

Harmonic Compliance Management Workshop

2 April 2019

national**grid**



Welcome and Overview

Maxwell Mulimakwenda

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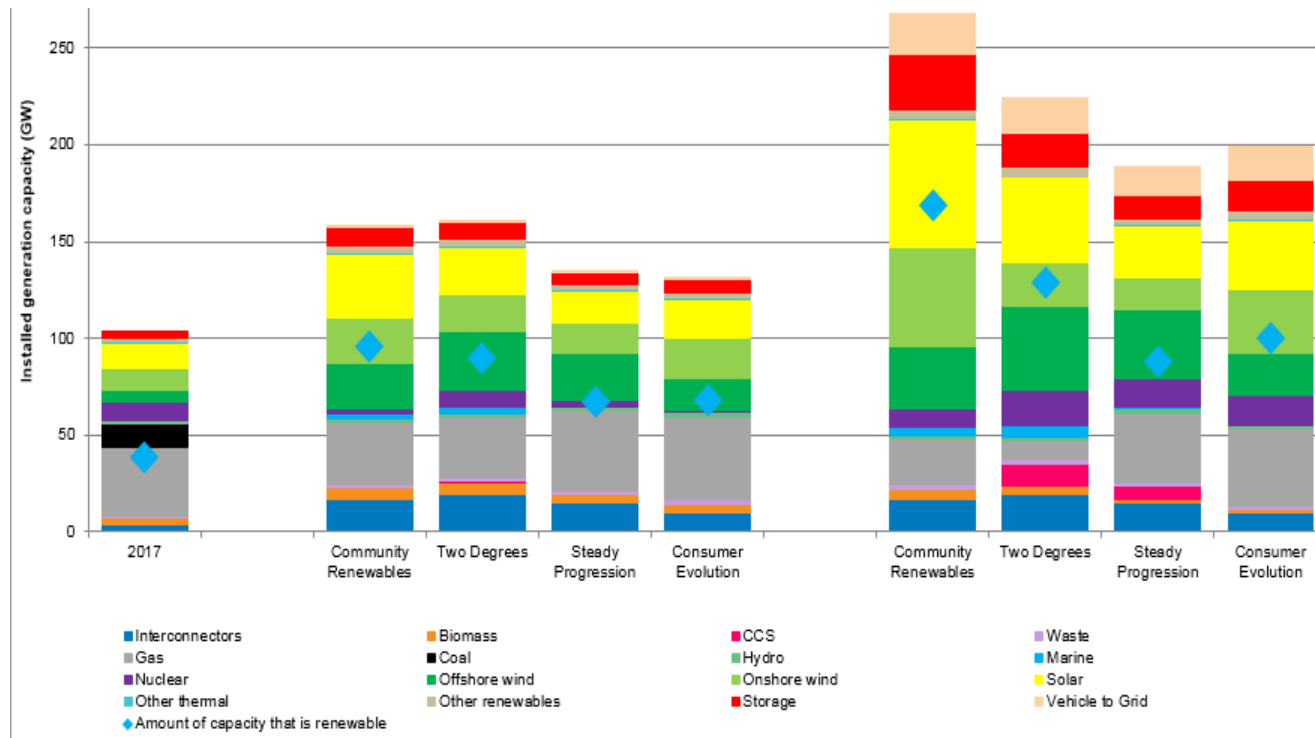


HARMONIC COMPLIANCE PROCESS

- Utilities required to maintain harmonic compliance
- ER G5/4 – Overarching standard
- To manage connection of non-linear load
- Current approach – polluter is responsible to “clean” it.
- Polluter pays for mitigation
- Policy might have served us well in the past
- But energy landscape is changing

