Flexible Generation Group

Proposed change to Transmission Network Charges

April 2019

Project Overview

Proposed modifications

The Flexible Generation Group (FGG) has proposed a modification to the existing transmission charging methodology that it believes will result in tariffs that better reflect the costs incurred in running the transmission system:

Increase in expansion constant

- Modifying the derivation of the expansion constant and locational security factor used in the transport and tariff model to be fully cost reflective.

The FGG believes there are two key issues with the derivation of the locational tariffs that lead to it not being fully cost reflective:

1. **Locational security factor–** the security factor (currently set 1.8) does not account for all of the network capacity the transmission owner has to build.
2. **Exclusion of substation costs –** the expansion constant derivation explicitly excludes substation costs, which make up a significant proportion of network costs.

These issues are discussed in more detail in the rest of this report.

Project Overview

Summary of the findings of the analysis

The analysis in this study suggests that:

- If the full cost of substations was included in cost-reflective charges, the expansion constant would need to be significantly increased (even accounting for the substation costs already included in the local substations charge).
- The locational onshore security factor (LOSF) does not cover all of the costs associated with the current transmission network capacity. We identified two possible explanations for this:
  1. There is currently significant overcapacity on the network, due to legacy network capacity created by generator retirements and decreases in transmission network demand. (These costs are not reflective of the level of new investment we would expect looking forward, and should not be included in the LOSF)
  2. The transmission network is typically built to greater than 1.8x contingency, to accommodate the maximum capacity of all generators including low-load factor intermittent plant. (These additional costs should be reflected in the LOSF)
  - Our analysis showed that both explanations account for a significant proportion of the spare network capacity not covered by the LOSF. The second explanation suggests that the LOSF may need to be adjusted to account for the network being sized to accommodate the maximum capacity of all connected generators.
- In addition, our research shows that alternative estimates for the expansion constant – including a calculation based on recent levels of the TSO's load-related expenditure – are generally higher than the current expansion constant.

DCLF ICRP Transport model overview

Background

How does the DCLF ICRP transport model work

As noted in CUSC 14.14.6, the underlying rationale behind Transmission Network Use of System (TNUoS) charging is that efficient economic signals are provided to users when services are priced to reflect the incremental costs of supplying them. Therefore, charges should reflect the impact that users at different locations would have on the Transmission Owner's (TO) costs if they were to increase or decrease their use of the system.

These costs are primarily defined as:

- the investment costs in the transmission system;
- maintenance of the transmission system; and
- maintaining a system capable of providing a secure supply of electricity.

The TOs have an obligation to ensure the system conforms to a particular security standard and capital investment requirements are largely driven by this. It is this obligation, which provides the underlying rationale for the ICRP approach, i.e. for any changes in generation and demand on the system, the TO must ensure that they satisfy the requirements of the security standard.

Background

How does the DCLF ICRP transport model work

The Direct Current Load Flow Investment Cost Related Pricing (DCLF ICRP) Transport Model is used by National Grid to estimate the power flows on the transmission network, and determine the marginal nodal costs that are used to calculate the locational TNUoS tariffs.

In this model, the power network is represented as nodes and links:

- Each node has an associated demand and generation (under both peak and year round conditions).
- Each link connects two nodes and has an associated length (km) and an expansion factor that represents the cost of the link relative to a 400kV overhead line

Voltage (kV)	Link type	Expansion factor*
400	OHL	1.0
275	OHL	1.2
132	OHL	2.9
400	Cable	10.2
275	Cable	11.4
132	Cable	22.6

* **Note:** Values shown apply to NGET and SP. Slightly lower values used for 132kV SSE lines

Background

How does DCLF ICRP model work

The Transport Model calculates the marginal cost at each node. This represents the change in total network cost, in MW-km terms, of injecting an extra 1MW at the node, with an offsetting reduction at the reference node.

Tariff model

The nodes are aggregated into geographic zones (which have similar marginal costs), and the marginal cost of each zone is used to determine the locational tariff for each zone.

