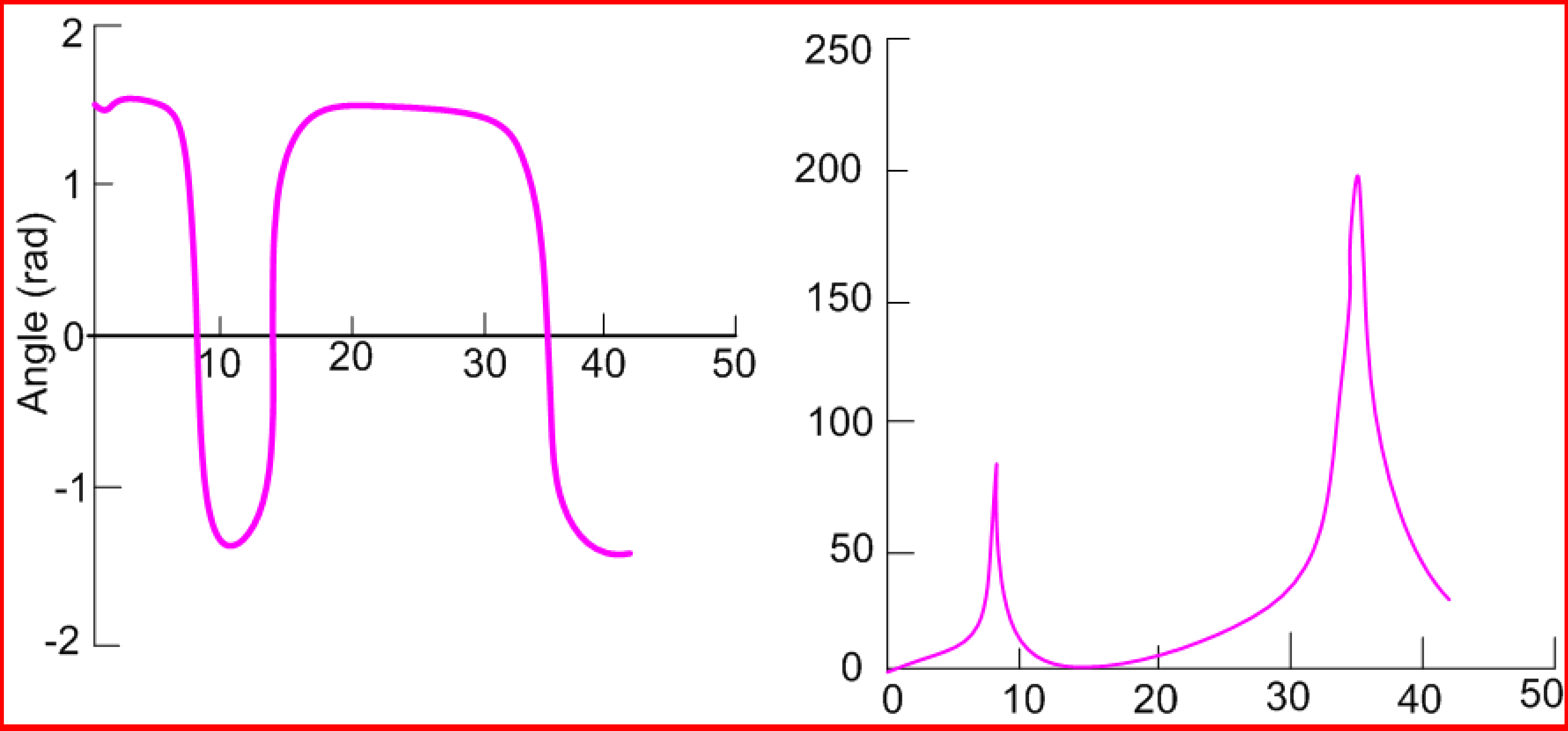
Planning Levels for Harmonic Voltages in Systems >20 kV and <145 kV. (Energy Network Association UK)