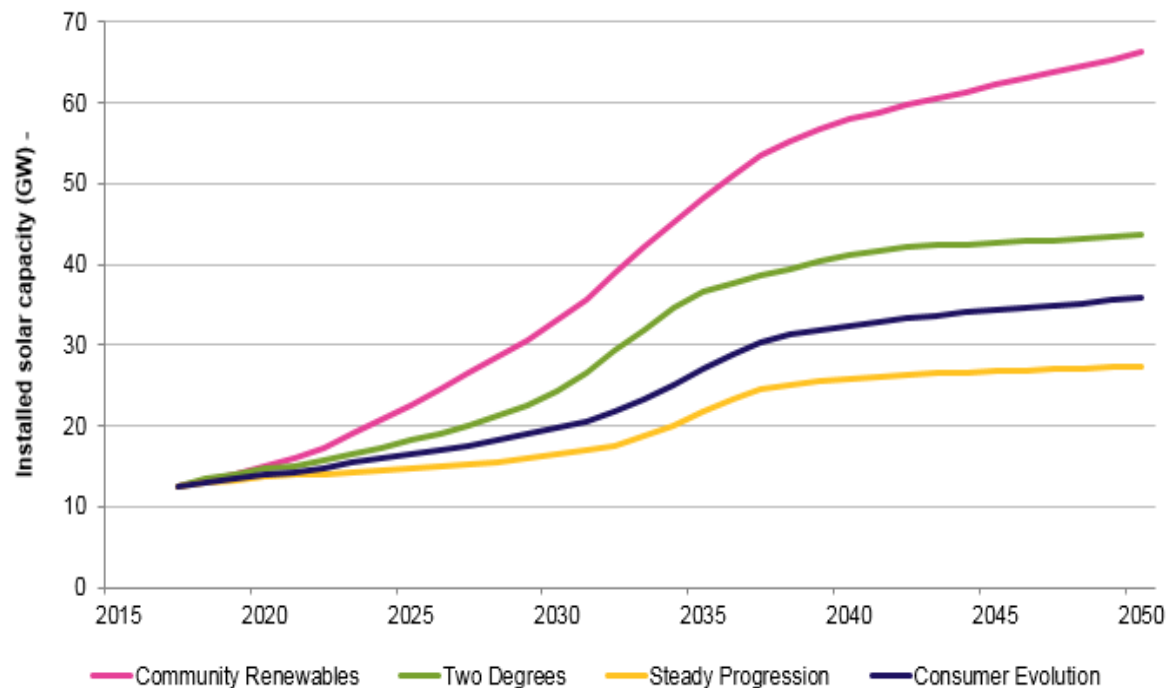
CONTEXT – ENERGY LANDSCAPE IS CHANGING

- Energy supply



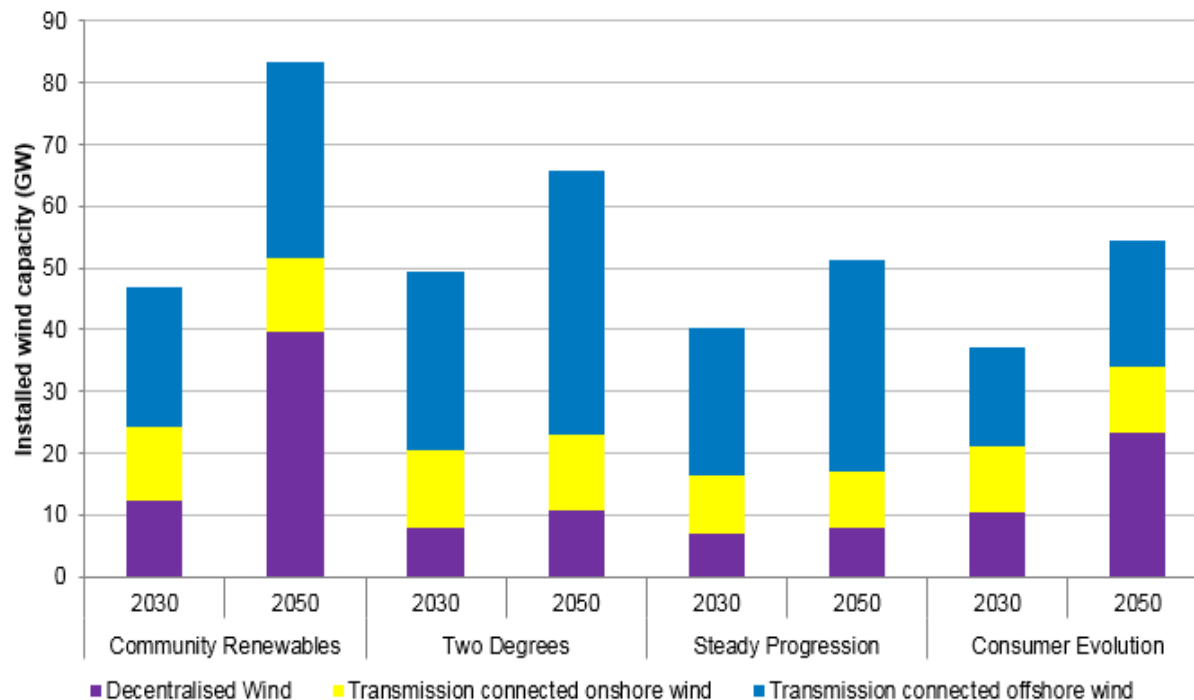
CONTEXT- ENERGY LANDSCAPE IS CHANGING

Solar Capacity



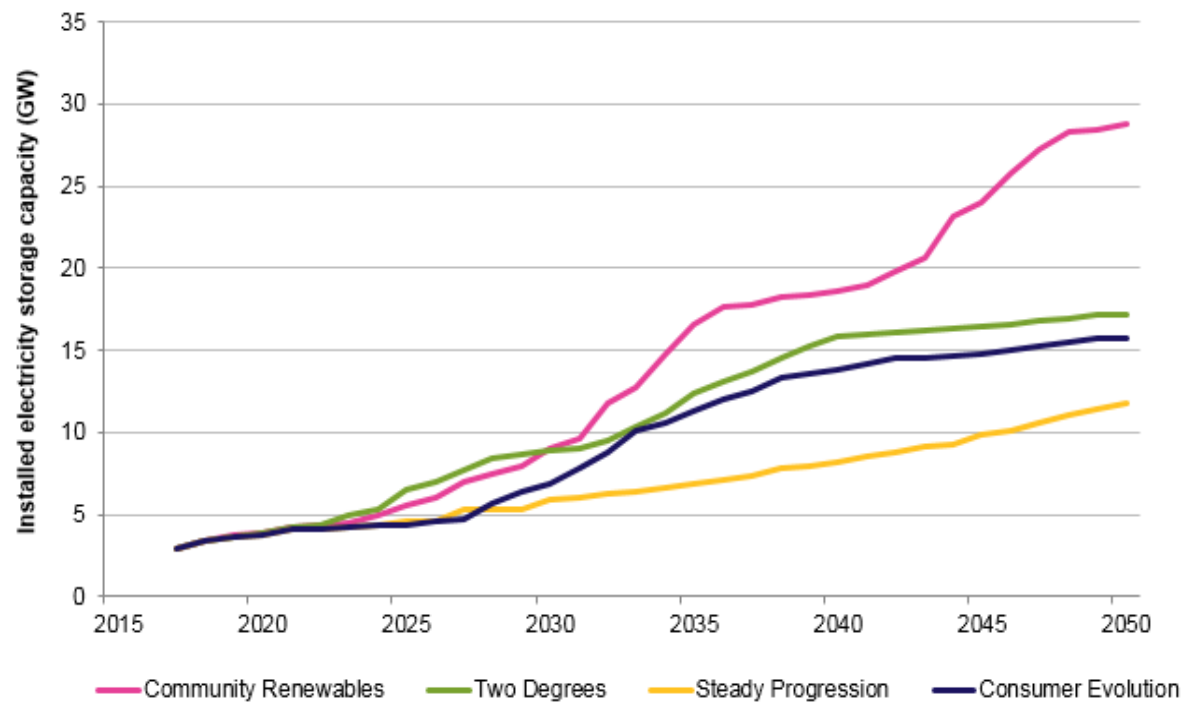
CONTEXT – ENERGY LANDSCAPE IS CHANGING

- Wind Capacity



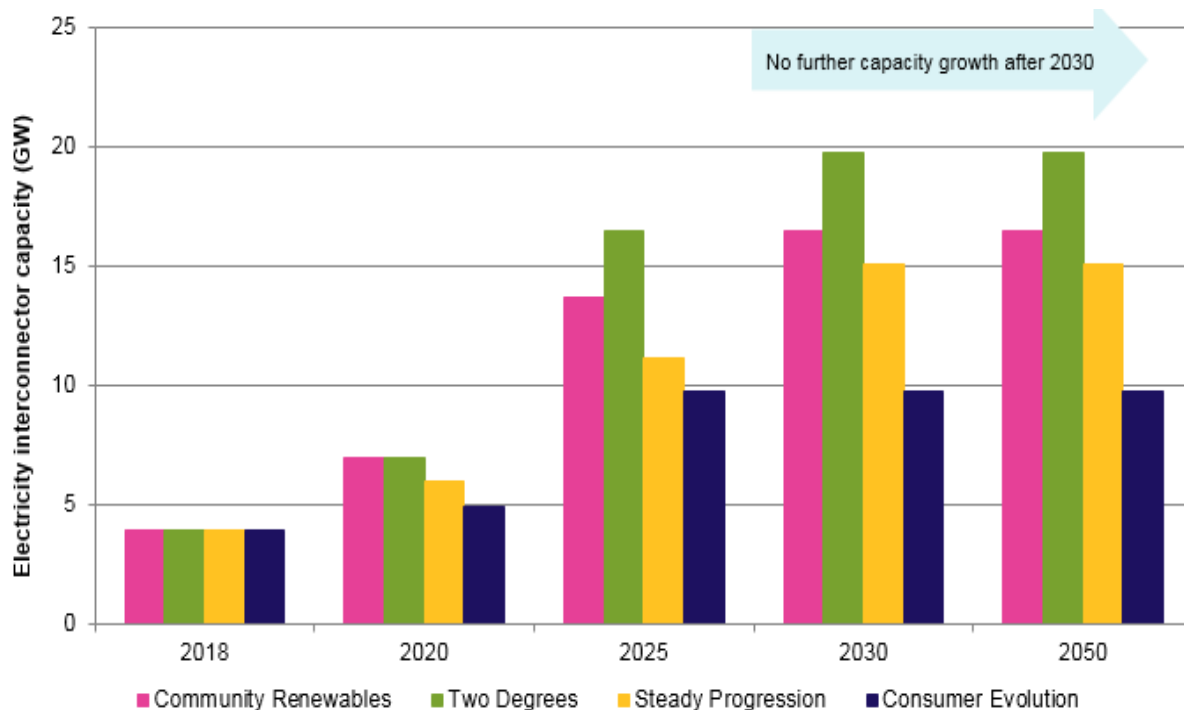
CONTEXT – ENERGY LANDSCAPE IS CHANGING

- Storage Capacity



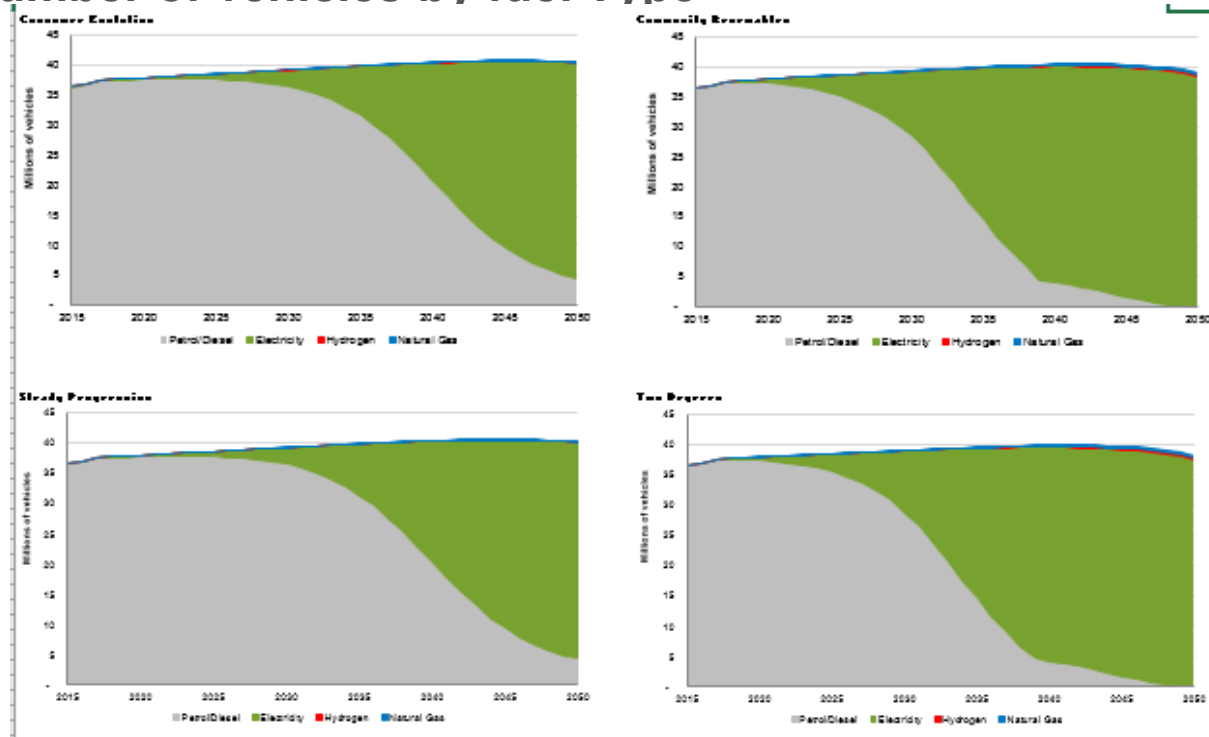
CONTEXT – ENERGY LANDSCAPE IS CHANGING

- Interconnector Capacity



CONTEXT – ENERGY LANDSCAPE IS CHANGING

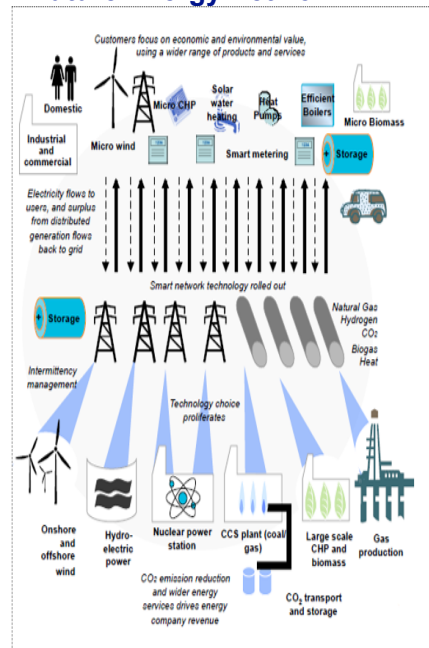
Number of vehicles by fuel Type



CONTEXT – ENERGY LANDSCAPE IS CHANGING

- Changing utility network
- Weaker systems (short circuit levels)
- Consumer loads (Reducing damping due to disappearance of incandescent lights)
- Rail electrification
- Data centres

Future Energy Network



CONTEXT – STAKEHOLDER VOICE

- How easy is it to attribute responsibility to one party?
- Is the process efficient & effective technically and economically
- Does the process benefit the consumer? Lack of Coordination
- Does it benefit connectees? Project risks
- Does it apportion liability effectively?
- Does it facilitate connections?

CONTEXT – UTILITY VOICE

- **No allowance for utility intervention within RIIO -1 to:**
 - ✓ Coordinate & optimise mitigation
 - ✓ Create headroom in order to facilitate connections
 - ✓ Take corrective measures
 - ✓ Harmonic compliance in future will be complex and time consuming

WORK DONE SO FAR:

- Case studies undertaken by NGET
- Case studies undertaken by SPT
- Independent studies done by PSC and Atkins

OBJECTIVES OF THE HARMONIC REVIEW

- To find a way of managing harmonic compliance in a way that is coordinated and optimised for connectees and consumers.
- To facilitate connections & decarbonisation
- To improve effectiveness & efficiency of the process
- To simplify harmonic process

TODAY's WORKSHOP

- Seek views and feedback from industry leaders
- Determine next steps

Agenda

Time		Item	Speaker
09.15-09.45	30 mins	Registration and refreshments	
09:45-10.05	20 mins	Welcome and overview	Maxwell Mulimakwenda
10:05-10:35	30 mins	Technical Analysis NGET	Forooz Ghassemi
10:35 -11:05	30 mins	Technical Analysis SPT	Cornel Brozio
11:05-11:20	15 mins	Refreshments	
11.20-11:50	30 mins	Approach adopted in other countries	PSC
11:50-12:40	50 mins	Alternative options for managing harmonic compliance Questions	PSC
12:40-13:20	40 mins	Lunch	

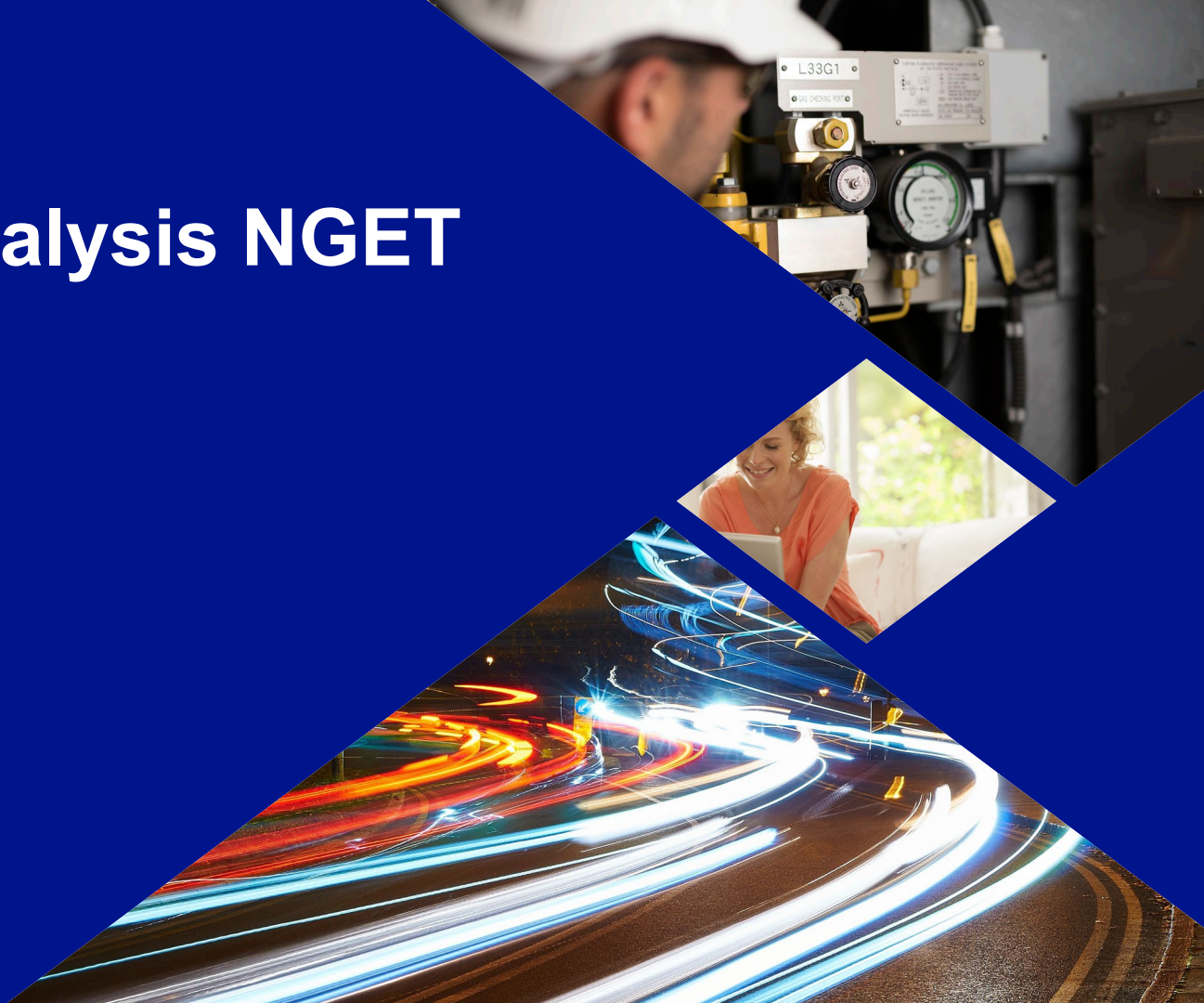
Agenda

Time		Item	Speaker
13:20-14:10	50 mins	Risk/Liability allocation framework	PSC
14:10-15.00	50 mins	Existing cost recovery methods for harmonic mitigation	Atkins Global - - Vandad Hamidi
15.00-15.15	15 mins	Refreshments	
15.15-15.45	30 mins	Impact of proposed approach on different stakeholders	Atkins Global - Vandad Hamidi
15.45-16.00	10 mins	Closing remarks and finish	Maxwell Mulimakwenda

Technical Analysis NGET

Forooz Ghassemi

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Overview

- Utilities are required to maintain harmonic compliance
- ER G5/4 is a DCode qualifying document
- The Grid Code refers to ER G5/4
- Utilities ensure compliance by the users through Bilateral Connection Agreement (BCA)
- Network users must comply with the harmonic specification in the BCA
- Polluter designs and pays for mitigation
- Harmonic specification determines the size and type of the mitigation

Objectives

- To determine if saving can be made if NGET manage harmonic compliance by designing and installing less number of harmonic filters than Users
- By doing so, how many filters are needed to achieve compliance
- To estimate the reduction in number of filters compared to the existing practice when the Network Users install filters
- Taking the risk of delay in project off the User
- Whether there will be any optimisation in number of filters and hence cost saving compared to the case when Network Users pay for mitigation

Study scope

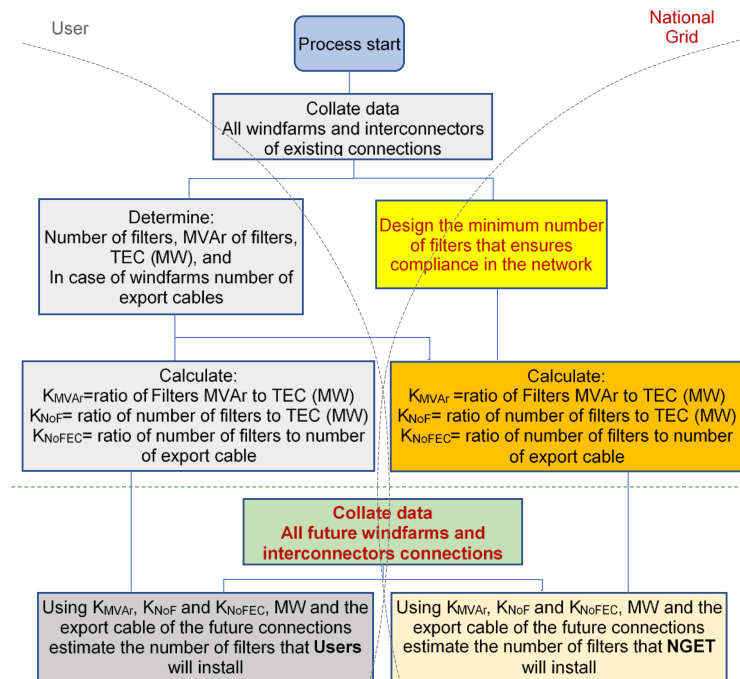
- Include windfarms
 - Determine TEC (MW) for each connection
 - Determine number of filters and their MVar
 - Determine the number of export cable
- Include HVDC interconnectors of VSC type
 - Determine TEC (MW) for each connection
 - Determine number of filters and their MVar
 - The filters are usually small (physical size and MVar)
- Exclude HVDC interconnectors of CSC type
 - Filters are part of converter operation for reactive power generation and not only harmonic related
 - Considered not realistic to include in the scope which may mislead the conclusion

Approach

- Analyse the past:
 - collate the existing harmonic filter data;
 - How many have been installed by Network Users
 - How much MVar is generated by harmonic filters
 - The Users installed MW that have installed harmonic filter
 - NGET design harmonic filters for optimum locations which ensures compliance for the same number of connections and same amount of connected MW
 - Determine a parameter that relates the number of filters to the connected Users
- Look into the future:
 - Collate data for the future connection
 - Use the parameter to estimate the number of filters that will be used for future connections

Process flowchart

- Two steps approach
 - First step is to determine how many filter can be designed to replace the existing Users' filters
 - Second step is to determine how many filter will be used for the future connection

