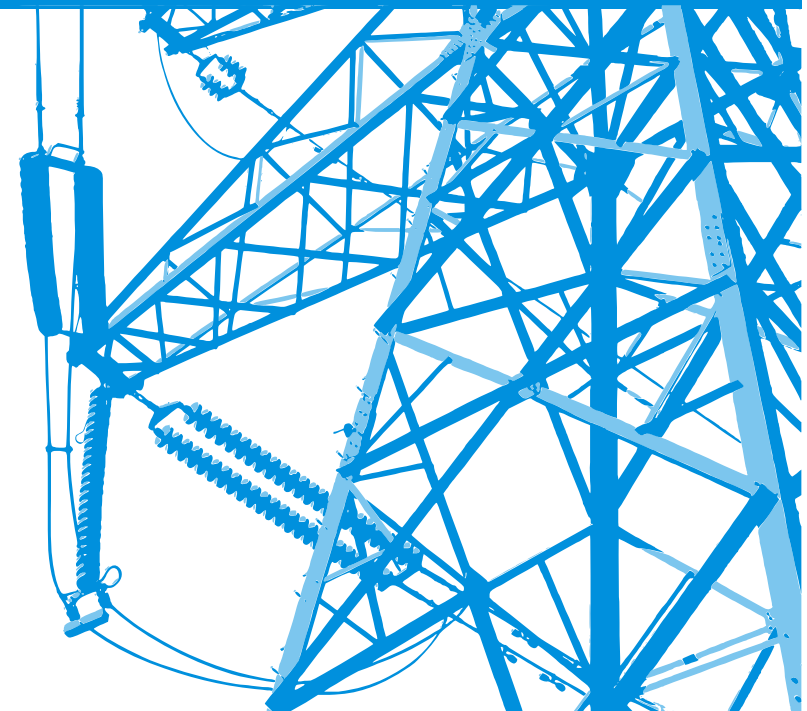


AC Filters for Systems with Multiple DC Infeeds

R.S. Burton, M. Heidari, H. Zhao,
A.F. Lee, M.A. Mihalchuk
Teshmont Consultants LP

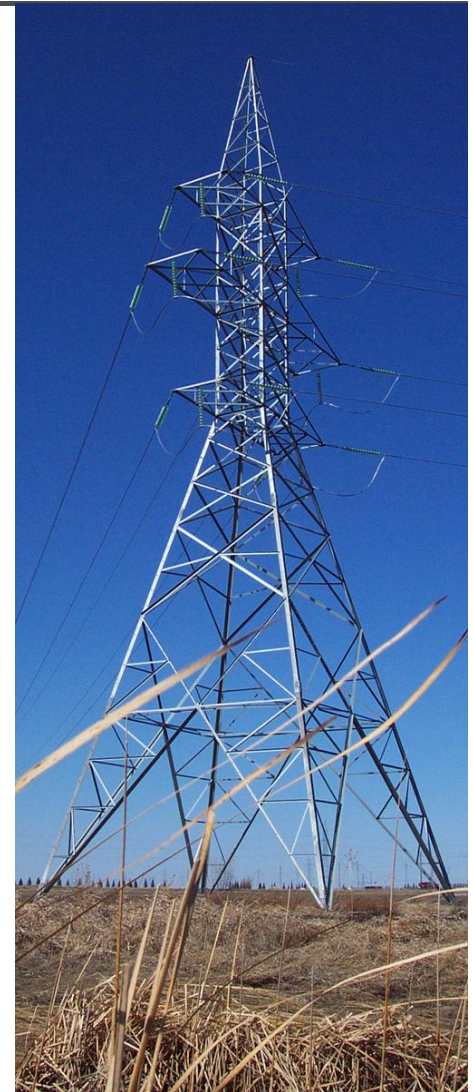
P. Wang, I.T. Fernando, C. Zhou
Manitoba Hydro

IEEE PES - Winnipeg Section
June 2012



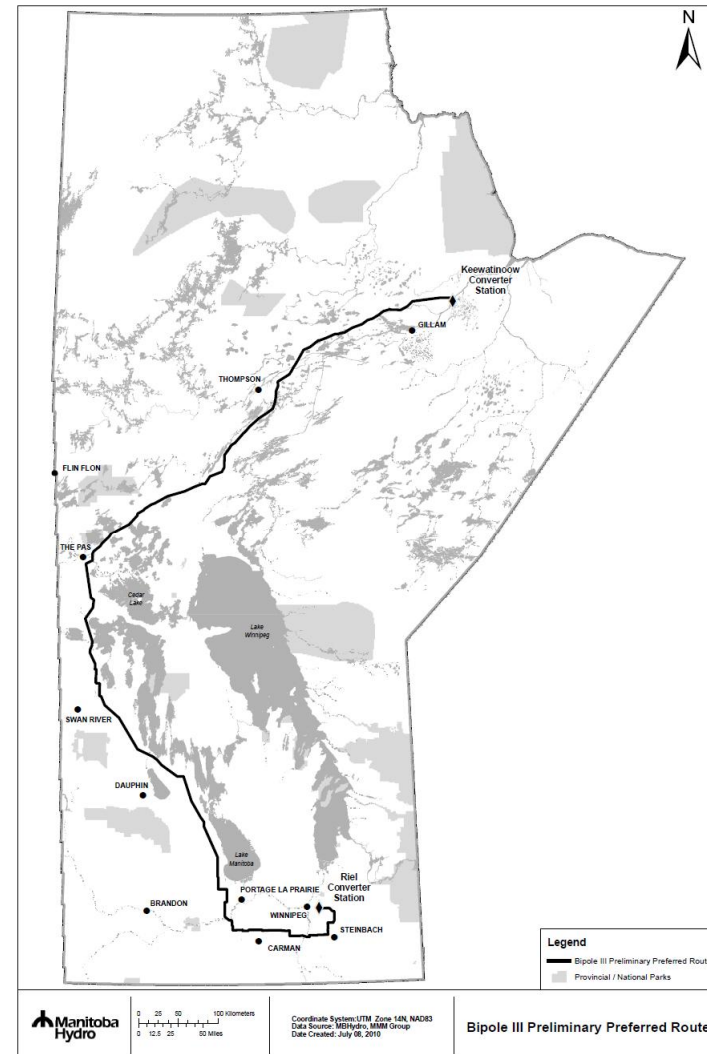
Outline

- **Background: Bipole III Project**
Systems with Multiple DC Infeeds
Review of Dorsey Filter Ratings
Concluding Remarks