Odd Harmonics		Triplen Harmonics		Even Harmonics	
Order	Voltage %	Order	Voltage %	Order	Voltage %
5	2.0	3	2.0	2	1.0
7	2.0	9	1.0	4	0.8
11	1.5	15	0.3	6	0.5
13	1.5	21	0.2	8	0.4
17	1.0	>21	0.2	10	0.4
19	1.0			12	0.2
23	0.7			>12	0.2
25	0.7				
>25	0.2+0.5(25/h)				

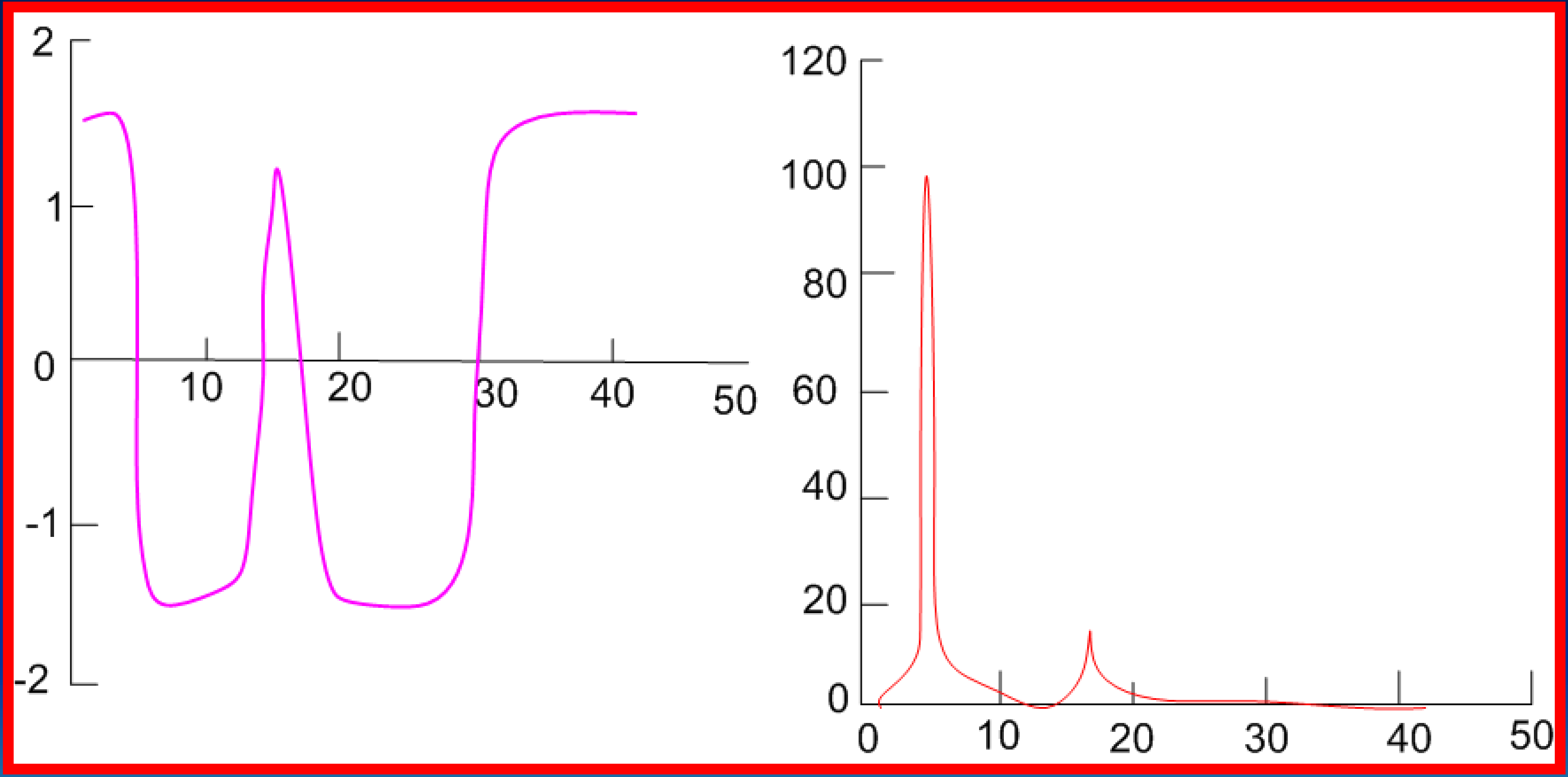
Typical Harmonics from DFIG

Harmonic Order	Harmonic Current % of fundamental	Harmonic Order	Harmonic Current % of fundamental
2	1.0	17	0.76
3	0.51	19	0.42
4	0.43	22	0.33