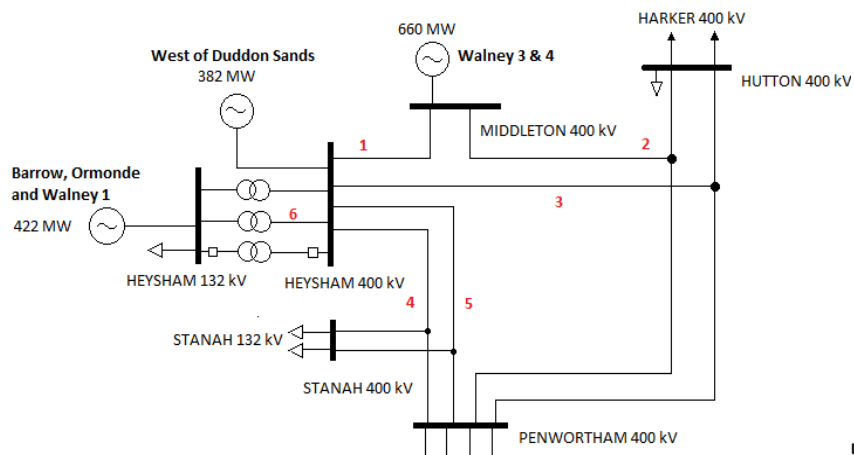


Study methodology

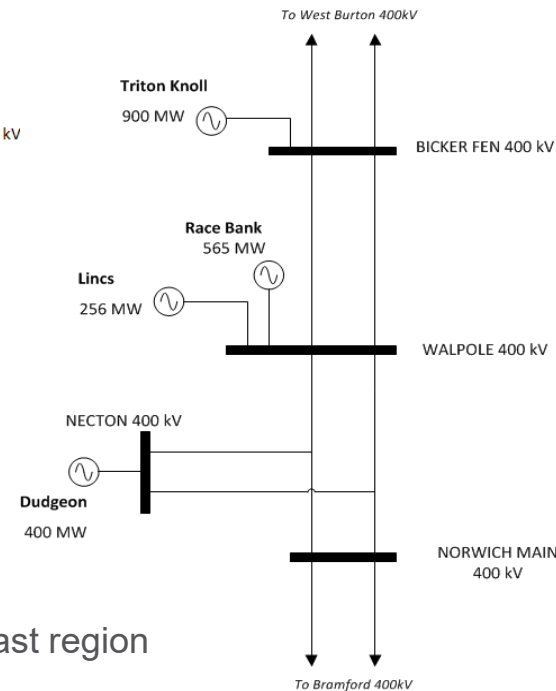
- To follow a sequential connection approach
 - based on year of connection
 - and study the impact on harmonic distortion for each connection
 - then develop the appropriate filter solution
 - and compare that against the performance of the filters installed by the OFTO(s)
- To evaluate performance, compare the resultant amplification due to NG designed filters and that of existing OFTO filters
- This was deemed the most pragmatic approach considering:
 - that nearly all existing OFTO filters commissioned and installed to date were targeted to deal with amplification and tuned at the lower harmonic order
 - and that the NGET designed filter would be a high pass filter to deal with lower as well as the higher order emissions from the wind farms

Regions considered

- A concentration of wind farm connection with harmonic filters in the north west
- Large number of wind farm connection in the east
- Large number of future connections in the east and south east sectors



North east region

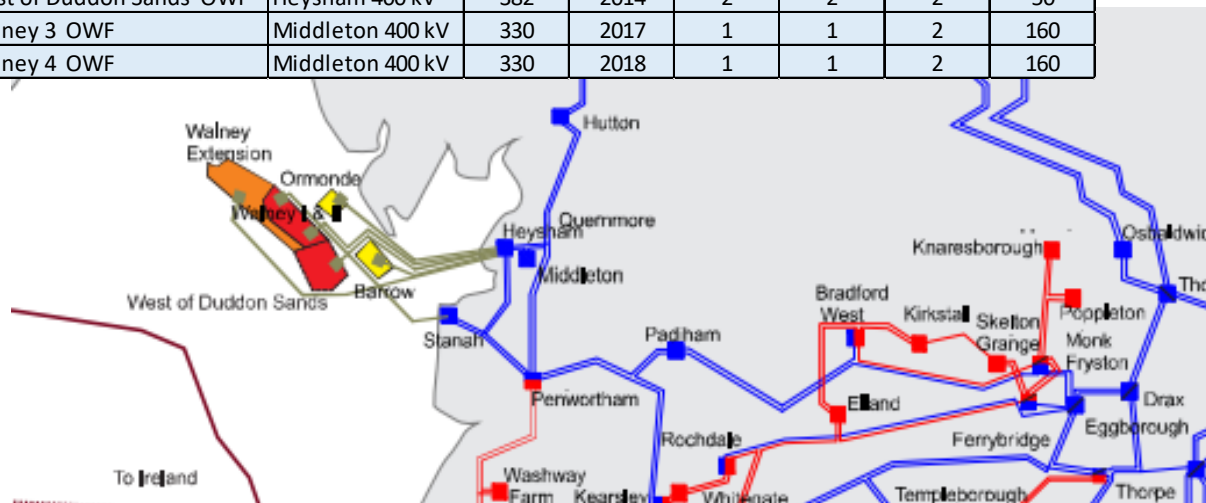


East region

North west region

Connections included in the study

Project Name	PCC	Capacity (MW)	Connecti on Year	# of bays	# of export cables	Number of filters	Filter Rating (MVar)
Barrow OWF	Heysham 132 kV	90	2008	1	1	0	0
Ormonde OWF	Heysham 132 kV	150	2012	1	1	1	20
Walney I OWF	Heysham 132 kV	182	2012	1	1	1	27
West of Duddon Sands OWF	Heysham 400 kV	382	2014	2	2	2	50
Walney 3 OWF	Middleton 400 kV	330	2017	1	1	2	160
Walney 4 OWF	Middleton 400 kV	330	2018	1	1	2	160

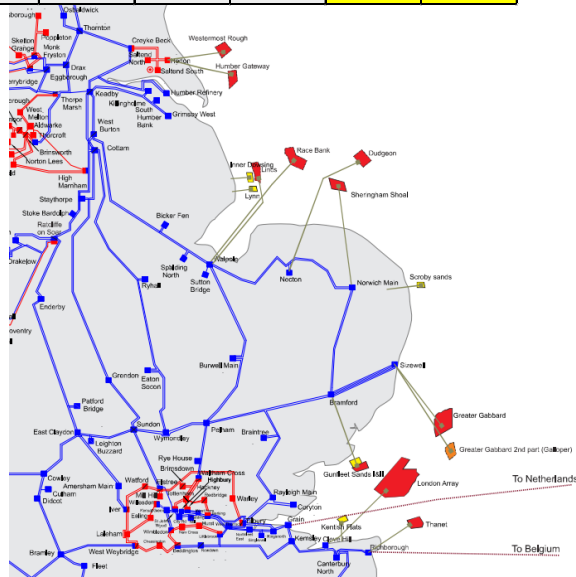


East region

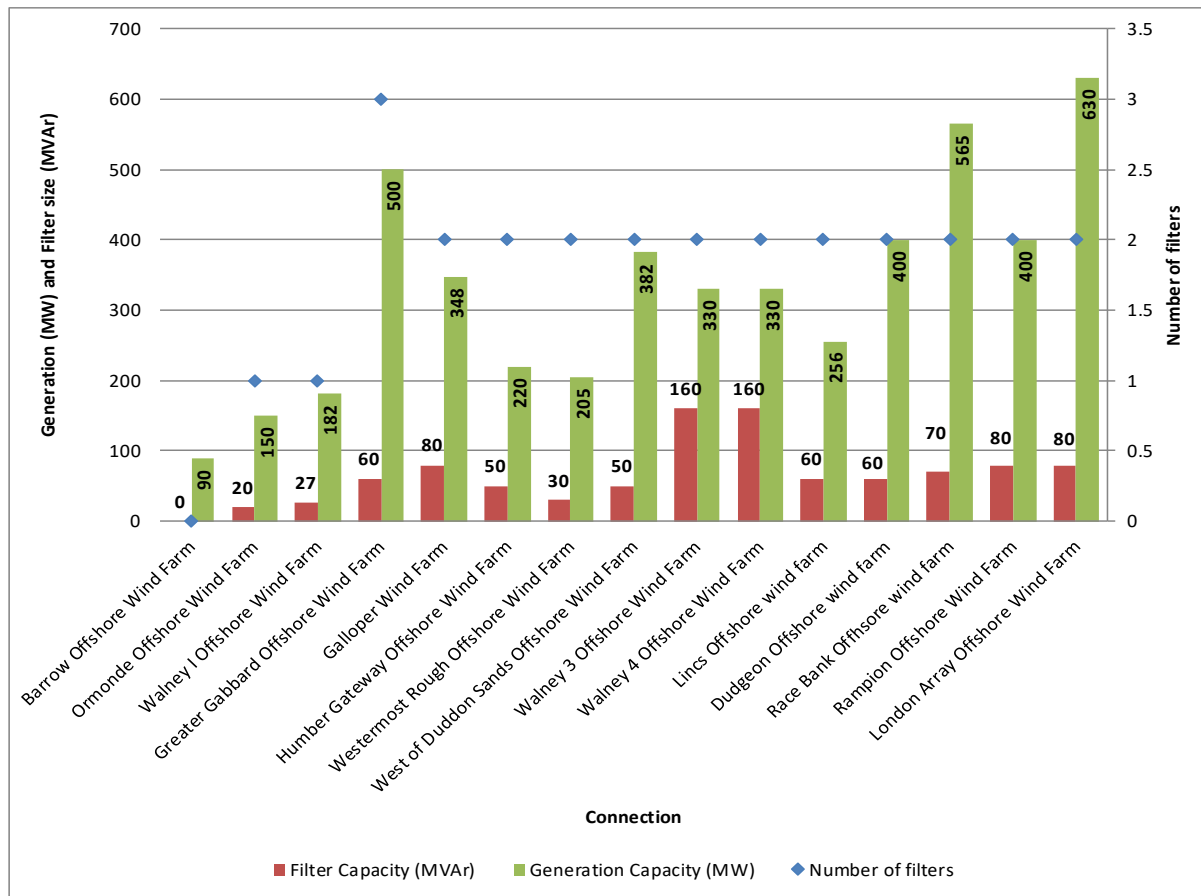
Connections included in the study

Project Name	PCC	Capacity (MW)	Connection Year	# of bays	# of export cables	Number of filters	Filter Rating (MVar)
Lincs OWF	Walpole 400 kV	256	2013	1	2	2	60
Dudgeon OWF	Necton 400 kV	400	2017	2	2	2	60
Triton Knoll OWF	Bicker Fen 400 kV	900	2017	2	2	2*	70
Race Bank OWF	Walpole 400 kV	565	2018	2	2	2	70
Viking Link (interconnector)	Bicker Fen 400 kV	1500	2022	2	2	2*	50

* These customers have not finalised their filter design. The figures in the table are prediction.

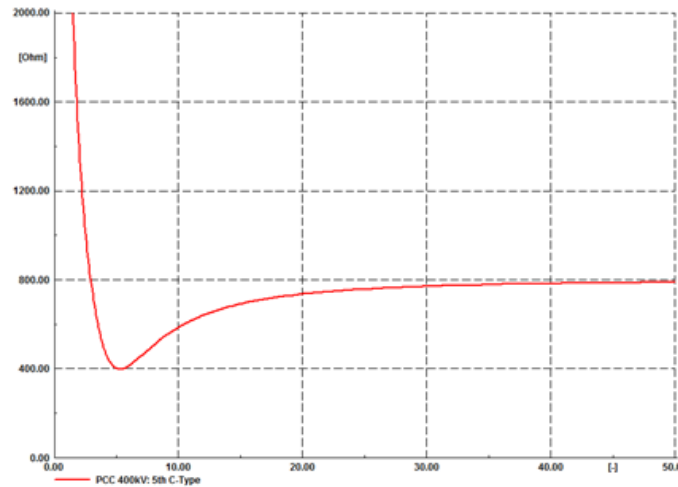
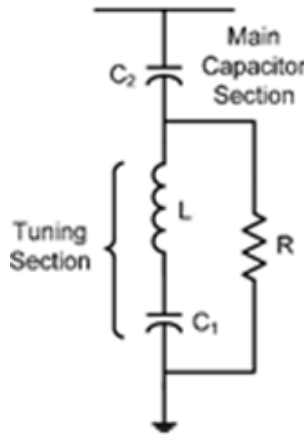


Wind farms already connected



NGET solution

- Standardised solution to reduce cost
- C-Type filter was found to be the most suitable
- Tuned frequency is, in most cases, set at around the 5th harmonic



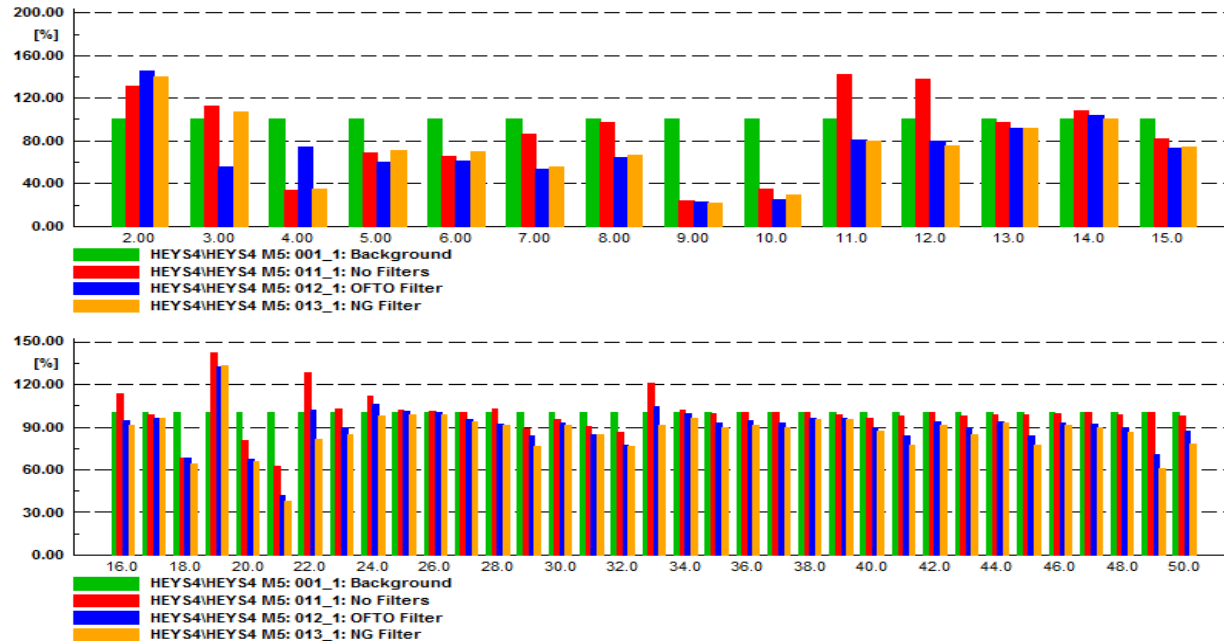
The results

- The redundancy is based on the NGET being able to coordinate the planned outages of the filters with the rest of network maintenance
- The other OWF which are far from the area of study were not included in the study, i.e. their filters are in the background in both cases

PCC Voltage	# of Customers	# of export cables	MWs Connected	Filter owner	# of Filters connected	Total Filter capacity (MVar)
North-West Region						
132 kV	3	3	422	OFTO	2	47
				NGET - no redundancy	1	50
400 kV	2	4	1042	OFTO	6	370
				NGET - no redundancy	2	160
East Region						
400 kV	4	8	2121	OFTO	8	260
				NGET - no redundancy	2	100
Total						
400 kV & 132 kV	6	15	3585	OFTO	16	677
				NGET - no redundancy	5	310
			Reduction		68.8%	54.2%
			Reduction with redundancy of 1.5		50.0%	31.3%

Final solution for Heysham in the north west

- Graphs show the % change in the background
- No filter means OWF connected with no filter in service
- The blue bars are for the case when all OFTO filters are in
- Yellow bars are for the case when all NGET filters are in