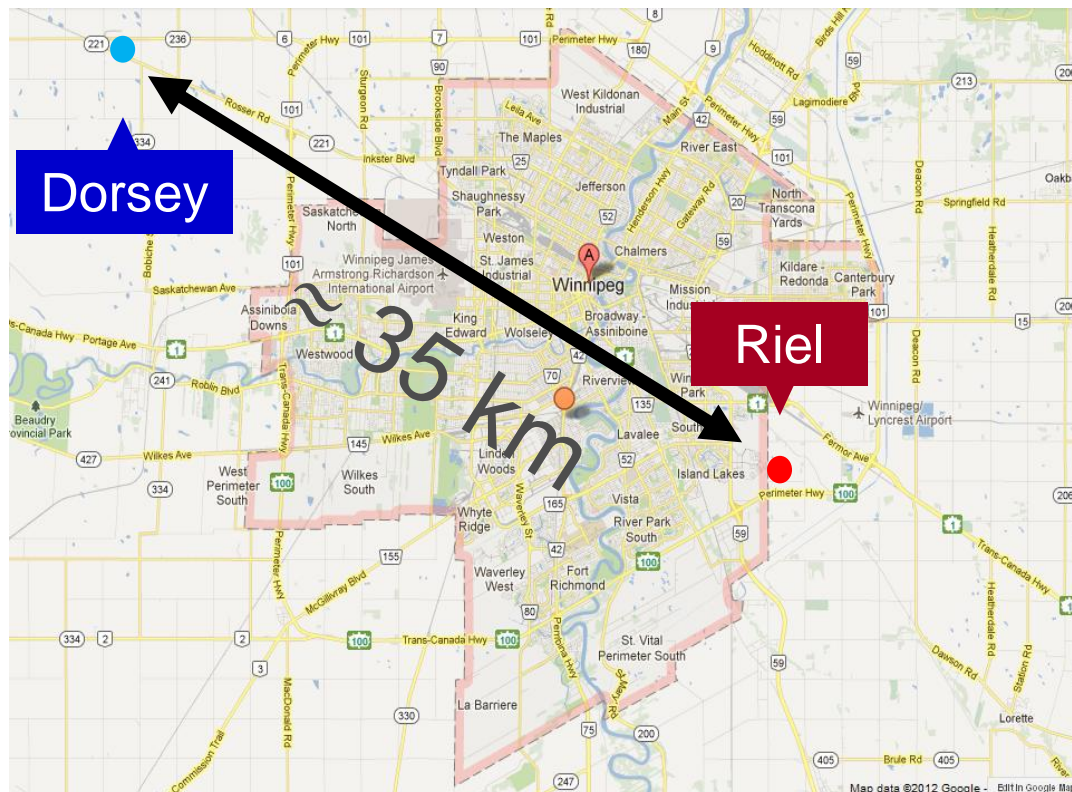


Bipole III Transmission Reliability Project

- Bipole III is a proposed HVDC transmission project between Keewatinow in northern Manitoba and Riel in southern Manitoba.
- The main purpose of Bipole III is to increase the overall system reliability and availability.

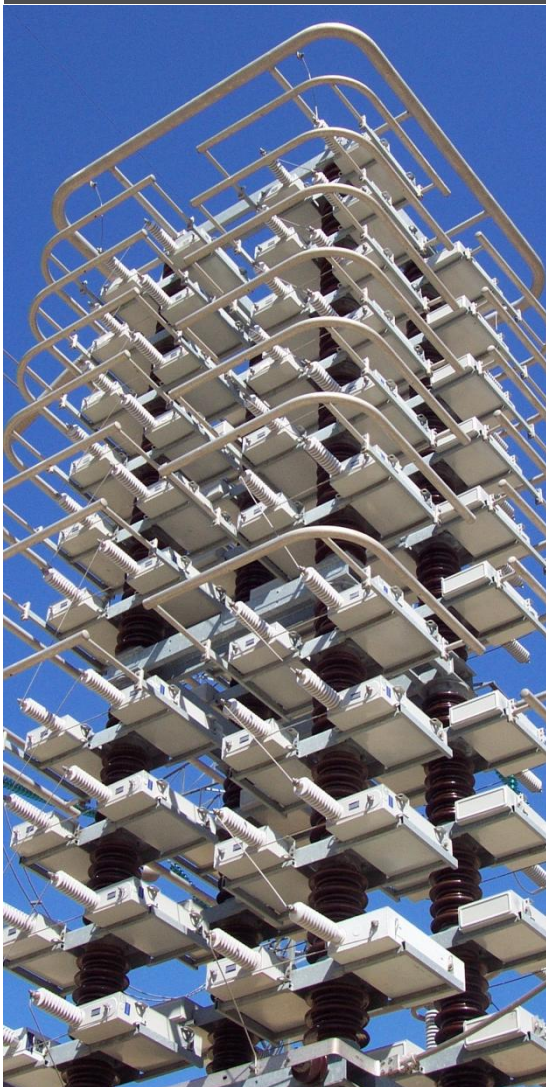


Riel Harmonic Impedance Studies



- The southern terminal of Bipole III is Riel, which is in close proximity to Dorsey (the existing converter station for Bipole I and Bipole II).
- Harmonic interaction between the converter stations was one of the major issues considered when performing the studies.