5	1.32	23	0.41
6	0.42	25	0.24
7	1.11	26	0.2
8	0.42	28	0.15
10	0.61	29	0.27
11	1.52	31	0.24
13	1.91	35	0.35
14	0.50	37	0.26
16	0.37		

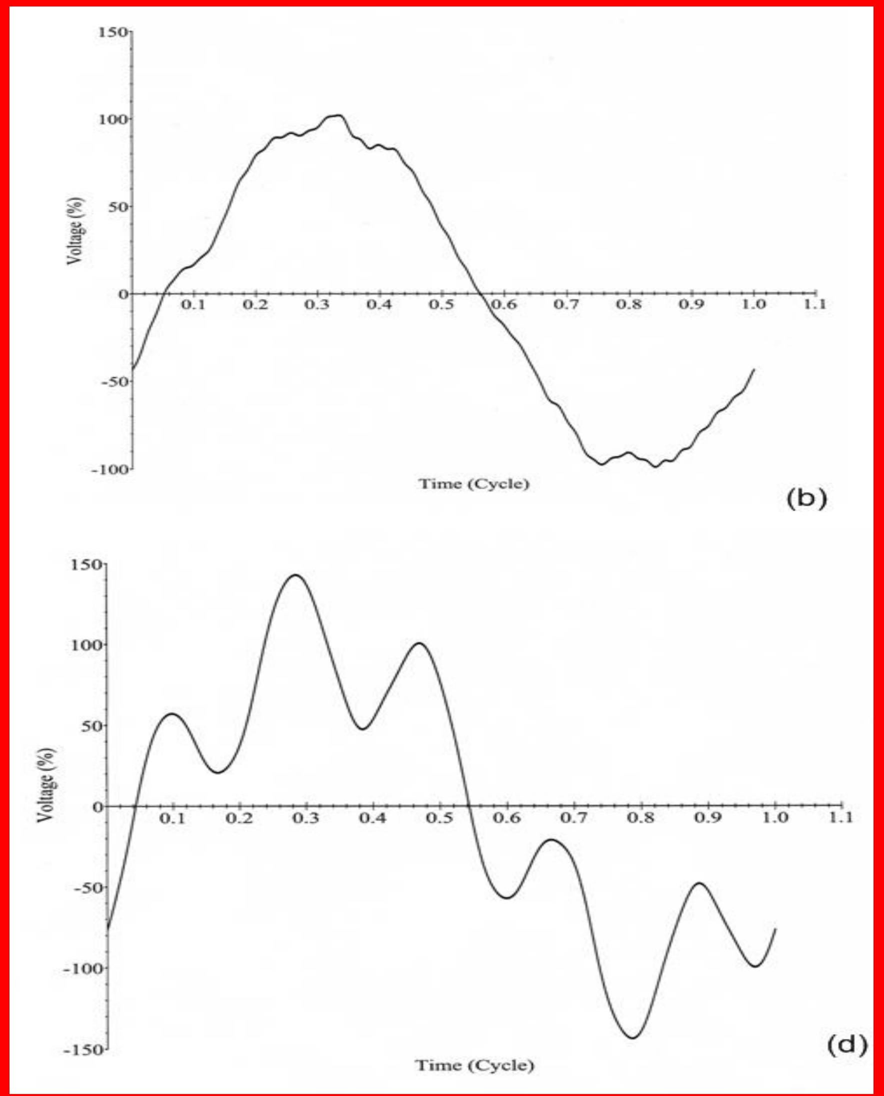
Without 30 Mvar Bank



With 30 Mvar Bank



Waveforms without and with 30 Mvar bank



Study with 30 Mvar bank

- TDD permissible as per IEEE 519=5%
- Without 30 Mvar bank, TDD=4.39%
- With 30 Mvar bank= 73.80%
- Resonance occurs at 5th harmonic
- See Table 3 of the paper-not reproduced.