Future connection

- Methods were devised to estimate the number of filters for future connections if the customer and NGET were to install filters
- Projects connecting in RIIO-T1 were not considered, hence, only projects connecting from 2022/2023 were included
- Offshore wind farms
 - K_{MVAr} is the ratio of the filters MVA_r to the TEC (MW)
 - K_{NoF} is the number of filters to the TEC (MW)
 - K_{NoFEC} is based on the number of filters to the export cable
- The above factors, based on the historical data and NGET designed filters, are used to estimate the filters that would be installed by offshore wind farms in the future
- HVDC VSC technology
 - Usually small filters, e.g. 5 MVA_r to 30 MVA_r
 - A search on installed VSC HVDC across the world revealed that on average 2 are used for each connection irrespective of MW size
- Considering the network coordinated approach, 1 filter per connection is considered for NGET harmonic management initiative

Estimation factors for the future connections

- K_{MVAR} is used to estimate the required filter MVar for a given TEC (MW)
 - Typical filter MVar size is then used to estimate the number of filters required
- K_{NoF} is used to estimate the number of filters directly, for a given TEC (MW)
- K_{NoEC} is used to estimate the number of filters for a given number of export cable

PCC Voltage	# of Customers	# of export cables	MWs Connected	Filter owner	# of Filters connected	Total Filter capacity (MVar)	K _{MVar} MVar / MW	K _{NoF} # of filter / MW	K _{NoEC} # of Filter / # of export cables
North-West Region									
132 kV	3	3	422	OFTO	2	47	0.111	0.005	0.667
				NGET - no redundancy	1	50	0.118	0.002	0.333
400 kV	2	4	1042	OFTO	6	370	0.355	0.006	1.500
				NGET - no redundancy	2	160	0.154	0.002	0.500
East Region									
400 kV	4	8	2121	OFTO	8	260	0.123	0.004	1.000
				NGET - no redundancy	2	100	0.047	0.001	0.250
Total									
400 kV & 132 kV	6	15	3585	OFTO	16	677	0.189	0.004	1.067
				NGET - no redundancy	5	310	0.086	0.001	0.333
			Reduction			68.8%	54.2%		
			Reduction with redundancy of 1.5			50.0%	31.3%		

Future connection: offshore wind farms

- Averaging the number of filters estimated by different factor
- a total of 56 filters, equivalent to 2676 MVar would be needed if existing approach is considered
- If NGET were to manage harmonic mitigation then 24 filters, equivalent to 1440 MVar, will be needed
- With redundancy considered, the total number will be 34 filters

Project Name	PCC	Capacity (MW)	Connection Year	# of export cables	Filter Capacity required (MVar) - based on K_{MVar}	OFTO Filters				NGET Filters			
						# of filters required - based on K_{MVar} and typical filter size	# of filters required - based on K_{NoF}	# of filters required - based on K_{NoEC}		Filter Capacity required (MVar) - based on K_{MVar}	# of filters required - based on K_{MVar} and typical filter size	# of filters required - based on K_{NoF}	# of filters required - based on K_{NoEC}
Hornsea Project 2	Killingholme 400 kV	1200	2022	4	226.09	5	5	4		120.42	2	2	2
Dogger Bank (P1)	Creyke Beck 400 kV	1000	2023	4	188.41	4	4	4		100.35	2	1	2
East Anglia 3	Bramford 400 kV	1200	2024	2	226.09	5	5	2		120.42	2	2	1
Dogger Bank (P4)	Creyke Beck 400 kV	1000	2025	4	188.41	4	4	4		100.35	2	1	2
Hornsea Project 3 (3A + 3B)	Norwich Main 400 kV	1000	2025	4	188.41	4	4	4		100.35	2	1	2
East Anglia 2	Leiston 400 kV	1200	2026	4	226.09	5	5	4		120.42	2	2	2
Codling Wind Park	Pentir 400 kV	1000	2028	5	188.41	4	4	5		100.35	2	1	2
Dogger Bank (P2)	Lackenby 400 kV	1000	2028	4	188.41	4	4	4		100.35	2	1	2
East Anglia 4	Necton 400 kV	900	2028	1	169.57	4	4	1		90.31	1	1	0
East Anglia 5	Necton 400 kV	900	2028	4	169.57	4	4	4		90.31	1	1	2
Hornsea Project 3 (3C + 3D)	Norwich Main 400 kV	1000	2028	4	188.41	4	4	4		100.35	2	1	2
Dogger Bank (P3)	Lackenby 400 kV	1000	2030	4	188.41	4	4	4		100.35	2	1	2
East Anglia 6	Necton 400 kV	1800	2030	6	339.14	8	8	6		180.63	3	3	2
		14200		50	2675.41	59	59	50		1424.96	25	18	23

Future connections: VSC HVDC

- 7400 MW of connection until 2030
- Based on average number of filter of 2 for each connection, 12 filters will be needed
- Considering network wide management/coordination of filters, 6 will be needed if NGET were to manage harmonic mitigation

Project Name	PCC	Capacity (MW)	Connection Year	# of filters required based on average # of filters per connection	# of filters required - NG
Greenlink	Pembroke 400 kV	500	2023	2	1
NeuConnect (Greenage)	Grain 400 kV	1400	2024	2	1
Nautilus (NEMO2)	Leiston 400 kV	1500	2025	2	1
Cronos VOLTA B	Kemsley 400 kV	1400	2025	2	1
Eurolink	Leiston 400 kV	1600	2024	2	1
Gridlink	Kingsnorth 400 kV	1500	2022	2	1
		7900		12	6

Summary of future filter requirement

- Redundancy is generally 1.5 but considering network wide coordination, i.e. connections electrically close will have coordinated redundancy
- The overall reduction for OWF without redundancy is 57.1% and with redundancy is 39.3%
- The overall reduction including the interconnectors is 55.9% and with redundancy 36.8%

Offshore Wind Farms				
PCC	Capacity (MW)	OWF Filters	NGET Filters (No redundancy)	NGET Filters (with redundancy)
Killingholme 400 kV	1200	5	2	3
Creyke Beck 400 kV	1000	4	2	3
Bramford 400 kV	1200	4	2	2
Creyke Beck 400 kV	1000	4	2	3
Norwich Main 400 kV	1000	4	2	2
Leiston 400 kV	1200	5	2	3
Pentir 400 kV	1000	4	2	3
Lackenby 400 kV	1000	4	2	3
Necton 400 kV	900	3	1	2
Necton 400 kV	900	4	1	1
Norwich Main 400 kV	1000	4	2	3
Lackenby 400 kV	1000	4	2	3
Necton 400 kV	1800	7	2	3
	14200	56	24	34

Interconnector				
PCC	Capacity (MW)	Interconnector filters based on average number of filters per connection	NGET filters	NGET filters with redundancy
Pembroke 400 kV	500	2	1	2
Grain 400 kV	1400	2	1	1
Leiston 400 kV	1500	2	1	2
Kemsley 400 kV	1400	2	1	2
Leiston 400 kV	1600	2	1	1
Kingsnorth 400 kV	1500	2	1	1
	7900	12	6	9

Conclusions

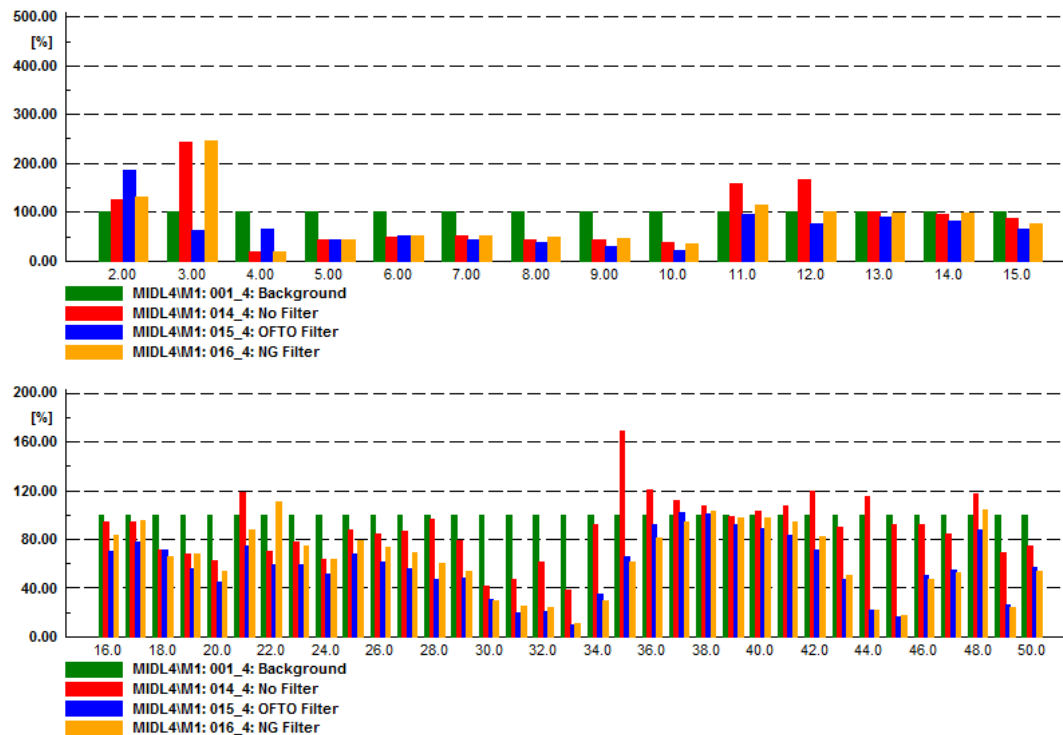
- NGET design filters for the existing connections in the north west and east sectors
- It was shown that if NGET had managed harmonic mitigation in the past 54.2% and 31.3% less filters would have been installed respectively without redundancy and with redundancy of 1.5
- The historical data was used to determine the estimating factors to estimate how many filters will be used by the future connections if Users and also NGET were to manage users impact
- Results show that at least a reduction of 36.8% in the number of filters can be achieved with good degree of redundancy

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Back up slides

NO coordination

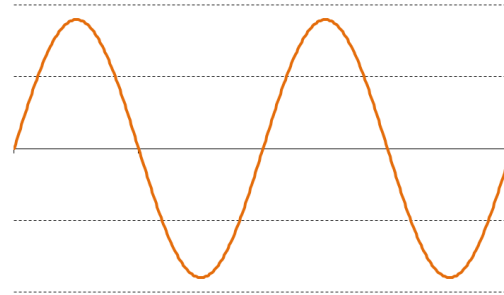
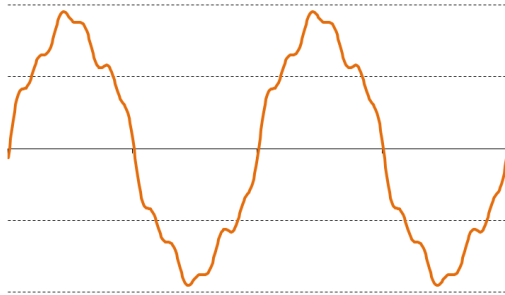
- Good example of benefits if NO manage harmonic filters



Harmonics Management in the SPT Area

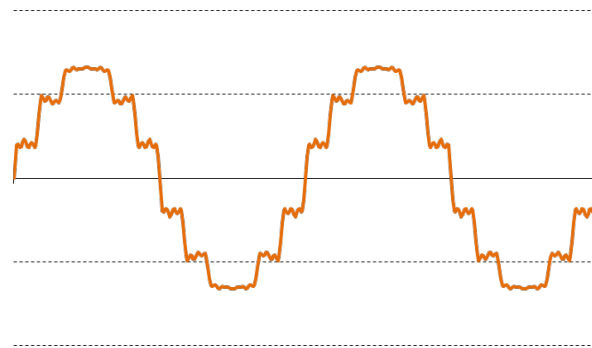
Harmonics Management in the SPT Area

- Existing approach
- Harmonic resonance problems
- Issues with the existing approach
- Studies carried out
- SPEN proposals



Existing Approach

- “Polluter Pays” principle
- SPEN provides limits and impedance data
 - Impedance loci
 - Impedance scans
 - Network data not normally provided
- Background measurements
- User carries out studies
- Compliance measurements
- Marginal non-compliance can be resolved by measurement



**The User is responsible for
harmonic compliance**

- Harmonic resonance problems
 - Radial 132kV collector networks
- Harmonic resonance
 - Weak network
 - Low load
 - Windfarm array cable capacitance
 - 132kV cable capacitance
 - Cable often user choice



More issues as more renewables connect

Issues with the Existing Approach

- Network does not exist – no background measurements
- Final network design uncertain
- Windfarm design and harmonic emissions not known
- Engineering Recommendation G5/4 sequential process
- How to apportion headroom fairly?
- Inefficient mitigation
- Filter redundancy
- Mitigation costs may not be distributed equitably between Users
- Late identification of problems

**Harmonic compliance is an increasing
problem for Users and TOs**

Who is responsible in case of a network resonance?