Outline



Background: Bipole III Project

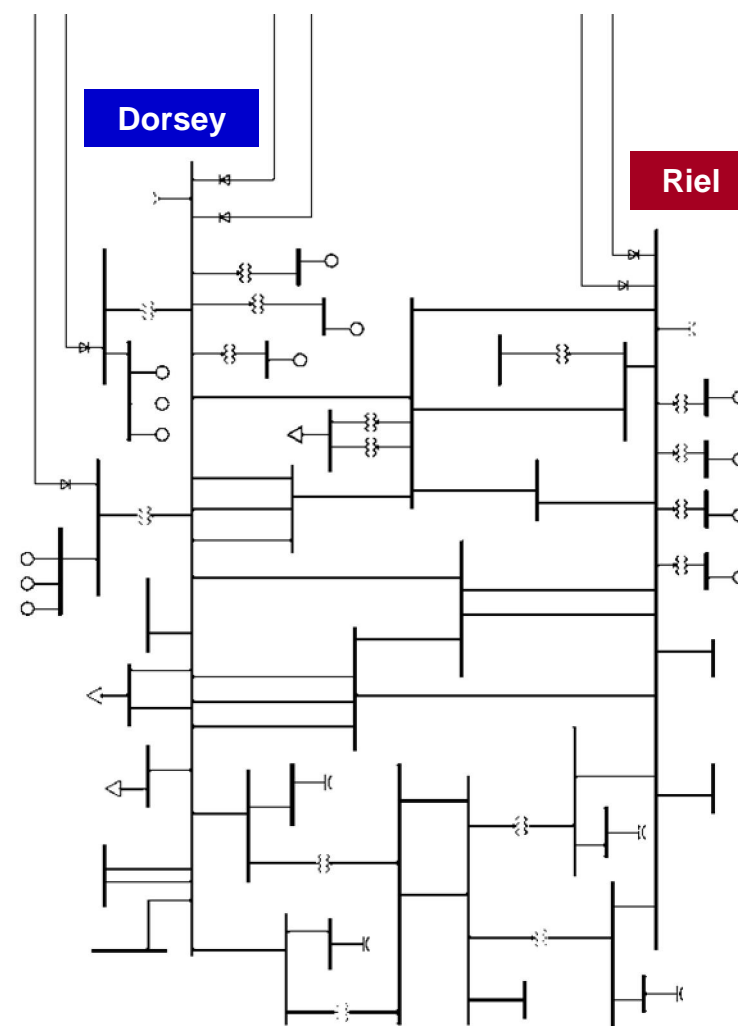
- **Systems with Multiple DC Infeeds**

Review of Dorsey Filter Ratings

Concluding Remarks

Systems with Multiple DC Infeeds

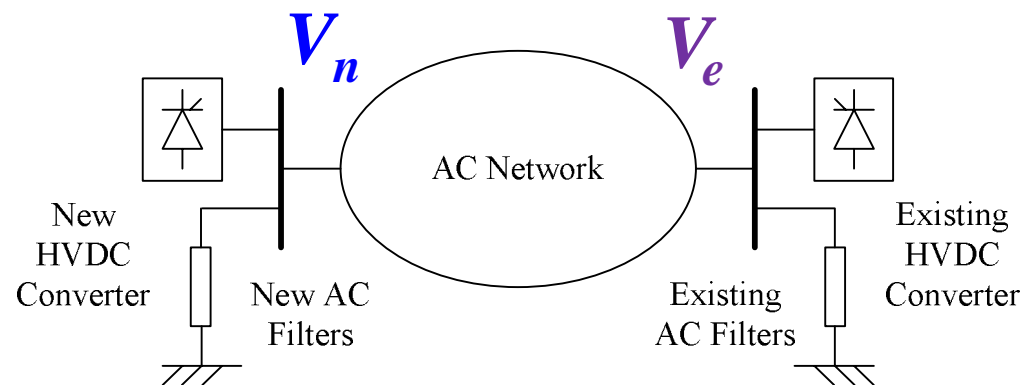
- AC systems with multiple HVDC links terminating in close electrical proximity are considered multi-infeed.
- CIGRE working group B4.41 has recently published a comprehensive technical brochure that addresses various aspects of multi-infeed systems.



Multi-Infeed Interaction Factor (MIIF)

- MIIF is one of the basic indicators of interaction level between converter stations.
- According to the CIGRE report, a MIIF value of less than 0.1 is unlikely to cause harmonic interaction issues.

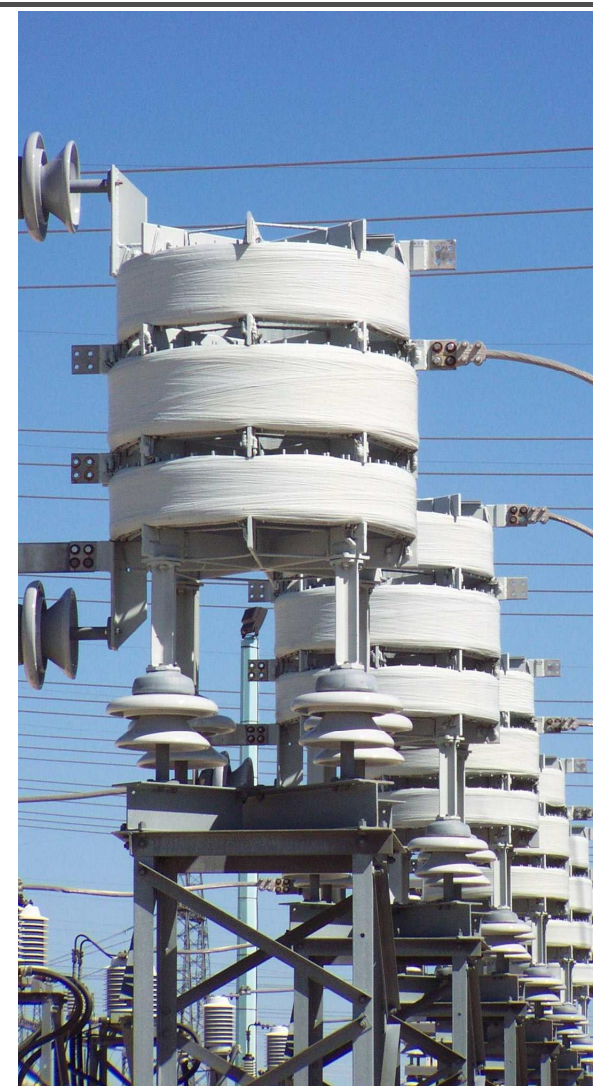
$$MIIF_{en} = \frac{|\Delta V_e|}{|\Delta V_n|}$$



MIIF between Dorsey and Riel is between 0.55 to 0.71

CIGRE Guideline for Characteristic Harmonics

- “With the same harmonic standard for new and existing HVDC converters, no specific precaution is required for characteristic harmonics.”
- “A more limiting harmonic standard for new HVDC system will only affect the filter design of the new system.”
- “A less limiting harmonic standard for the new system, though unlikely, could require a re-evaluation of the design for existing filters.”