Study with 30 Mvar bank

- Voltage distortion with 30 Mvar bank=44.25%
- 43.82% distortion occurs at 5th harmonic
- Permissible limit = 5%
- Resonance established at 5th harmonic
- See Table 4 of the paper-not reproduced.

Study with various filter types for harmonic control

- Turn 30 MVAR bank into a ST filter-try various tuning frequencies.
- Two ST filters with a third damped filter-total amounting to 60 Mvar
- Gives better control of harmonics, but this is not acceptable.
- Use a 30 Mvar STATCOM.
- The STATCOM itself is not free of harmonics and does produce some
- Harmonics which should be modeled.
- The results with STATCOM are approximately acceptable-
- see Table 5, except that :

8^{th} harmonic = 2.88% Permissible=1.0% (TDD)

11^{th} harmonic = 2.33% Permissible 2.0% (TDD)

Harmonic Order	With STTATCOM	IEEE Limits	Voltage Distortion
Fundamental	1572.3A (100%)		
2	0.49	1.0	0.12
4	0.35	1.0	0.17
5	0.32	4.0	3.13
7	0.38	4.0	1.95
8	**2.88**	1.0	2.78
10	0.53	1.0	0.64
11	**2.33**	2.0	1.61
13	0.34	2.0	0.90
14	0.13	0.5	0.23
16	0.07	0.5	0.14
17	0.32	1.5	0.21
19	0.07	1.5	0.13
22	0.04	0.375	0.11
23	0.05	0.6	0.14
25	0.03	0.6	0.08
26	0.02	0.15	0.08
28	0.02	0.15	0.06
29	0.03	0.6	0.11
31	0.03	0.6	0.13
35	0.17	0.3	0.69
37	0.05	0.3	0.25
41	0.01	0.3	0.06
43	0	0.3	0.03
47	0	0.3	0.02
50	0	0.075	0.01

Final Filter Configurations

1. STATCOM provides 20 Mvar
2. One 5 Mvar ST filter tuned to 147 Hz
3. One 5 Mvar ST filter tuned to 602 Hz.

Reduce the harmonic pollution to IEEE Limits and provide required reactive Power compensation.

Total permissible THD_I=5%
Calculated THD_I=3.09
THD_V=4.69

Harmonic Order	With STTATCOM And Filters	IEEE Limits	Voltage Distortion
Fundamental	1572.3A (100%)		
2	0.34	1.0	0.10
4	0.31	1.0	0.20
5	0.96	4.0	3.57
7	1.77	4.0	0.07
8	0.26	1.0	0.32
10	0.95	1.0	1.48
11	1.98	2.0	2.19
13	0.04	2.0	1.08
14	0.12	0.5	0.26
16	0.06	0.5	0.15
17	0.23	1.5	0.27
19	0.04	1.5	0.13
22	0.03	0.375	0.11
23	0.04	0.6	0.14
25	0.02	0.6	0.08
26	0.02	0.15	0.07
28	0.01	0.15	0.05
29	0.02	0.6	0.10
31	0.02	0.6	0.11
35	0.07	0.3	0.37
37	0.09	0.3	0.51
41	0.01	0.3	0.09
43	0.01	0.3	0.04
47	0	0.3	0.03
50	0	0.075	0.01

Conclusion

Reactive power compensation and harmonic control in a difficult Situation with ambient harmonics for a 100 MW wind generating Plant is demonstrated.

QUESTIONS

- Questions?

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