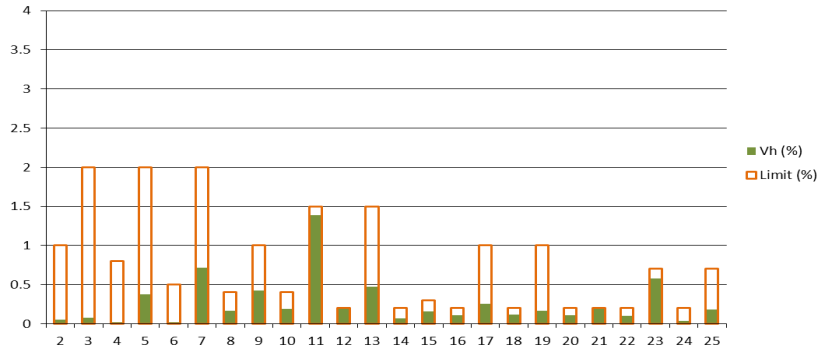
Transmission Owner

- Background not from new windfarm
- Cable circuits

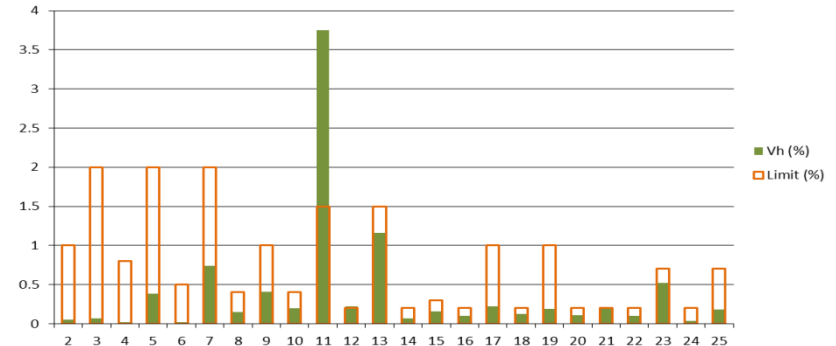
User (Windfarm)

- Cables part of the resonant circuit

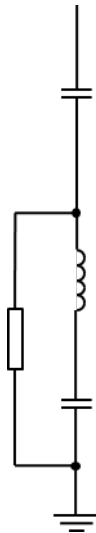
Before connection



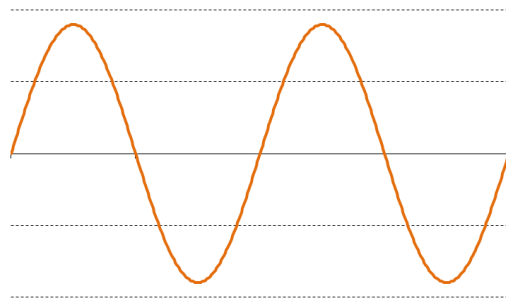
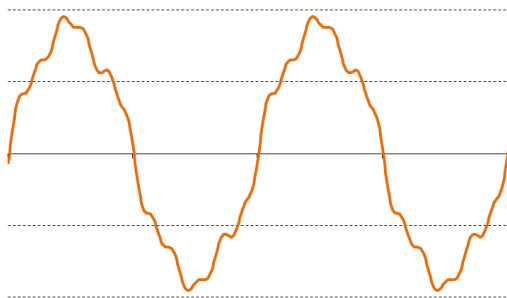
After connection



- What have we done so far?
- WSP/PB (NIA_SPT_1506)
 - Development of a Standard 33kV Harmonic Filter
 - Standard design at all windfarm connection points?
 - Filters best placed at 132kV and 33kV
- EPRI (NIA_SPT_1610)
 - South West Scotland Harmonics Study
 - 132kV 20Mvar damped filters proposed



- Who should pay?
 - Network used mostly by wind generators
 - Background harmonics caused by wider customers
- Mitigation by TO more economic and efficient



- Harmonic mitigation by TO
 - Where more economic and efficient
 - Whole system approach
- RIIO-T2
 - Standardised 132kV, 20Mvar damped filters
- Polluter continues to pay
 - E.g. large HVDC converter
- User remains responsible for compliance at connection point
- Filter may appear as one-off works in offers
 - E.g. if User opts for cable connection



Summary

- Harmonic resonance
 - Weak networks
 - Increasing use of cable
- TO solution often more economic and efficient
- Users also have responsibility
- Polluter continues to pay



Western Link harmonic filters
during construction

Refreshment Break

10 minutes

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Specialist Consultants
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HARMONIC COMPLIANCE MANAGEMENT INTERNATIONAL APPROACHES

David Mills – David.Mills@PSCconsulting.com

Zia Emin – Zia.Emin@PSCconsulting.com

2nd April 2019



AGENDA

- ▶ Approach By Others
- ▶ Who Is Responsible?
- ▶ Financial Arrangements



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OTHER COUNTRIES

- ▶ TSOs Contacted
 - EirGrid
 - Energinet
 - TenneT
 - RTE
 - AEMO
 - TasNetworks
 - Manitoba Hydro
 - Hydro-Quebec
 - Brazil



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UK

- ▶ G5/4 (G5/5) considering background and 1st/1st approach
- ▶ Establish limits and specification – utility responsibility
- ▶ Compliance with limits is customer responsibility
- ▶ Consider N-1 contingencies and remote nodes
- ▶ Limits and impedance data provided
- ▶ Mitigation by connectee if required and provide compliance report
- ▶ Multiple connections → 1st come 1st served



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QUESTIONNAIRE

- ▶ Who is responsible.
 - Utility/customer
 - What point
- ▶ How limits are derived and how do you keep them within these
 - Applicable standard
 - IEC 61000-3-6 (Voltage Distortion)
 - IEEE 519 (Current Injection)
- ▶ What approach is used where
 - Utility handles network amplification
 - Customer handles internal network and harmonic injection
- ▶ Who Pays for what part
 - Connectee as part of connection
 - Socialised within system use charge



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RESPONSIBILITY

- ▶ Utility derives emission limits
 - Mixed approaches as to the way the limits are determined
 - Specify at the PoC/PCC (form is important)
 - But the devil is usually in the detail
- ▶ Connectee has to comply with the issued emission limits
- ▶ What approach is used where
 - Utility handles network amplification
 - Customer handles internal network and harmonic injection
- ▶ Who Pays for what part
 - Connectee as part of connection
 - Socialised within system use charge



Derivation of limits

▶ IEC 61000-3-6 (Voltage Distortion)

- EirGrid
- Energinet
- TenneT
- TasNetworks

Amplification of existing distortion
&
Distortion due to active injection

▶ IEEE 519 (Current Injection)

- RTE
- Manitoba Hydro
- Hydro-Quebec

Measure the injected current



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EirGrid/Energinet/Tennet/TasNetworks

- ▶ IEC 61000-3-6 (but considering background) (slight mods in AUS)
- ▶ Calculate limits for a new connectee
- ▶ Use of available headroom – (maintain some margin for future)
- ▶ Consider N-1 contingencies and remote nodes
- ▶ Multiple connections → share of headroom
- ▶ Limits and impedance data provided
- ▶ Mitigation by connectee if required and provide compliance report
- ▶ Single connectee → Infrastructure change → amplification issue → utility specifies mitigation for the transmission system → cost passed to the connectee (EirGrid)
- ▶ Temporary acceptance until measurements over 3 months confirm (Energinet)
- ▶ Responsibility of background amplification is on the TSO (TenneT)



RTE/Manitoba Hydro/Hydro Quebec

- ▶ Harmonic current limits derived wrt IEC 61000-3-6 and/or IEEE519
- ▶ Diverse approaches
- ▶ All trying to limit overall system level
- ▶ CART levels higher than IEC 61000-3-6 used by RTE
- ▶ Not much experience so far with limits being an issue to comply with



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ONS (Brazil)

- ▶ ONS grid code and technical specs
- ▶ Individual (at PCC for individual customers) and Global limits (to verify whole system performance) all fixed
- ▶ Global limits have a band, connections classed as “under observation” if distortion is within the band
- ▶ Global limit non-compliance triggers investigation → TSO or customer responsibility
- ▶ Customer impact evaluated at planning stage and customer is responsible for designing mitigation measures
- ▶ System data provided for mitigation measure design
- ▶ Temporary acceptance employed



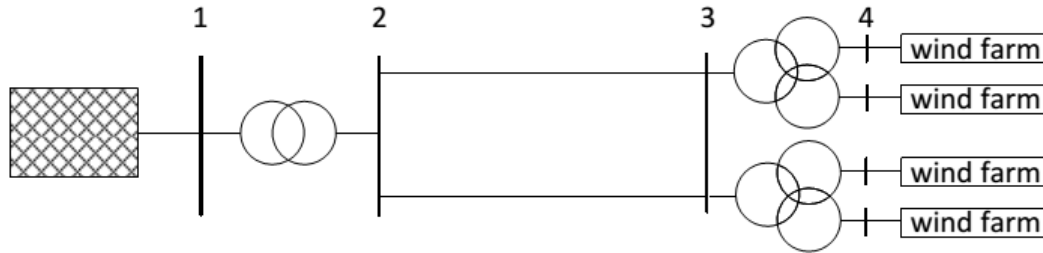
Responsibility for Paying

Country	Who Mitigates / Who Pays		
	Passive Amplification		Active Injection
	Network Development	Connectee's System	
Ireland (EirGrid)	New Connectee	New Connectee	New Connectee
Denmark (Energinet)	Socialised	New Connectee	New Connectee
Netherlands (TenneT)	Socialised	Socialised	New Connectee



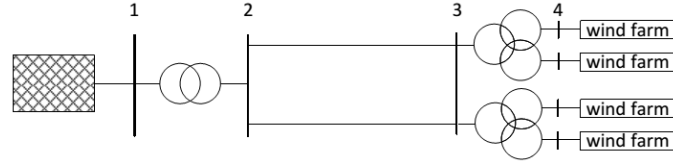
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Simple case study



- ▶ PoC is node 1
- ▶ Background information at node 1 is available
- ▶ Amplification due to the connection is available
- ▶ Active injection not an issue

Simple case study - summary



	PoE	Mitigation Required?	Responsibility to mitigate	Who will pay
Brazil	1	Yes as individual limits reached	Customer to resolve	Customer
Denmark	4	Yes as background is amplified at nodes 1, 2 and 3	TSO	TSO and will recover cost from all system users
Ireland	3	Yes as background is amplified at nodes 1, 2 and 3	TSO	TSO and will recover cost from customer
United Kingdom	1	Yes as background is amplified	Customer	Customer



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THANK YOU

Any Questions?

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HARMONIC COMPLIANCE MANAGEMENT ALTERNATIVE UK MODEL

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Zia Emin – Zia.Emin@PSCconsulting.com

2nd April 2019



AGENDA

- ▶ Background
- ▶ Alternative Approaches Considered
- ▶ Details of Proposed Alternative Approach
- ▶ Benefits / Risks / Opportunities / Challenges
- ▶ Questions



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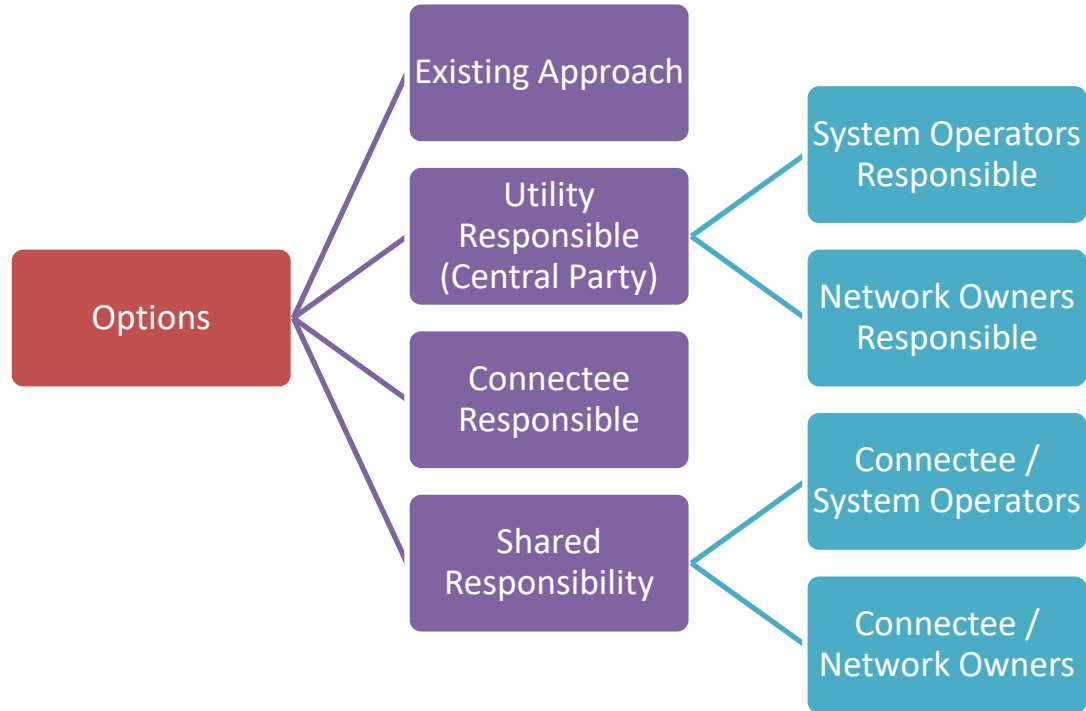
BACKGROUND

- ▶ Opportunity for more efficient harmonic management approach
- ▶ Existing system does not account for increases in general consumer harmonic distortion
- ▶ Constantly changing system and requirement for harmonic mitigation introduces delays in the connection process
- ▶ Some potential harmonic issues may be resolved / not materialise due to future system developments.
- ▶ Existing approach makes both utility and customer responsible



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OPTIONS CONSIDERED



UTILITY RESPONSIBLE

- ▶ Utility fully responsible for harmonic compliance management
- ▶ Along side thermal and fault current studies carries out harmonic studies to determine impact of new connection.
- ▶ Identifies solution to harmonic mitigation:
 - Optimised location for passive harmonic filter (designs, builds and operates)
 - Contractual arrangements / ancillary services to reduce harmonic impact
- ▶ Take into consideration future connections
 - Single solution rather than multiple
 - Deferring harmonic mitigation until planning levels approached



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CONNECTEE RESPONSIBLE

- ▶ Connectee fully responsible for harmonic compliance management
- ▶ Connectee has to carry out own studies including obtaining measurements from network
- ▶ Identifies solution to harmonic mitigation:
 - Optimised location for harmonic filter through contractual arrangements with other parties
 - Make own contractual arrangements to reduce impact
 - Deferring harmonic mitigation until issue is realised / system developments completed
- ▶ Who is responsible for resolving background increase?



SHARED RESPONSIBILITY

- ▶ Connectee and networks share responsibility for harmonic compliance management
- ▶ Network studies system and identifies impact of new connectee on the system
- ▶ Network identifies solution to harmonic mitigation:
 - Optimised location for passive harmonic filter
 - Connectee responsible for design / installation / operation
- ▶ Harmonic distortion as a result of future changes
 - Utility able to consider impact of future system changes
 - Deferring harmonic mitigation until issue is identified



COMPARISON

Activity	Utility Responsible	Connectee Responsible	Shared Responsibility
Existing System Measurements	Utility	Connectee	Utility
System Modelling and Studies	Utility	Connectee	Utility
Mitigation Specification	Utility	Connectee	Utility
Mitigation Responsibility	Utility	Connectee(s)	Connectee(s)
Monitoring	Utility	Connectee	Connectee



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BENEFITS / OPPORTUNITIES

Utility Responsible	Connectee Responsible	Shared Responsibility
Utility has full system knowledge	Utility relieved of assessment responsibility	Utility identifies optimum solution
No requirement for connectee's own studies	Connectee has complete control over timescales for their own filter design / installation.	Connectee has control over timescales for filter design / installation
Alternative options for harmonic management	Contractual arrangements with other connectee's to optimise	Fewer harmonic filters and overall cost saving to consumers
Fewer harmonic filters and overall cost saving to consumers		
No delay waiting for studies to be completed		

RISKS / CHALLENGES

Utility Responsible	Connectee Responsible	Shared Responsibility
Timely installation of harmonic mitigation to avoid delaying connectee	Obtaining harmonic measurement data and system models	Responsibility issues if optimum location not on connectee's network
Cancelled connections and technology changes	Delays waiting for previous connectee to complete their designs.	Responsibility for changes in background distortion
Transparency of cost sharing and allocation	Considering impact of harmonic mitigation on wider system	Contractually may be very complex.
Scrutinising of the optimum solution	Limited opportunity for optimised solutions	System design / data exchange between parties
System design / data exchange between parties	Responsibility for changes in background distortion	
	Contractual arrangements between connectees	

SUMMARY

- ▶ Alternative approaches to responsibility for harmonic distortion management:
 - Utility responsible
 - Connectee responsible
 - Shared responsibility

- ▶ Some questions still to be answered:
 - Increases in general background distortion?
 - How is a connectee incentivised to consider their harmonic impact?
 - With changes in responsibility how would it be policed?