- *Locational tariff = marginal cost (MW-km per MW) * locational security factor * expansion constant (£/MW-km)*

Essentially we need to answer two key questions:

Marginal cost
What is the incremental cost (MW-km) throughout the system, that is caused by a 1MW injection at each node?

Expansion constant
What is the £ cost for each additional MW-km of maximum flow on the system?

Issue 1: Expansion constant derivation

Expansion constant

Expansion constant derivation

- The forward-looking expansion constant, expressed in £/MW-km p.a., represents the annuitized value of the transmission infrastructure capital investment required to transport 1 MW over 1 km.
- Its magnitude is derived from the projected cost of a 400kV overhead line, including an estimate of the cost of capital, to provide for future system expansion.
- It is used to convert marginal costs (in MW-km per MW) to a tariff (in £/MW) that acts as an investment signal.

2019/20 expansion constant:

£14.55/MW-km

Source of expansion cost data

- The transmission infrastructure capital costs used in the calculation of the expansion constant are provided via an externally audited process.
- They include information provided from all onshore Transmission Owners (TOs). They are based on historic costs and tender valuations adjusted so that the costs reflect current prices, making the tariffs as forward looking as possible.
- This cost data represents a best view; however it is considered as commercially sensitive and is therefore treated as confidential.

Expansion constant

Issue 1: Exclusion of substation costs

As noted in CUSC 14.14.5, the Expansion Constant *does not include substation costs in its derivation*."

The equipment in substations whose cost is not recovered includes:

- Switchgear
- Protection
- Transformers in transmission system between voltages (eg 400 / 275 kV)
- Quadrature boosters (to control flow on circuits)
- Shunt reactors (to manage flow and limit short circuit duty)
- Reactive compensation (to manage voltage on the network)

Expansion constant

How substation costs are recovered: Onshore local substation tariff

- Local substation tariffs reflect the cost of the first transmission substation that each transmission connected generator connects to.
- A generator’s charge is based on the voltage of the substation, whether there is a single or double (‘redundancy’) busbar, and the volume of generation TEC connected at that substation. Local onshore substation tariffs are set at the start of each TO financial regulatory period, and are increased by RPI each year.
- The 2019/20 tariffs are shown below

2019/20 Local Substation Tariffs (£/kW)				
Substation Rating	Connection Type	132kV	275kV	400kV
<1320 MW	No redundancy	0.197964	0.113248	0.081598
<1320 MW	Redundancy	0.436098	0.269817	0.196232
>=1320 MW	No redundancy	0	0.355083	0.256797
>=1320 MW	Redundancy	0	0.582955	0.425509

- These are projected to recover £19.4m in 2019/20, out of total network infrastructure allowed revenues of £2,837.4m (0.6%).

Expansion constant

How substation costs are recovered: Onshore local substation tariff

Local substation tariffs were introduced in 2009/10 as a result of ECM11. NGET argued that to truly reflect the infrastructure asset cost savings associated with local generator connections, it must include substation assets within the local charge.

However, the following remained in place :

1. The infrastructure substation costs associated with demand connections are included in the residual element of the overall demand TNUoS charge.
2. Wider system security infrastructure substation asset costs (e.g. protection equipment) are charged across all users through the residual element of the generator TNUoS charge, as these assets are deemed to benefit all users of the transmission system.

Neither of these appear to strictly cost reflective. Infrastructure substation costs fall into the same category as transmission lines that are not directly local to a generator – and as per the ICRP approach, the incremental cost on these could be considered.