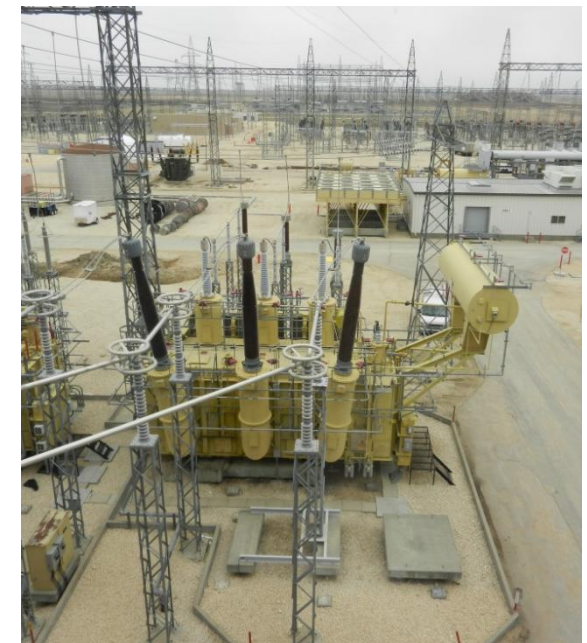
CIGRE Guideline for Harmonic Impedances



- “For characteristic harmonics in multi-infeed systems, since the system impedance would be somewhat based on speculation and thus have a safety margin included, the addition of another converter station and some additional transmission lines may not change the system impedance at harmonic frequencies to a great extent.”

CIGRE Guideline for Non-characteristic Harmonics

- A harmonic injection study can be used to determine the existence of potentially problematic resonance conditions in multi-infeed systems.
- The analysis is performed by injecting 1A of harmonic current at one converter bus and monitoring voltages at all the other converter buses. The ratio of the converter harmonic bus voltages can provide an indication of a problematic resonance condition.



Harmonic Injection Study

- The voltage amplification factors for most of the low-order harmonics for Riel and Dorsey are higher than one. This indicates a high level of interaction between the converter stations.

Harmonic No	Voltage Amplification Factor					
	Dorsey (Both57In)		Dorsey (One57Out)		Dorsey (Both57Out)	
	Min	Max	Min	Max	Min	Max
2	0.52	1.28	0.52	1.26	0.51	1.23
3	0.04	1.90	0.04	1.90	0.04	1.90
4	0.16	2.20	0.16	1.79	0.16	1.48
5	0.06	0.39	0.10	0.82	0.36	3.71
6	0.31	3.10	0.32	3.23	0.33	3.36
7	0.02	0.26	0.03	0.60	0.14	2.96
8	0.06	1.85	0.06	1.44	0.05	1.09
9	0.00	0.60	0.00	0.55	0.00	0.50
10	0.00	1.24	0.00	1.24	0.00	1.24
11	0.00	0.05	0.00	0.05	0.00	0.05
12	0.01	0.78	0.01	0.77	0.01	0.75
13	0.00	0.04	0.00	0.04	0.00	0.04
14	0.00	0.14	0.00	0.15	0.00	0.15
15	0.03	0.29	0.03	0.29	0.03	0.30
16	0.04	0.32	0.04	0.32	0.04	0.32
17	0.04	0.42	0.04	0.42	0.04	0.43
18	0.03	0.32	0.03	0.32	0.03	0.32
19	0.04	0.28	0.04	0.28	0.04	0.28
20	0.00	0.20	0.00	0.20	0.00	0.20
21	0.00	0.14	0.00	0.14	0.00	0.14
22	0.00	0.10	0.00	0.10	0.00	0.10
23	0.00	0.11	0.00	0.11	0.00	0.11
24	0.00	0.11	0.00	0.11	0.00	0.11
25	0.01	0.10	0.01	0.10	0.01	0.10

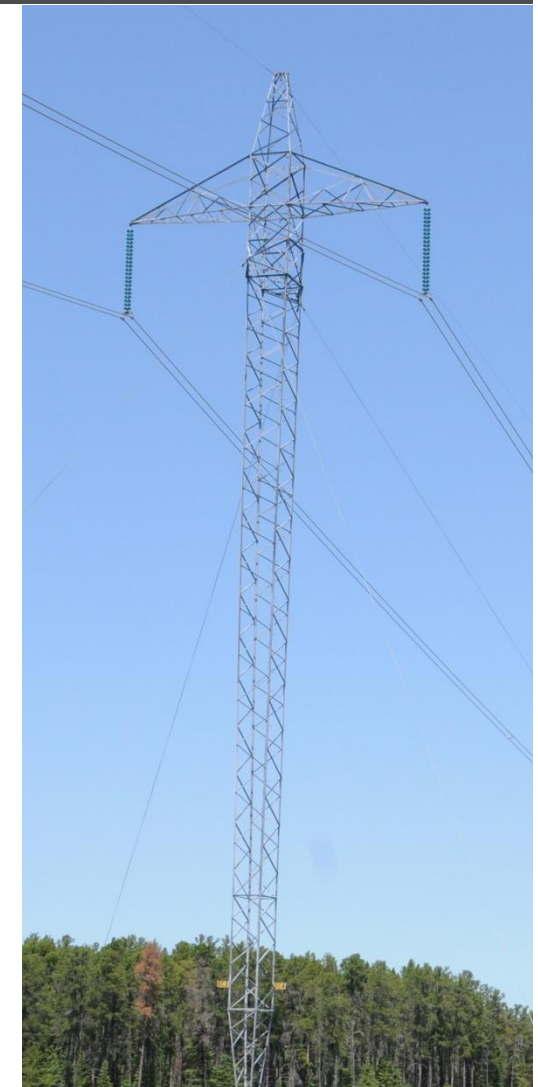
Both57In: 188,496 cases
 One57Out: 172,788 cases
 Both57Out: 172,788 cases

Min: Minimum value within ±1% frequency range
 Max: Maximum value within ±1% frequency range