THANK YOU

Any Questions?

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Questions and Voting

Maxwell Mulimakwenda

nationalgrid



There are four proposed options by which Harmonics can be managed in the future.....

On your sheets – Question 2, please rank the approach's

- 1. Existing Approach**
- 2. Utility responsible**
- 3. Connectee responsible**
- 4. Shared responsibility**

Please add any additional comments you may have

Lunch

40 minutes

national**grid**





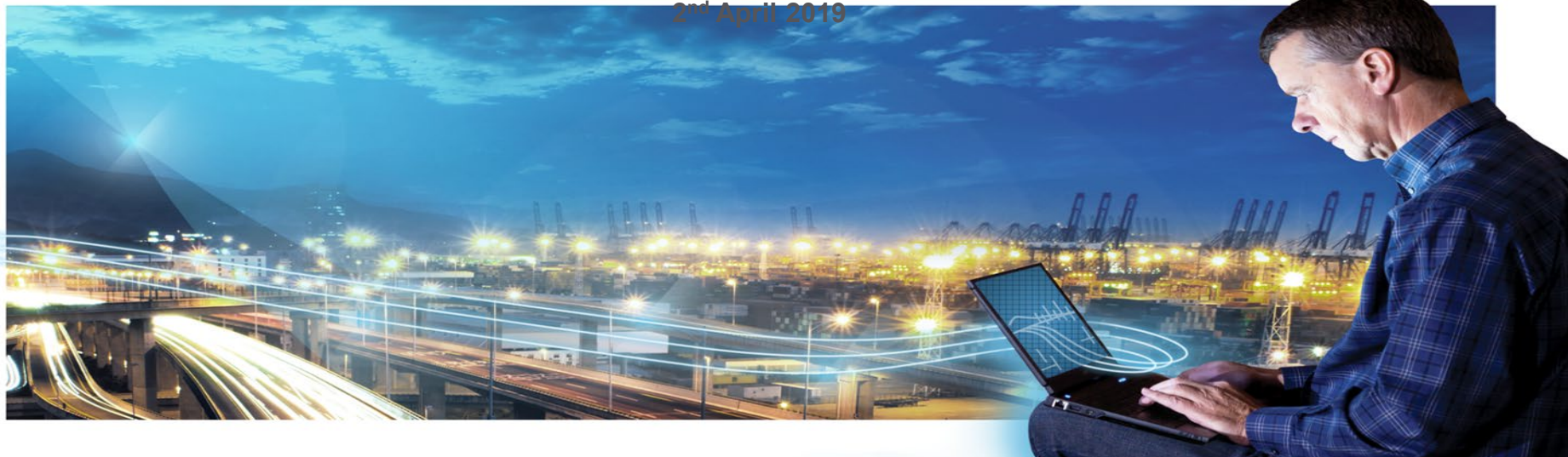
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HARMONIC COMPLIANCE MANAGEMENT INCENTIVISING CONNECTEE'S

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2nd April 2019



AGENDA

- ▶ Mechanisms to incentivise connectee's
- ▶ Proposed approaches
- ▶ Benefits / Risks
- ▶ Examples



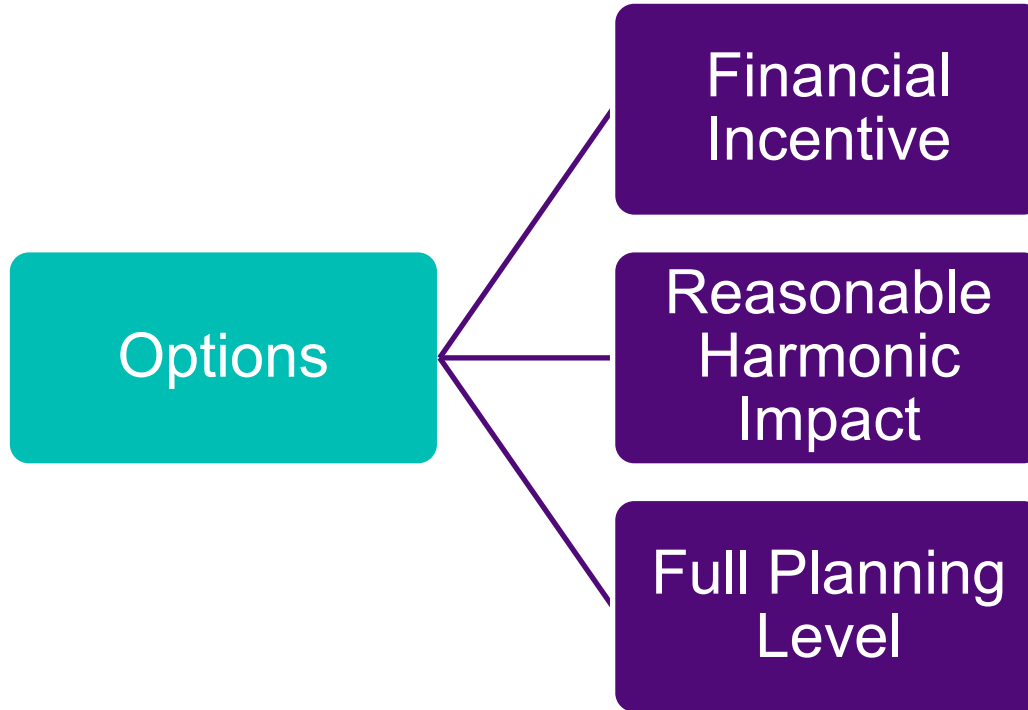
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BACKGROUND

- ▶ Utility responsible for harmonic compliance management
- ▶ Methods to incentivise connectee's to consider their harmonic impact?
- ▶ Accounting for increases in background distortion



PROPOSED APPROACHES



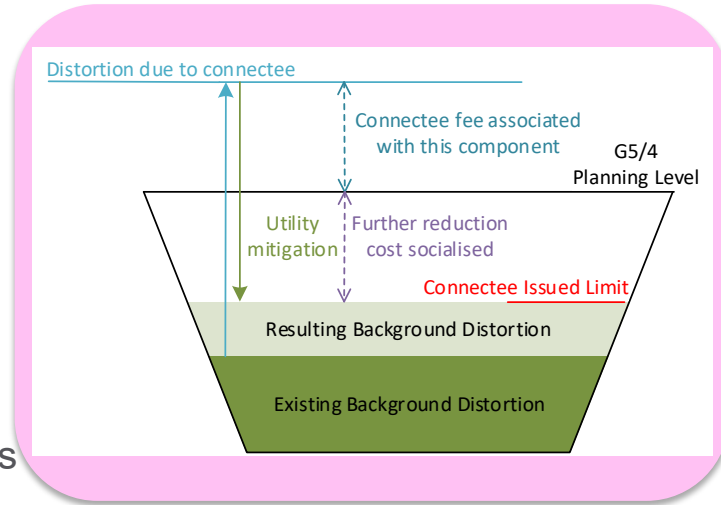
FINANCIAL INCENTIVE

- ▶ No mitigation by connectee
- ▶ Incentivised to reduce harmonic impact due to connectee fee
- ▶ Fee is not specifically dependant on cost of mitigation
- ▶ Connectee may consider changes to reduce fee:

Connection location

Connection arrangement

Choice of distorting equipment



REASONABLE HARMONIC IMPACT

- ▶ Utility determines reasonable impact of connectee based on:

Technology type

Connection location

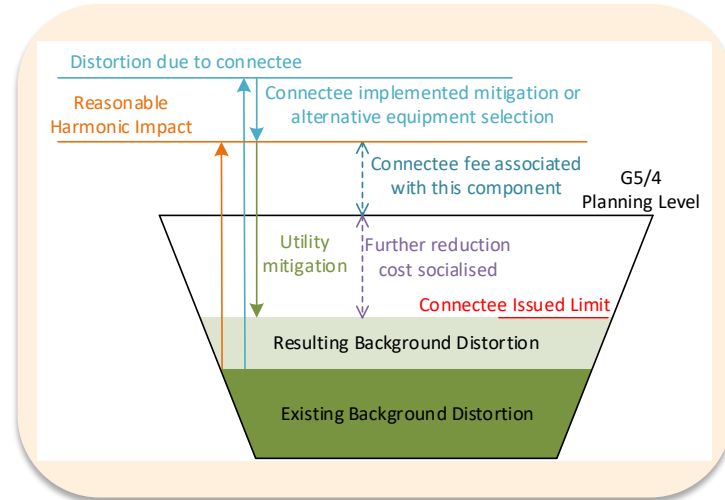
- ▶ Incentivised to go further due to connectee fee

- ▶ Connectee must ensure impact is reasonable by considering:

Choice of equipment

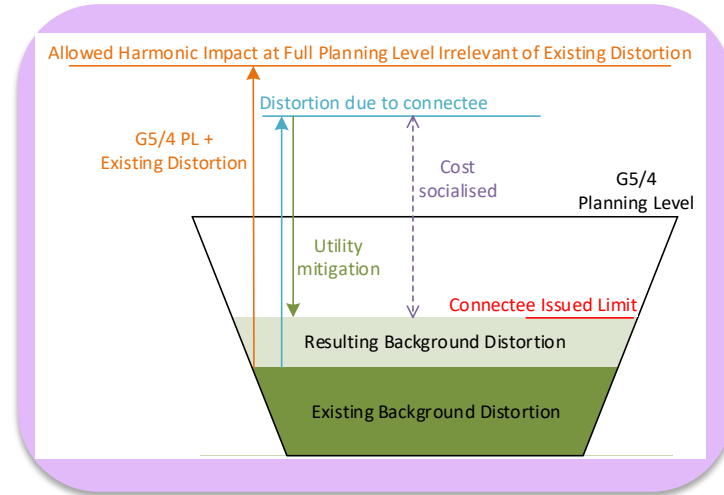
Internal network configuration

Own mitigation



FULL PLANNING LEVEL

- ▶ Connectee Allowed to Increase Background by Full Planning Level
- ▶ Utility Mitigates for Actual Impact of Connectee
- ▶ Connectee must ensure impact is less than planning level by:
 - Choice of equipment
 - Internal network configuration
 - Own mitigation



COMPARISON

Activity	Financial Incentive	Reasonable Harmonic Impact	Full Planning Level
Connectee System Data Upfront	Detailed	General	None
Connectee Harmonic Impact	No Restriction	Technology Based	Full Planning Level
Existing Background	Considered	Considered	Not Considered
Connectee Mitigation	None	Potentially	Unlikely
Connectee Fee	Proportional	Proportional	None



BENEFITS

Financial Incentive	Reasonable Harmonic Impact	Full Planning Level Available
Connectee financially incentivised to reduce impact	Connectee forced to select reasonable equipment	Level playing field for all connectees
Location in-dependant connections may benefit	Location in-dependant connections may benefit	Connectee can progress design without considering harmonic impact
Opportunity for ancillary service from connectee	Technology type limits can be changed over time to improve system compliance	Utility able to defer installation until issues materialise
	Opportunity for ancillary service from connectee	No data required from connectee initially
	Less data required from connectee initially	Facilitates faster connections to the system

RISKS

Financial Incentive	Reasonable Harmonic Impact	Full Planning Level Available
Payments associated with this model very complex	Choice of “reasonable” harmonic limits	No incentive for connectee’s to consider their harmonic impact
Requires transparent calculation of fee	Connectee still largely responsible for managing harmonic impact	Scrutiny of utility to justify investment decisions for socialised costs
Detailed data from connectee necessary at an early stage	Transparent model for calculation of fee required	
Changes in connectee data or cancelled connections	Detailed data from connectee necessary at an early stage	
Justification for creating harmonic headroom		

SUMMARY

- ▶ Connectee fee incentivises them to reduce their harmonic impact but charging mechanism will be very complex

How to apply connectee fee taking into consideration individual harmonics

What happens if a customer cancels

- ▶ Socialising all costs is simpler but doesn't incentivise the connectee to consider their contribution

- ▶ In either case some costs socialised to account for:

General increases in background distortion

Amplification of existing harmonics

- ▶ Would the utility be allowed to invest to create headroom for potential future connectee's?

THANK YOU

Any Questions?

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Questions and Voting

Maxwell Mulimakwenda

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Risk/Liability allocation framework

On your sheets – Question 3, please rank the approach's

- 1. Financial incentive**
- 2. Reasonable harmonic impact**
- 3. Full planning level**

Please add any additional comments you may have



National Grid Harmonic filter - Existing cost recovery methods for harmonics mitigation

2/04/2019

Vandad Hamidi

Increased geographic reach and offering

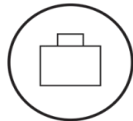


APPROXIMATELY
50,000
EMPLOYEES

SPEAKS
70
LANGUAGES

WORK FROM
OFFICES IN OVER
50
COUNTRIES

REPRESENTS
SOME
130
NATIONALITIES



Capital



Consulting
& Advisory



Digital
& AI



Design &
Engineering



Procurement



Construction
& Project
Management



Operations &
Maintenance



Sustaining
Capital



Background

Technical requirement

- › Grid Code (Connection Conditions (CC)) 6.1.5 Voltage Waveform Quality criteria
- › Requirement to monitor Voltage Waveform Quality in the System Operator Transmission owner Code STC section D
- › The responsibility to ascertain the requirement for harmonic filters lie on the developer
- › ER G5/4-1 sets the planning levels for harmonic voltage
- › Presently there is no requirement on the transmission network owner to build and maintain these assets