In addition, the local substation tariffs mean that there is no direct reflection in an individual generator's TNUoS charges of the capital costs (or savings) associated with variations to connection designs.

https://www.ofgem.gov.uk/sites/default/files/docs/2008/10/oct24-gb-ecm11-impact-assessment_0.pdf

Locational Onshore Security Factor

Application in final tariffs

NGET is made up of:

346 substations (transmission network)

14,500km lines/cables (2019/20 Transport Model)

9.8m MW-km maximum flow (2019/20 Transport Model)

This means there are 42km of lines/cables (or 28m MW-km) per substation. Based on this we can convert substation costs to £/MW-km figures:

Substation Cost	Raw Cost	Capacity (MW)	Cost (£/MW)	Annuitized cost £/MW-km
IEA (2014) study US costs	\$10.7k - \$24k per MW		8.2k – 18.4k	13 – 29
Hinkley Point C	\$60m	3200	14.4k	23
Hornsea Project One – onshore substation only	£24m	1218	20.5k	32

Conclusion: This suggests that if the full cost of substations was included in cost-reflective charges, the expansion constant would need to be significantly increased (even accounting for the substation costs already included in the local substations charge).

Issue 2: Locational security factor derivation

Locational Onshore Security Factor

A theoretical network is used to calculate marginal costs

All costs (MW-km) in the Transport Model are calculated for a theoretical network, which is "optimally"-sized:

- The actual length of the links (in km) are included in the cost calculation.
- But the actual capacities (in MW) of the links are not considered in the cost calculation. Instead, costs are based on the flows (in MW) the model calculates.

There are good reasons for this:

- Network builds are very "lumpy". When calculating marginal costs, we do not want to model this lumpiness, as the tariffs should be stable and predictable.
  - Adding 1 MW of additional capacity at a node is unlikely to have any cost implications (as there will be enough spare capacity to accommodate it). But eventually a tipping point will be reached and the addition of an extra 1MW (e.g. the 50th MW) will trigger a significant new investment. Modelling this dynamic would not result in stable and predictable tariffs.
  - The approach used is more mathematically robust than trying to capture this lumpiness. It avoids the need to work out precisely where the tipping point occurs and who was responsible for this tipping point.
- As a result, a theoretical network, with just enough capacity to accommodate the required flows is used to calculate the marginal costs. The amount of spare capacity on the actual network is ignored.

Locational Onshore Security Factor

Why is the security factor needed?

As described, costs in the Transport Model are calculated for an theoretical, optimally-sized network with just enough capacity to accommodate the required flows. Two things worth noting here:

1. Flows are calculated for both peak and year round conditions
2. Flows are calculated for under "intact" conditions, i.e. with no outages on the links

The transmission system however is highly integrated to ensure that when a network fault occurs, demand is not interrupted. There is an additional cost to building this level of security. For example, large parts of the network are built with double circuits.

To represent this security, a Locational Onshore Security Factor (LOSF) is applied to the marginal costs.

The security factor is set through nodal comparison of two DC load flow scenarios in the Transport Model:

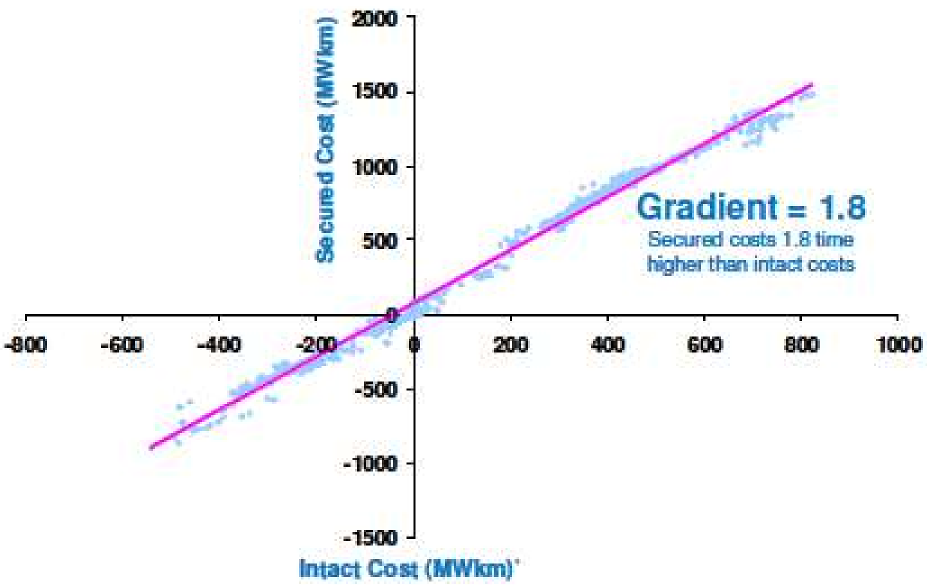
1. Intact run: an intact transmission system with no outages/faults
2. Secured run: a transmission system with a worst case "contingent event" for each transmission node e.g. a single / double circuit faults