Outline

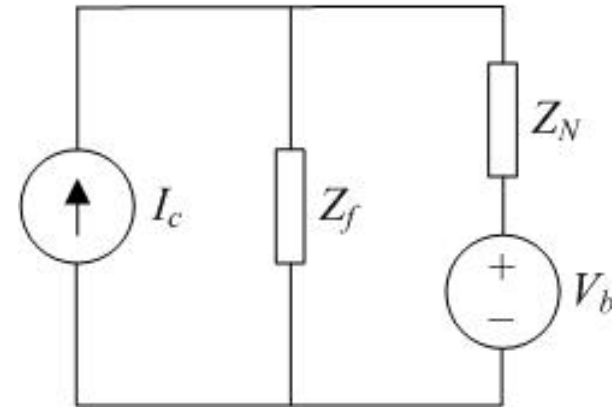
Background: Bipole III Project
Systems with Multiple DC Infeeds

- **Review of Dorsey Filter Ratings**
- Concluding Remarks



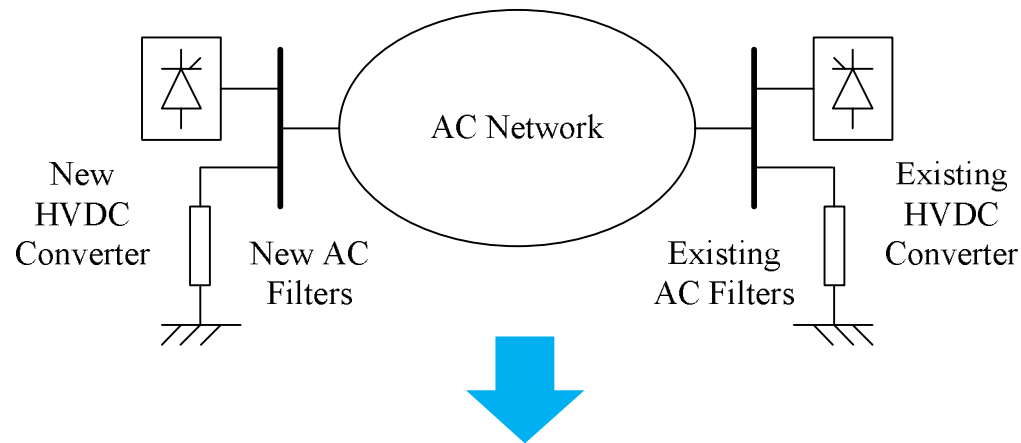
Preliminary Review of the Steady State Ratings at Dorsey

- Characteristic Harmonics
- Non-characteristic Harmonics

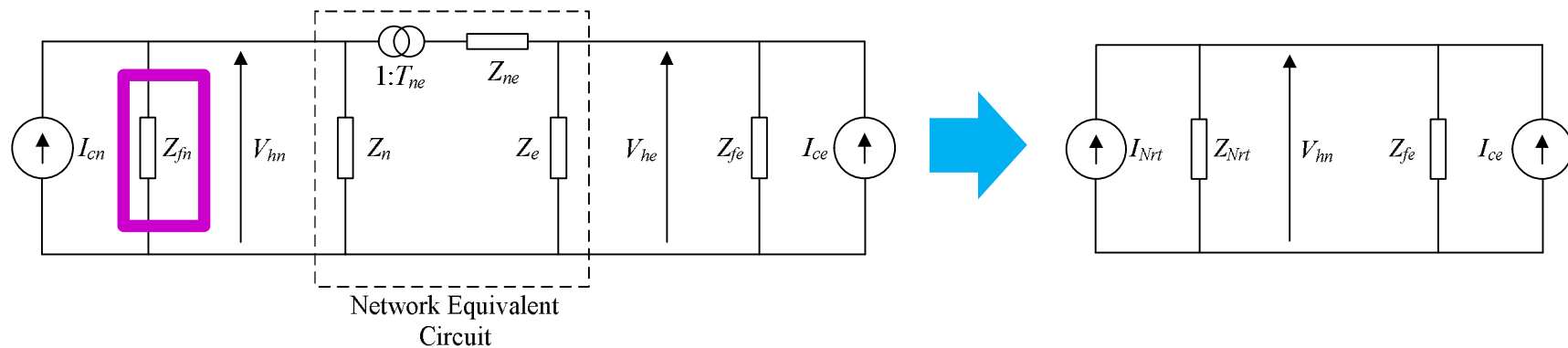


- Pre-existing Harmonics
 - Conventionally modeled by increasing the converter current by 10% – 20%.
 - The CIGRE guideline proposes to use a Thevenin voltage source behind the network impedance.

Use of a Norton Equivalent Circuit for Multi-Infeed Systems

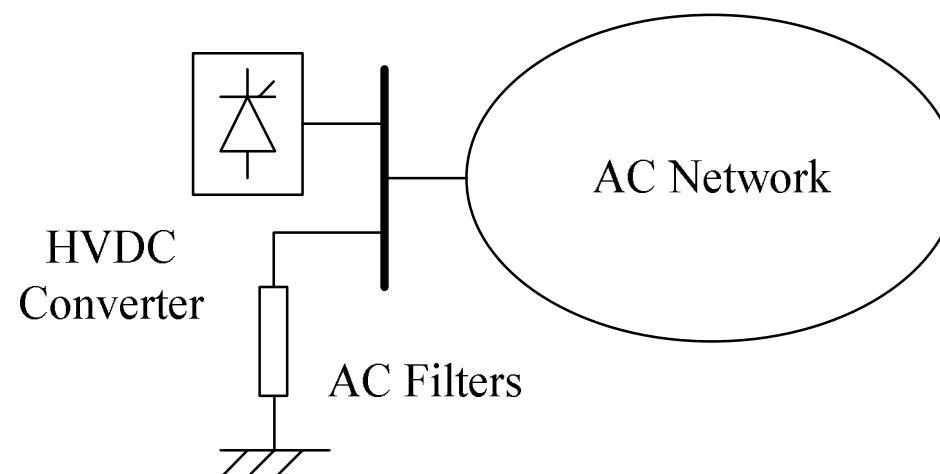


- A Norton equivalent circuit can be used for analysis of background harmonics caused by existing converters in the system.