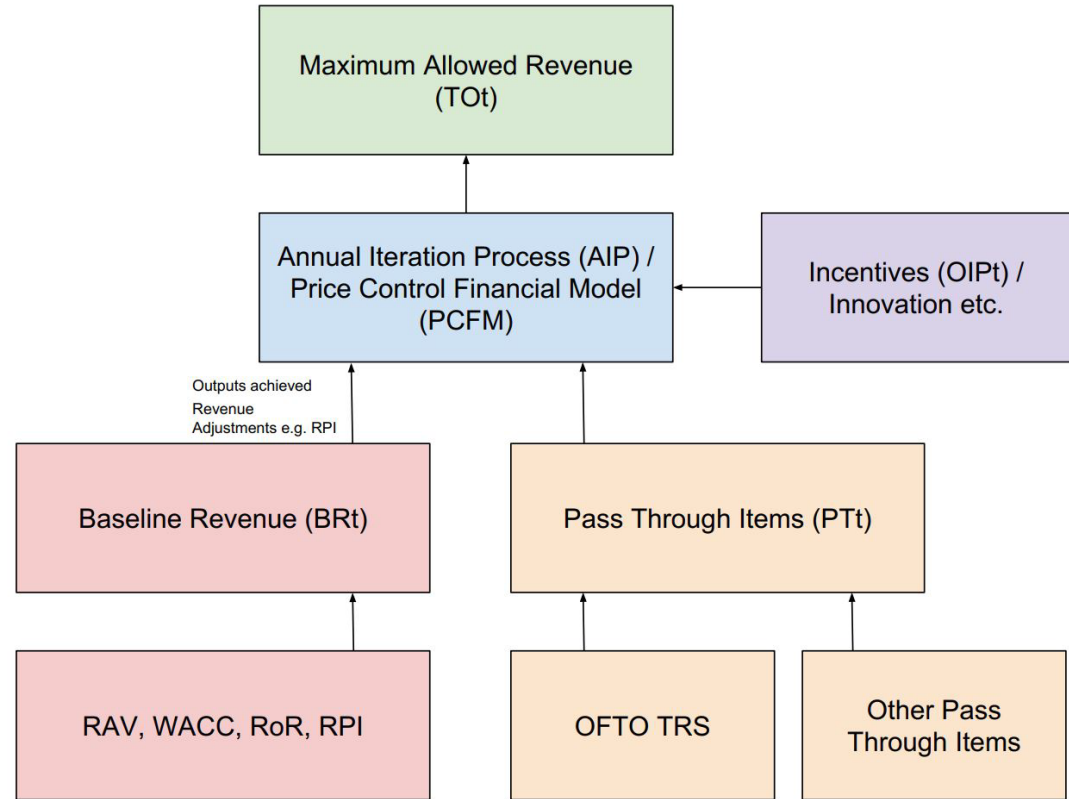
NGET technical study

- › 68 harmonic filters in the next 8 years
- › 56 harmonic filters OFTOs
- › 12 HVDC interconnectors
- › NGET build reduces this to 37 for OFTOs and 6 for HVDC interconnectors
- › Drop from 2600 Mvar to 2400 Mvar
- › Savings from centralized procurement - 19 for OFTOs and 6 for HVDC interconnectors (for the next 8 years)
- › Reduced project risks and reduced compliance requirements

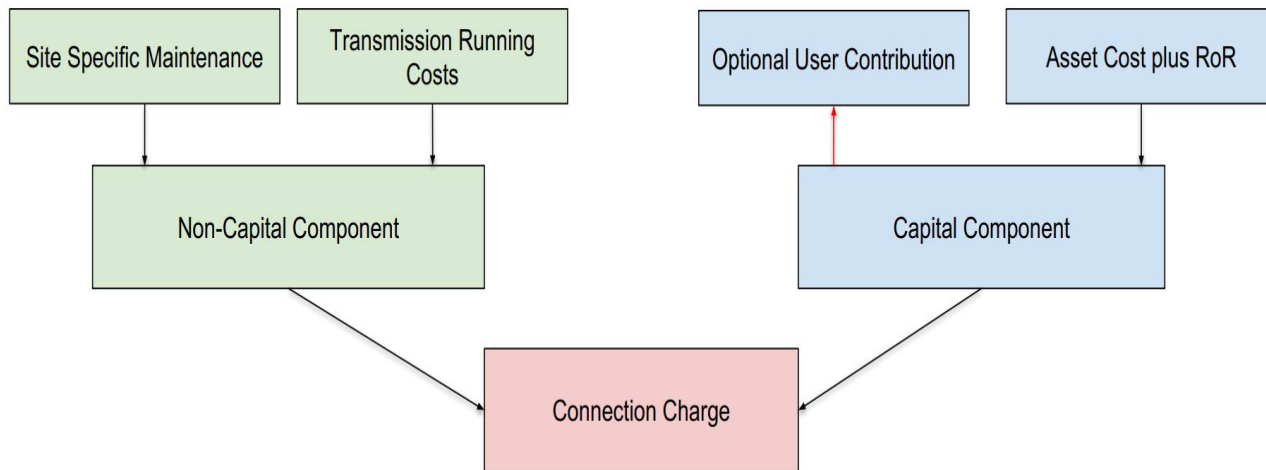


RIIO framework

- › Revenue = Incentives + Innovation + Outputs (RIIO)
- › Consists of baseline revenue and allowed pass through items (plus NIA/NIC revenue etc.)
- › Baseline revenue adjusted yearly through AIP based on outputs
- › Two types of outputs defined as:
 - › Individual projects with milestones
 - › Volume drivers (e.g. £/MW, £/OHLkm)
- › Maximum allowed revenue is calculated and feeds to the transport model for TNUoS calculation
- › Pass through components include OFTO TRS

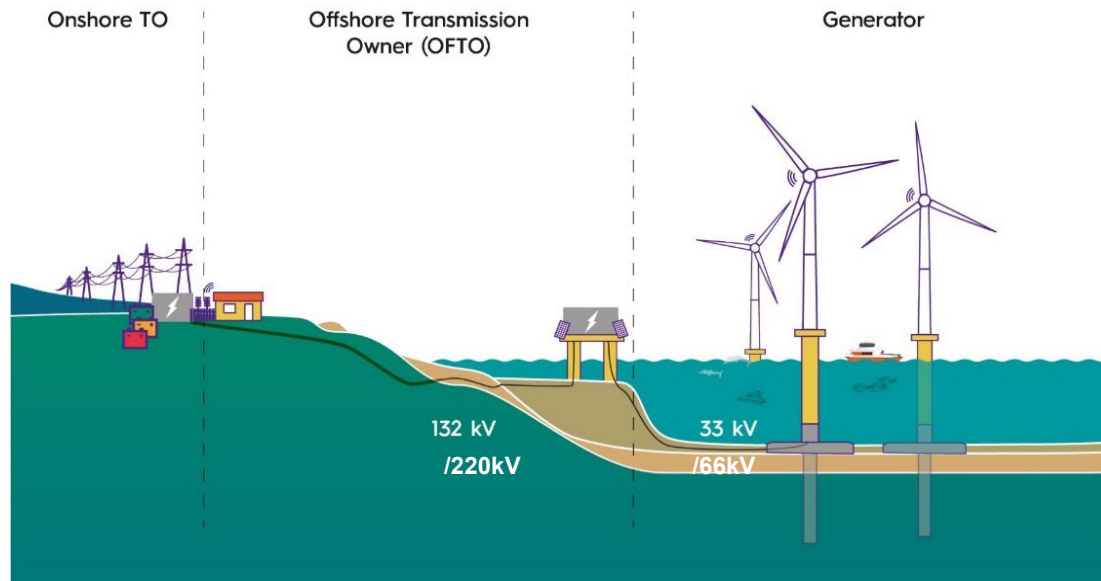


Connection charges

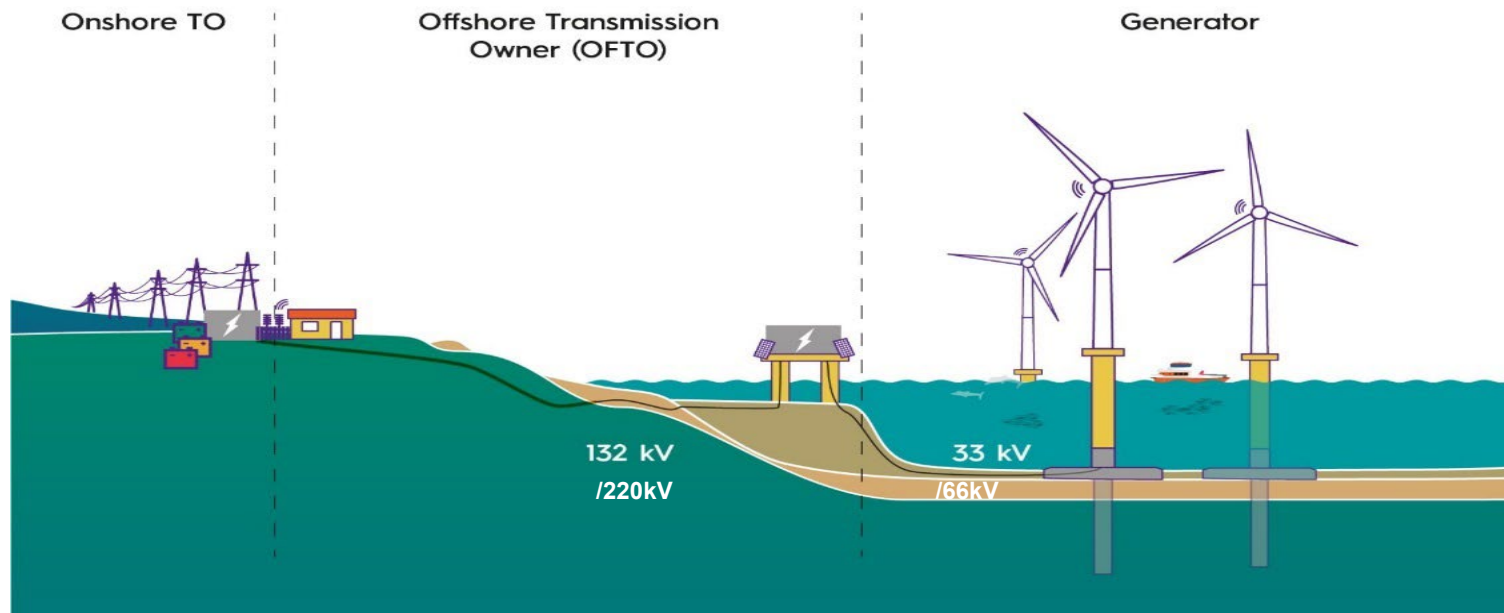


Example.

Harmonics Mitigations by Offshore Windfarms (in presence of OFTOs)

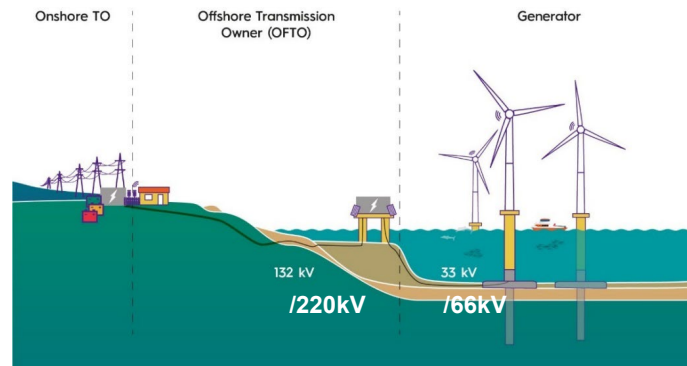


Background of OFTO Regime

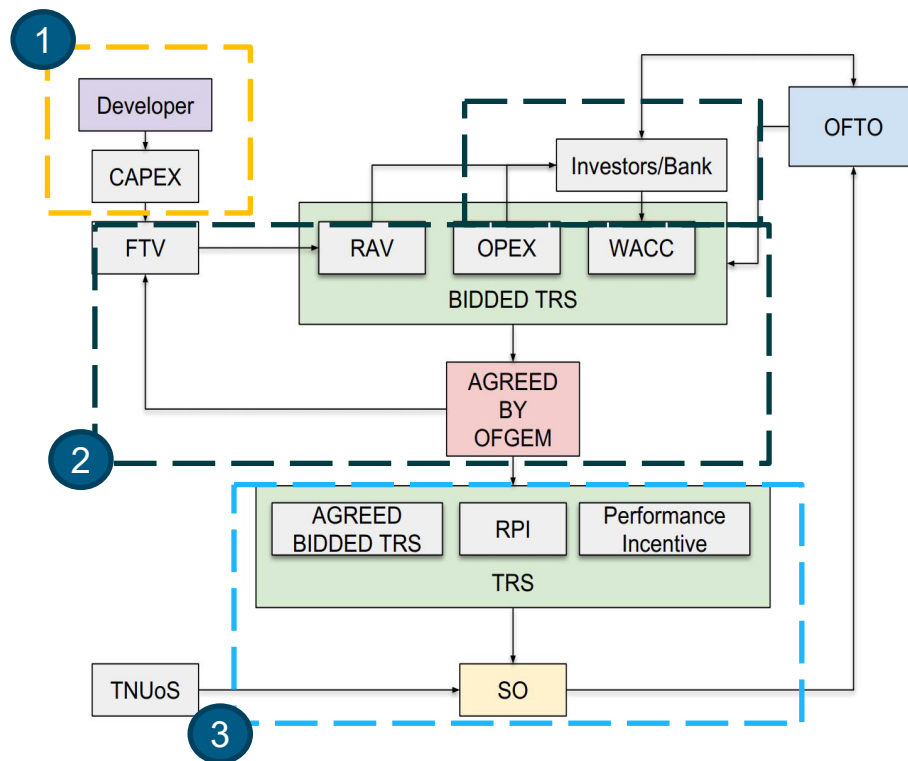
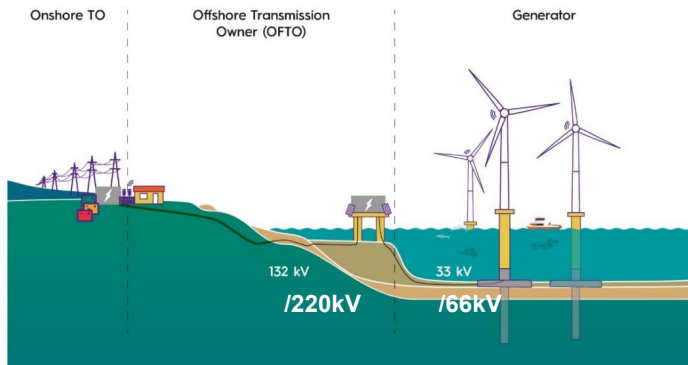


Harmonic Mitigations in Offshore Transmission System

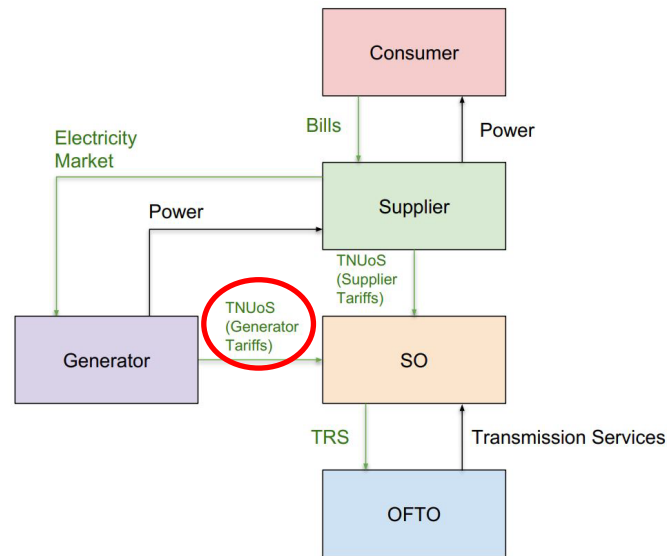
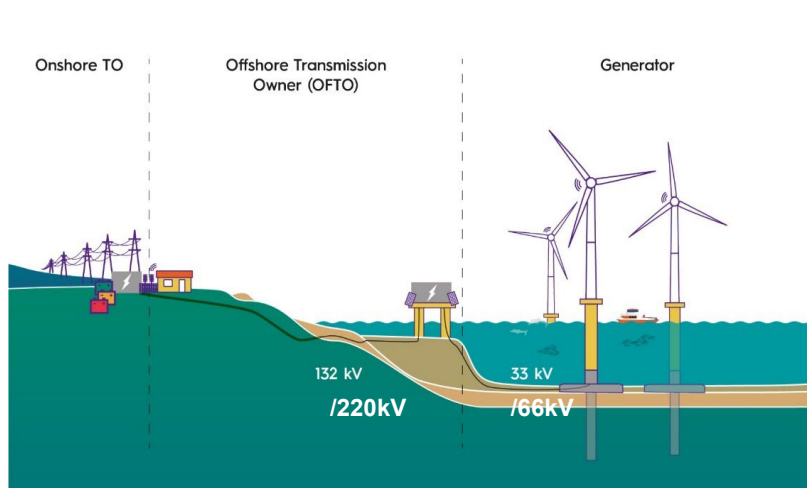
1. At the development stage, the offshore wind developer is responsible for compliance with the ER G5/4 at the “onshore” interface point
2. Background harmonic levels, WTG harmonic injection profile, increased resonance by the offshore cable all as per ER G5/4 determine the harmonic levels at the interface point and need for potential filter installations
3. Filter sizing etc. are all done by the developer
4. The harmonic filter will form part of **OFTO assets**