Locational Onshore Security Factor

Derivation

The locational onshore security factor was derived by National Grid as 1.8, based on an average from a number of studies to account for future network developments. The security factor is reviewed for each price control period and fixed for the duration.

A sample output from National Grid's analysis in 2010/11 is shown below. This shows that marginal costs in the secured runs are around 1.8x higher than in the intact run (Least Squares Fit Method is used to calculated this value).



Locational Onshore Security Factor:

1.8

Locational Onshore Security Factor

Accounting for full size of network

In determining the tariffs, all the marginal costs (MW-km per km) in the Transport Model are scaled up by 1.8 (Locational Onshore Security Factor) to account for the additional costs of building a network with the required level of contingency.

Accounting for this larger network makes sense. However, it is important to establish whether this larger network corresponds with the level of investment that is seen in practice.

Our analysis:

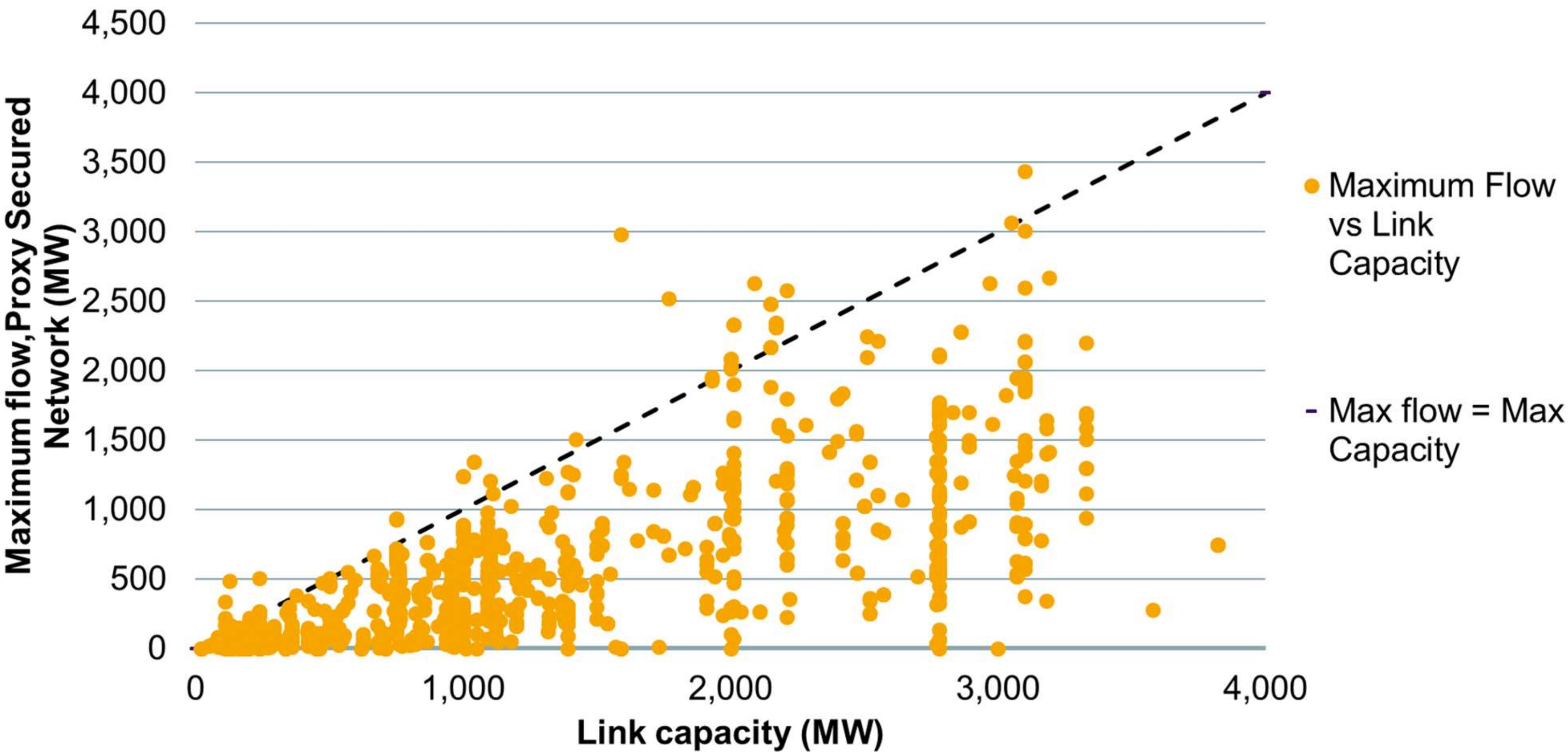
We have compared a proxy larger "secured" network with the actual network, using the 2019/20 Transport Model:

- Increased all flows by x1.8, as a proxy for the secured network
- This is in line with how the tariffs are calculated, i.e. all marginal costs are increased by a factor of 1.8

Locational Onshore Security Factor

Accounting for full size of network

Chart below shows the maximum flow (with 1.8x scaling factor applied) on each link in the 2019/20 Transport Model vs the Link's Capacity.



Virtually all links have flow below capacity. On average, flows are 43% of capacity.

Locational Onshore Security Factor

Accounting for full size of network

Using the link lengths and expansion factors, we can also calculate the costs associated with these two sets of flows. This gives a similar overall result:

Cost of Maximum Flow (MW-km)	Cost of Flows at Link Capacity (MW-km)	Proportion
23.4m	56.6m	41%

This suggests that almost 60% of the costs associated with transmission lines are not covered by the locational onshore security factor, and hence not funded by the locational tariffs.

Two possible explanations:

1. There is currently significant overcapacity on the network, and this is not reflective of the level of new investment would expect looking forward.
2. The transmission network is typically built to greater than 1.8x contingency, and the locational onshore security factor is too low.

Locational Onshore Security Factor

Accounting for full size of network

1. There is overcapacity which is not reflective of the level of investment looking forward.
   - This could be due to legacy network infrastructure that was built to accommodate generation units (such as coal and oil) that have now closed, or levels of demand that have now reduced
   - (Note: Low average load factors of older plant do not matter for peak security analysis)

   Test 1: Repeat analysis with retired plant added back into network and higher peak demand.

2. Overcapacity, as network is typically built to greater than 1.8x contingency.
   - One potential reason for this is low load factor intermittent generation. The network is built to accommodate higher maximum flows from these plant than are modelled in the peak or year-round Transport Model.

   Test 2: Repeat analysis using max contracted TEC for all plant’s injections.

Locational Onshore Security Factor

Test 1: Retired plant restored and peak demand increased

We have run the 2019/20 Transport Model :