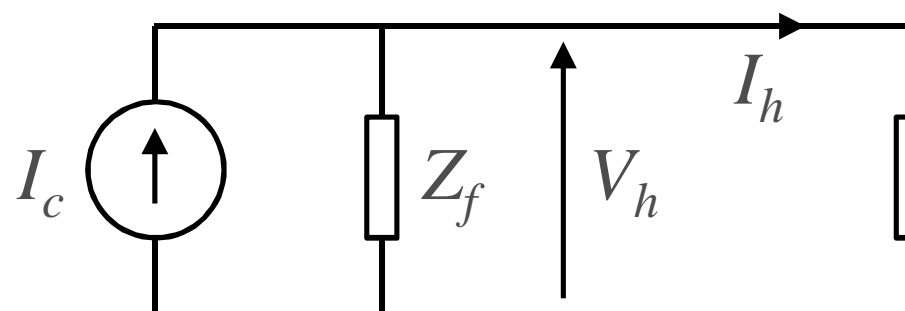


Preliminary Filters for Riel

- The main role of the ac filters is to provide a low impedance path for harmonic currents without causing a parallel resonance with the ac network.



- CIGRE working group 14.30 provides a comprehensive guide on specification and design evaluation of ac filters.



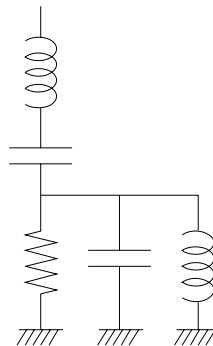
AC Filters for Line Commutated Converters (LCCs)

- Target specific frequency (or frequencies)
- Relatively low losses
- Susceptible to filter de-tuning

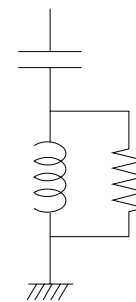
- Target a frequency range
- Typically higher losses compared to tuned filters
- Relatively insensitive to de-tuning



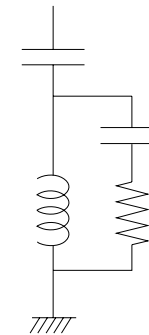
Single Tuned Filter



Double Tuned Filter



Single Tuned Damped Filter



3rd Order Damped Filter

Tuned Filters

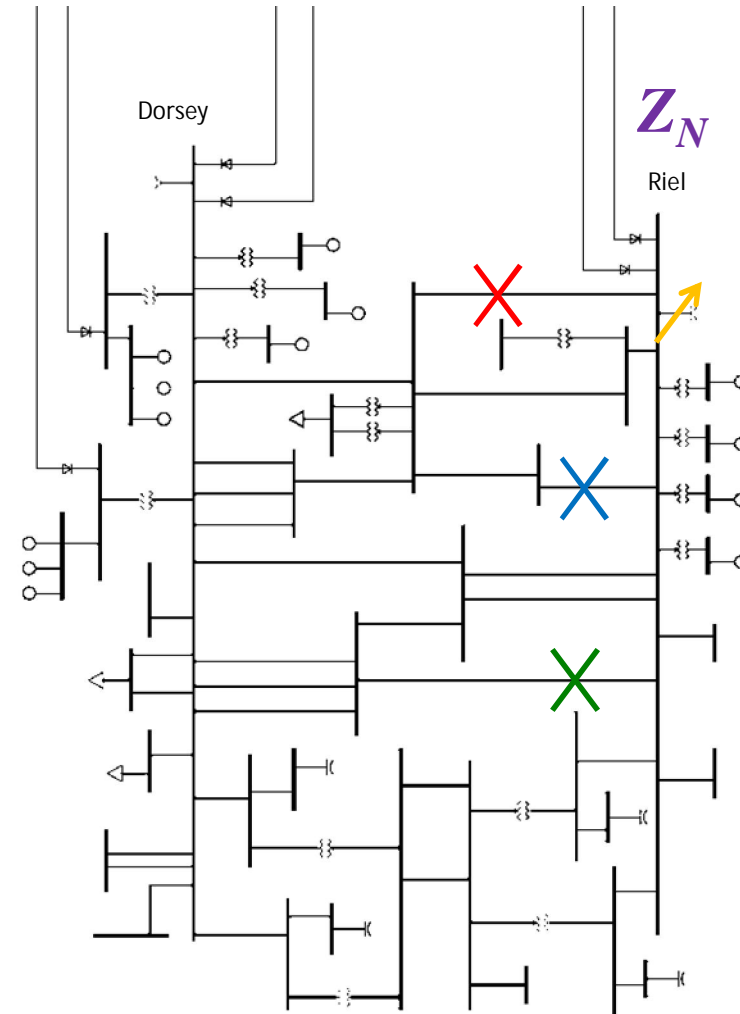
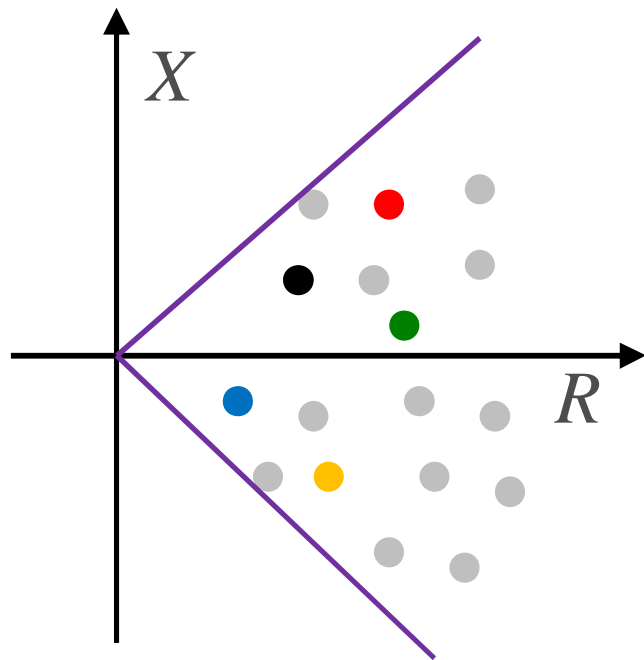
Damped Filters