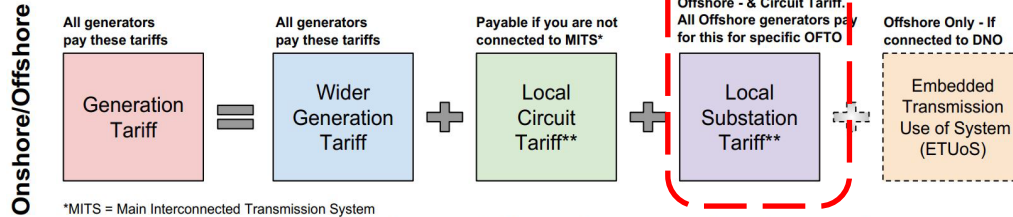
OFTO Cost Recovery



How the charges are paid



TNUoS



*MITS = Main Interconnected Transmission System

**BEGA = Bilateral Embedded Generation Agreement. If you have a BEGA the Local Substation and Local Circuit Tariffs are not applicable.



HH users: (Tariff - £/kW)
Suppliers/users directly connected to the transmission system, generally commercial/industrial.

Charged (£) on gross demand and based on average consumption over triads on a kW basis.



EET users: (Tariff - £/kW)
HH demand users & embedded (<100MW)

Credited (£) based on gross embedded export volume produced over triads on a kW basis.



NHH users: (Tariff - p/kWh)
Domestic or small non-domestic premises through suppliers.

Charged (£) on net demand and based on average consumption between 4 and 7pm in kWh.

Revenue Recovery Model for Offshore Windfarms (in presence of OFTO)

- › Generator builds the OFTO assets
- › The assets are transferred through to an OFTO through a tender process carried out by Ofgem
- › Asset value is determined by Ofgem following benchmarking as part of an Final Transfer Value (FTV)
- › O&M values are submitted by bidder
- › FTV and O&M translates (including RPI, WACC, RoR) to a tender revenue stream
- › Collected on behalf of the OFTO through the TNUoS – the local substation element of the generation tariff and charged to the windfarm owner/developer



Summary

Compliance with ER G5/4 in offshore transmission system at the development stage sits with the developer

Following the transfer of the OFTO assets, compliance with G5/4 is responsibility of the OFTO (through normal maintenance of the harmonic filters)

Any Harmonic Filter installation by the developers to mitigate the increased harmonic levels is charged back to the generator (i.e. developer) through TNUoS charges (local substation charge)

The developers are still paying for wider charges (charges which reflect maintenance of the onshore transmission systems) which are determined through CUSC



Questions and Voting

Maxwell Mulimakwenda

nationalgrid



Cost recovery options

On your sheets – Question 4, please indicate which one you agree with marking with a ✓

1. Cost recovery by changes to the base transmission revenue

Or

2. Cost recovery based on connection charges

Please add any additional comments you may have

Refreshment Break

10 minutes

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SNC • LAVALIN

ATKINS

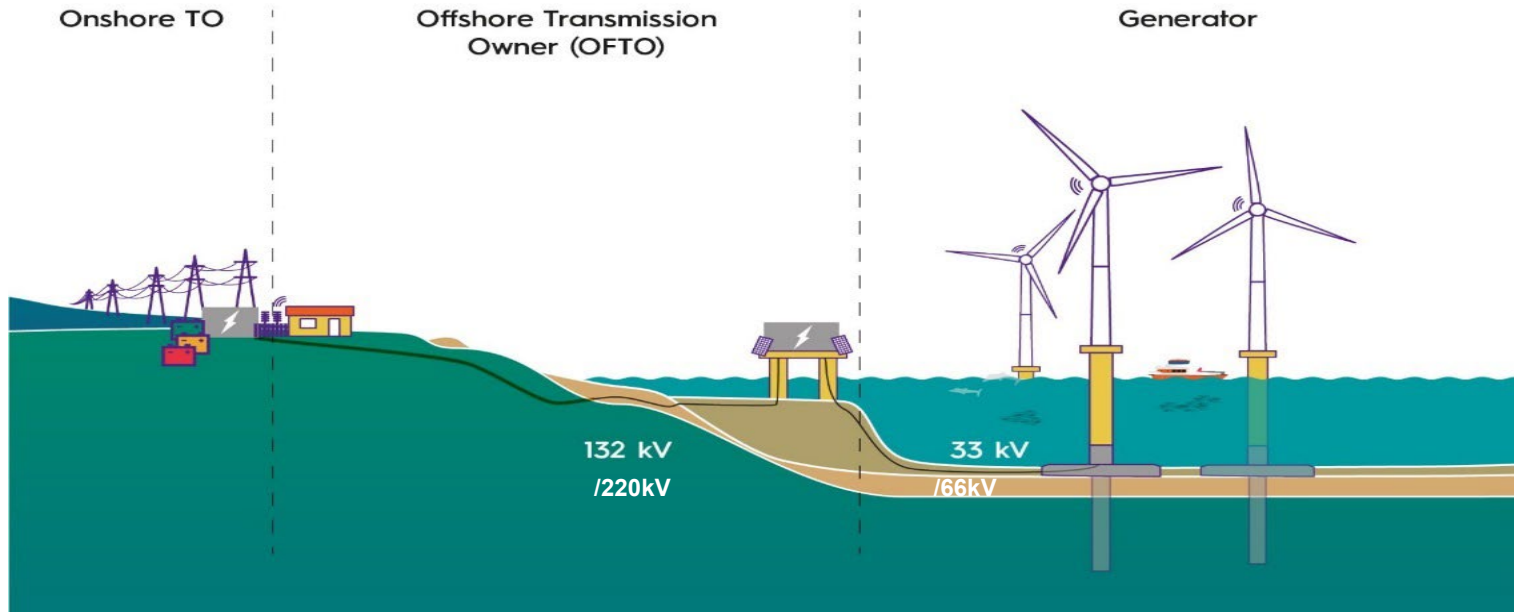
Member of the SNC-Lavalin Group

National Grid Harmonic filter - Impact of proposed approach on different stakeholders

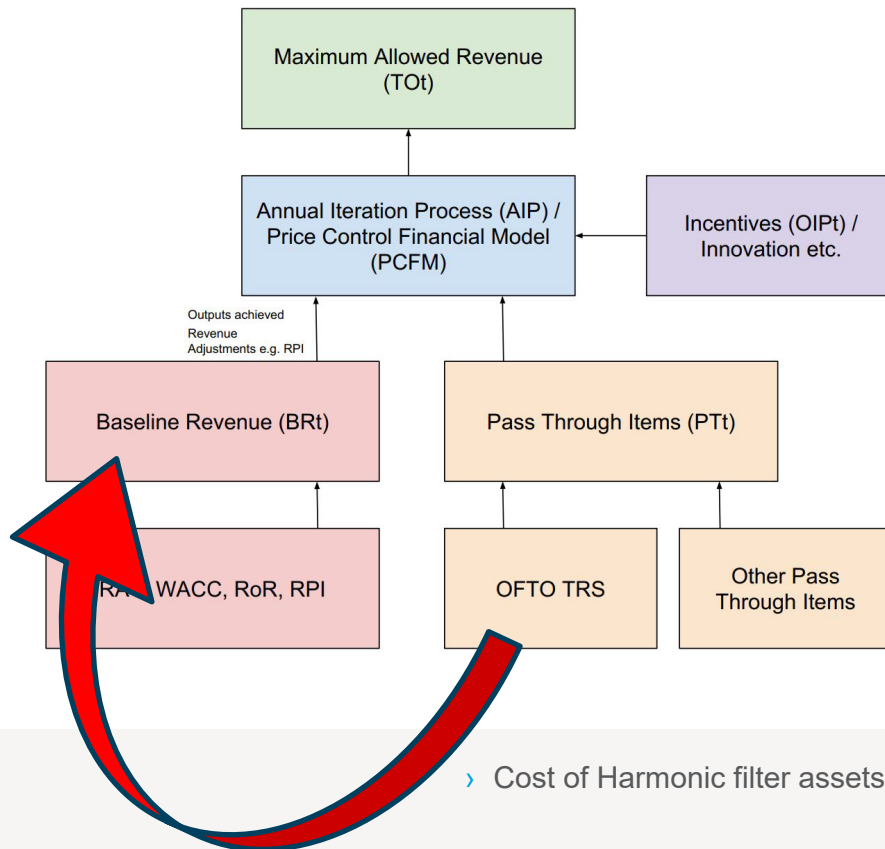
2/04/2019

Vandad Hamidi

Recap



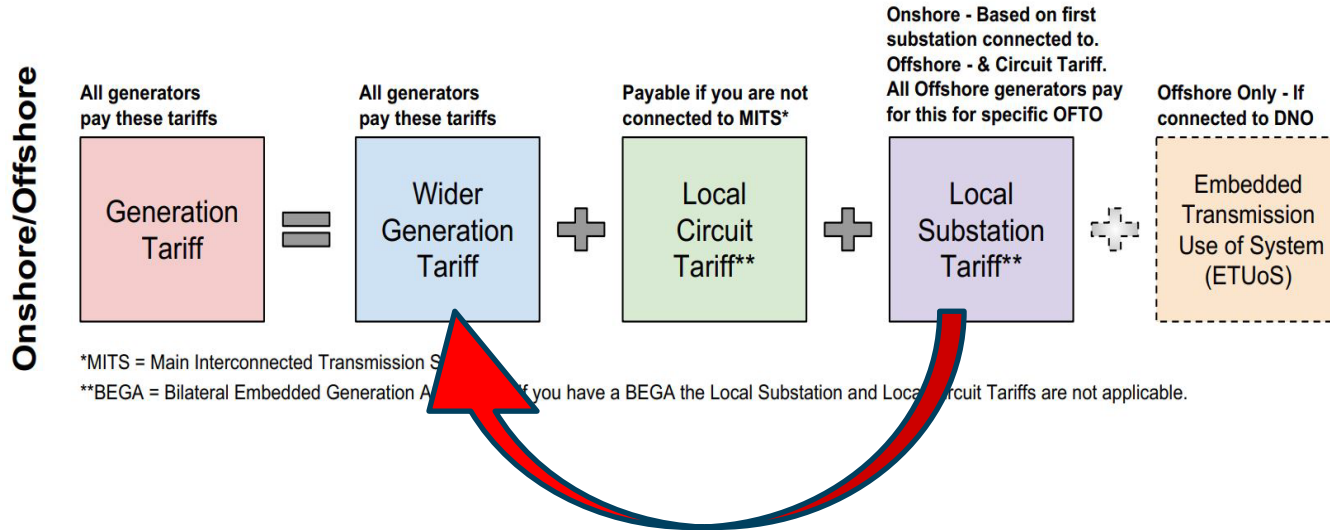
Impact of moving to TO investment



› Cost of Harmonic filter assets



Impact of moving to TO investment



Option 1: Cost recovery by changes to the base transmission revenue

Assume similar model to RIIO-T1

- › **Option 1: Cost recovery by changes to the base transmission revenue**
 - › Pre-defined projects with specific milestones or,
 - › A pre-defined revenue driver, with output targets such as £/MVA, £/MVA_r, £/MW headroom of generation connection facilitated
 - › Recovered from the maximum allowed revenue, translates into a higher TNUoS – specifically the wider generation tariff



Option 2 – cost recovery based on connection charges

- › Variant 1:
 - › *Identified and installed assets as part of individual connections constructed by NGET*
 - › *Recovered through a new set of connection charges to the developer within BCA*
- › Variant 2: *A project developer following identification of the requirements as part of the CION process build the asset and hand over to the onshore TO instead of the OFTO. TO pays for these assets (similar to an FTV paid by the OFTO) and the costs being then recovered by the TO through annual connection charges*
- › The locational benefit of centralized ownership may be lost
- › Unclear how a parallel process of asset transfer for one part of the OFTO process will be implemented



Stakeholder impact

Stakeholder	TO	Offshore generator (assuming generator build option)	OFTO	Interconnector	Generators	Consumer
Option 1 impact	Higher maximum allowed revenue	Marginally lower cost of financing Reduced TNUoS	Marginally lower cost of financing Marginally lower O&M cost Marginally lower TRS but no requirement to acquire harmonic filter assets Lower risk with regards to availability incentive	Lower cost of financing Lower O&M cost	Increased TNUoS	Reduced contribution due to lower number of required harmonic filters (for OFTO associated harmonic filters) Potential slight increase in contribution if interconnector harmonic filters are picked up by the TO
Option 2 impact	Higher maximum allowed revenue	No change to cost of financing if asset is built by the developer and transferred to the TO Reduced cost of financing if asset is constructed by the TO No changes to TNUoS	Lower cost of financing Lower O&M cost Lower TRS but no requirement to acquire harmonic filter assets Lower risk with regards to availability incentive Lower decommissioning liability requirement	Lower cost of financing Lower O&M cost	No impact	Possible reduced contribution due to lower number of required harmonic filters (for OFTO associated harmonic filters) – requirement to identify the locational benefit of such a model Potential slight increase in contribution if interconnector harmonic filters are picked up by the TO

Next steps

- › Quantify the savings – possibly consider savings across the Scottish TOs and the distribution networks for adopting the same approach
- › Identify Codes and standard changes required – CUSC/Grid code/SQSS
- › Propose codes and standard modifications
- › These will need to be underpinned by CBA (maximum and minimum cases)
- › Quantify the impacts on the connected users and the overall savings to consumers within the CBA
- › In parallel discuss with Ofgem the potential for revenue driver model



Closing remark

Maxwell Mulimakwenda

nationalgrid