Calculation of Harmonic Currents

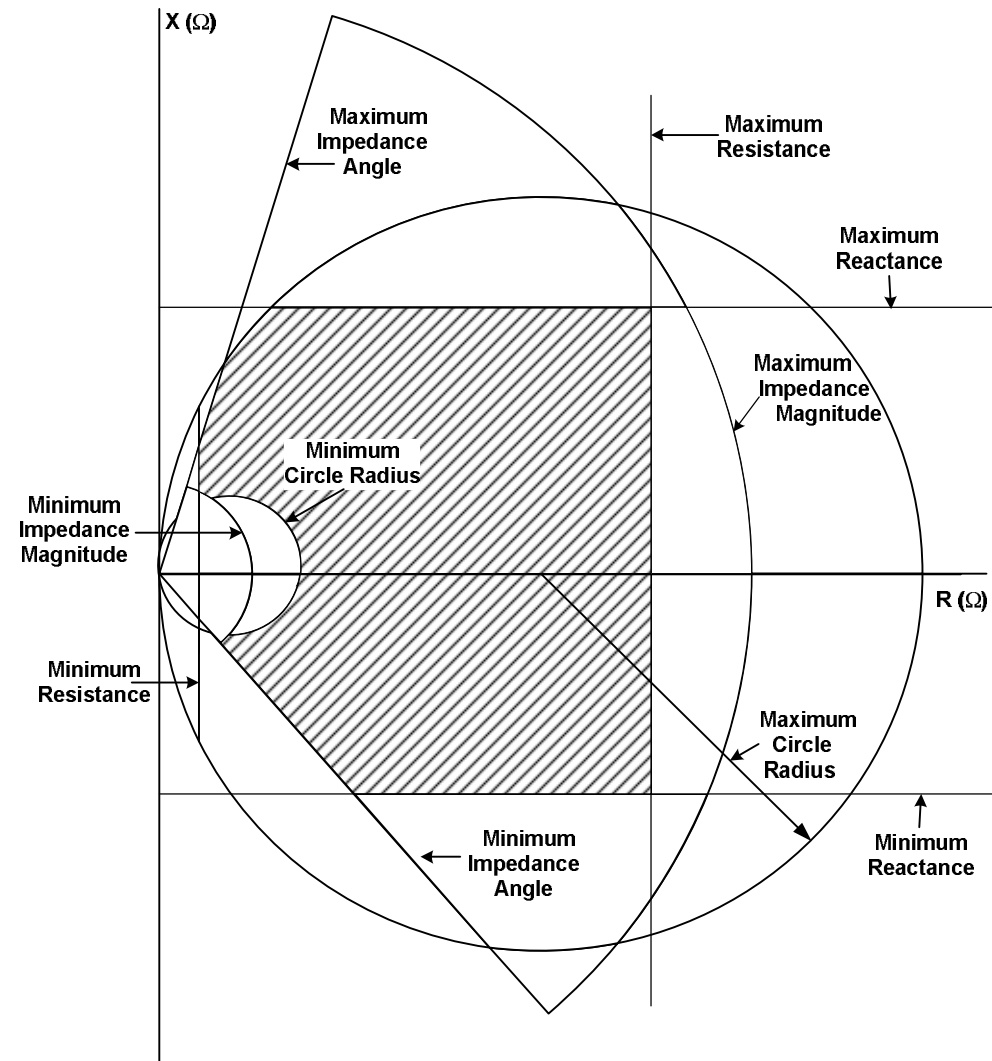
- Both characteristic and non-characteristic harmonics need to be calculated.
- For practical purposes it is also necessary to consider variation of ac system voltage, converter firing angle, commutating reactance, and dc current.



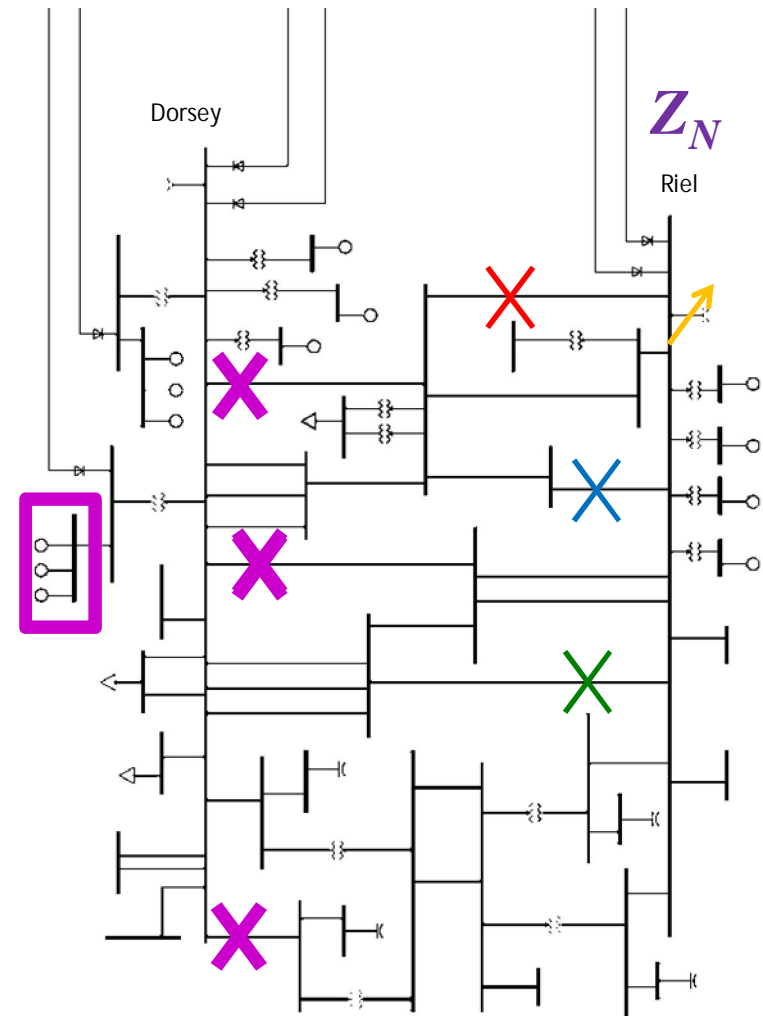
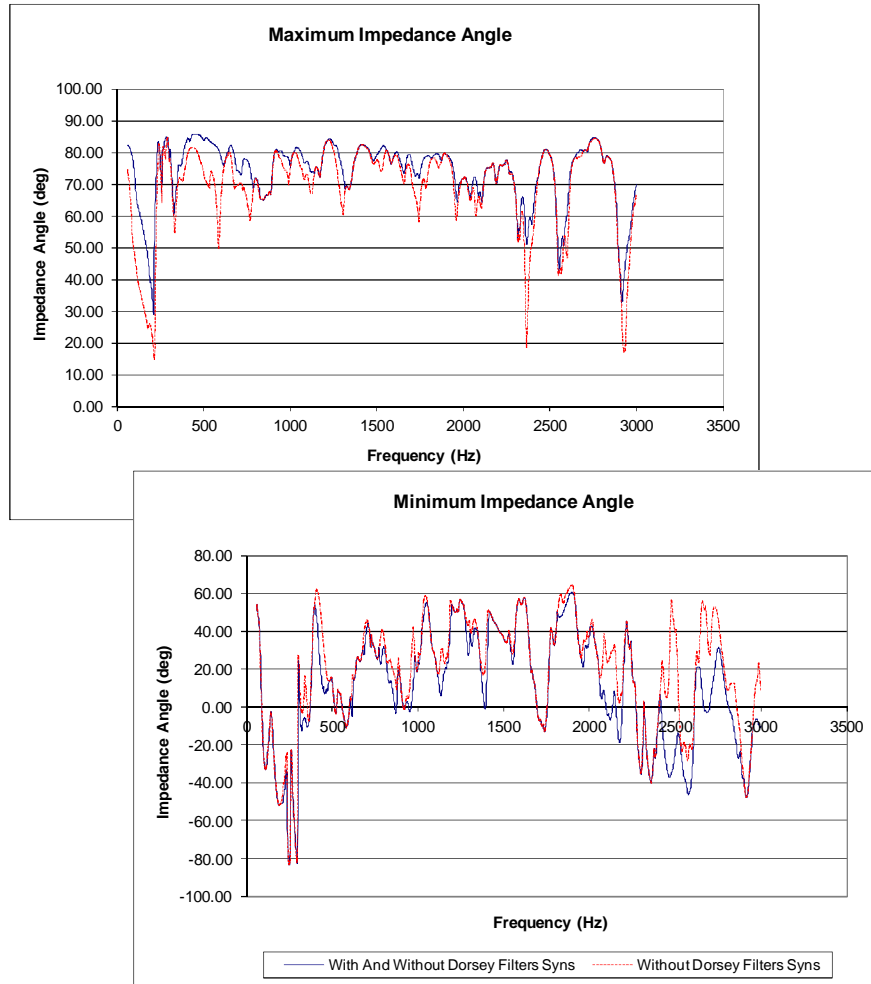
Network Harmonic Impedance



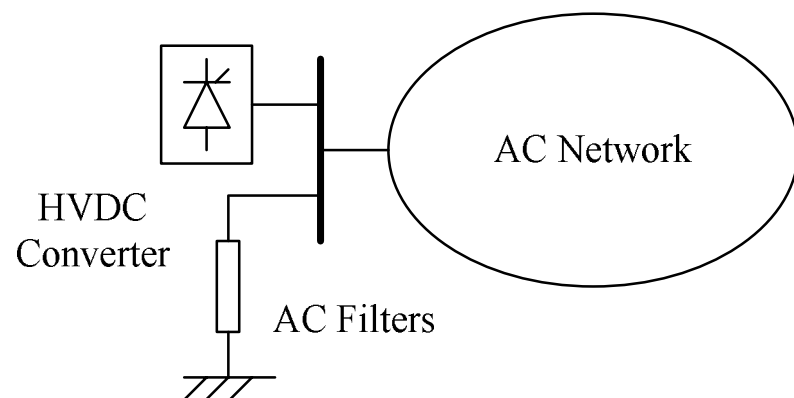
Network Harmonic Impedance



Inclusion of Dorsey in Riel Harmonic Impedance



Selection of Filter Parameters



Harmonic No	TIF	Harmonic No	TIF	Harmonic No	TIF
1	0.5	17	5100	31	7820
3	30	18	5400	33	8330
5	225	19	5630	35	8830
6	400	21	6050	36	9080
7	650	23	6370	37	9330
9	1320	24	6560	39	9840
11	2260	25	6680	41	10340
12	2760	27	6970	43	10600
13	3360	29	7320	47	10210
15	4350	30	7570	49	9820
				50	9670

$$D_h = \frac{V_h \times 100\%}{V_1} \quad THD = \sqrt{\sum_{h=2}^{50} D_h^2}$$

$$TIF = \frac{\sqrt{\sum_{h=1}^{50} (V_h T_h)^2}}{V_1} \quad IT = \sqrt{\sum_{h=1}^{50} (I_h T_h)^2}$$

■ Filter Optimization

$$OF = k_p \times Performance(R, L, C) + k_c \times Cost(R, L, C)$$

Impact of Dorsey on Harmonic Performance at Riel

- Originally, preliminary filters were designed without considering the impact of Dorsey.
- The performance of the filters was then evaluated using the harmonic impedances that include the impact of Dorsey.



Filter Performance

	THD	TIF	IT
Without Dorsey Impact	1.1%	24.9	27,300
With Dorsey Impact	1.4%	25.2	42,300
Specified Limit	1.5%	25.0	39,000

Ratings of Filters at Dorsey

- Maximum magnitude of Norton currents were calculated for various harmonics.
- Harmonic injections at Riel do not significantly affect the 11th and above harmonic filters.
- Dorsey 5th and 7th harmonic banks require more detailed studies.

Harmonic No	% of Bipole I Harmonic Currents
5	27.7%
7	23.0%
11	7.7%
13	8.6%
23	6.7%
25	4.0%

Maximum Values of Norton Equivalent Currents due to Riel
(at least one bank of 5th and 7th harmonic filters in service)

Outline

Background: Bipole III Project
Systems with Multiple DC Infeeds
Review of Dorsey Filter Ratings

■ **Concluding Remarks**



Concluding Remarks



- The studies show a high level interaction between Riel and Dorsey converters stations; therefore, multi-infeed effects need to be considered in the specification of filters for the Riel converter station.
- Based on the results of the harmonic injection study, low order harmonic interactions between Riel and Dorsey need to be considered in harmonic performance evaluation for Riel and Dorsey.
- The preliminary rating studies showed that 5th and 7th filters at Dorsey require further attention.

Concluding Remarks

Considerations for multi-infeed systems:

- Although usually ac filters and synchronous condensers at nearby converter stations do not significantly affect the harmonic impedance for a new converter station, the findings of this study showed that for high MIIF values, these impacts may be considerable.
- In calculation of filter ratings for a new converter station, it is proposed to use Norton equivalent currents to model the impact of harmonic injections at nearby stations.



Thank you.



Questions?