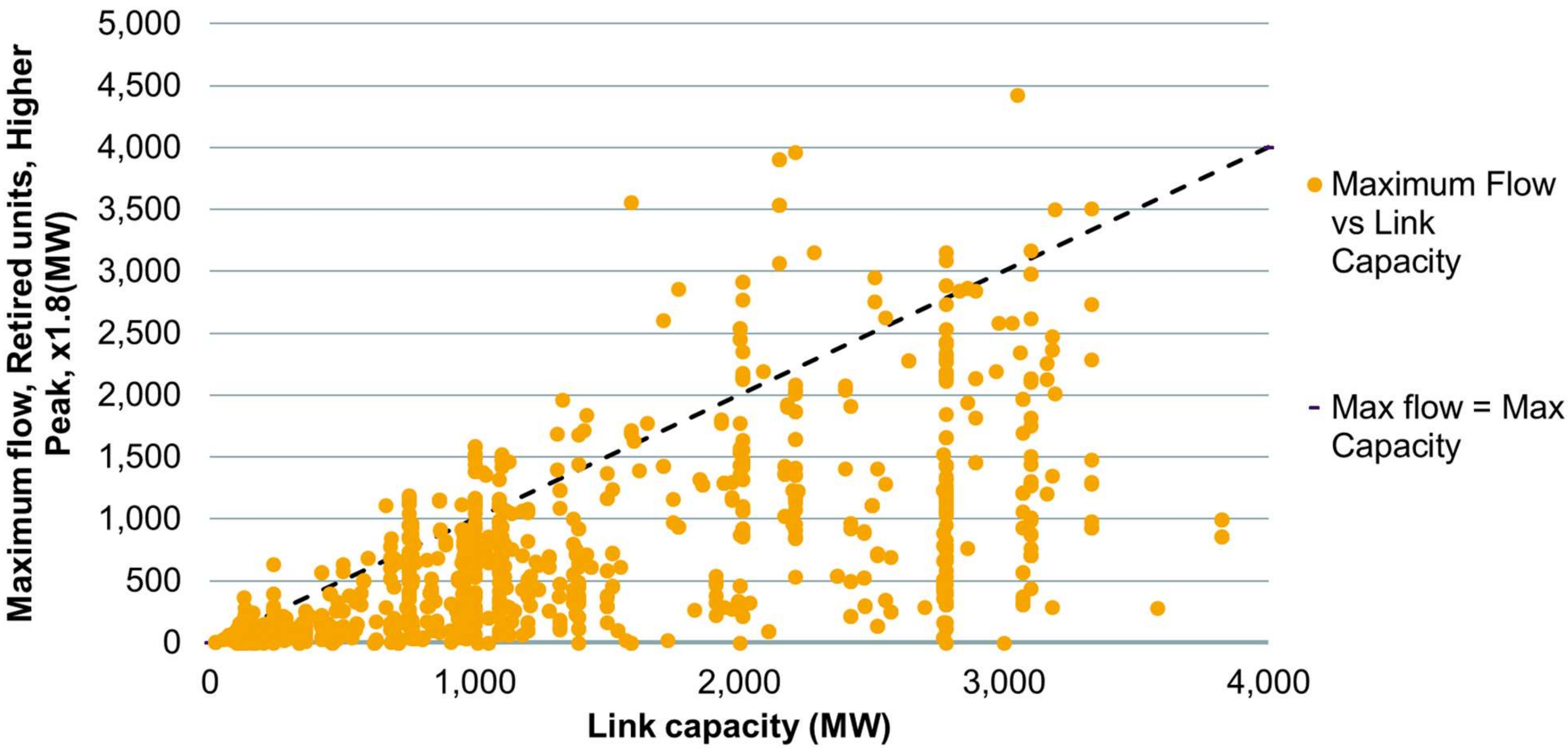
- 21GW of retired units added back onto network.
  - This represents all the major retirements over the 2005-2019 period. Predominantly coal, oil and nuclear plant.
  - Total flows are scaled up to account for this additional capacity, so that both the existing units and retired units are generating at same level that existing units generated in baseline model.
- In addition, peak demand is scaled to account for the drop from 60GW in 2005 to 49.5GW in 2019/20. It is assumed the current network was built to accommodate this higher level of demand. Demand is scaled up evenly across the system (no change in geographic distribution assumed).
- Locational security factor of 1.8 is still applied

These changes means a significantly larger network (in terms of maximum flows) is modelled.

Locational Onshore Security Factor

Test 1: Retired plant restored and peak demand increased

Results from this test are shown below.

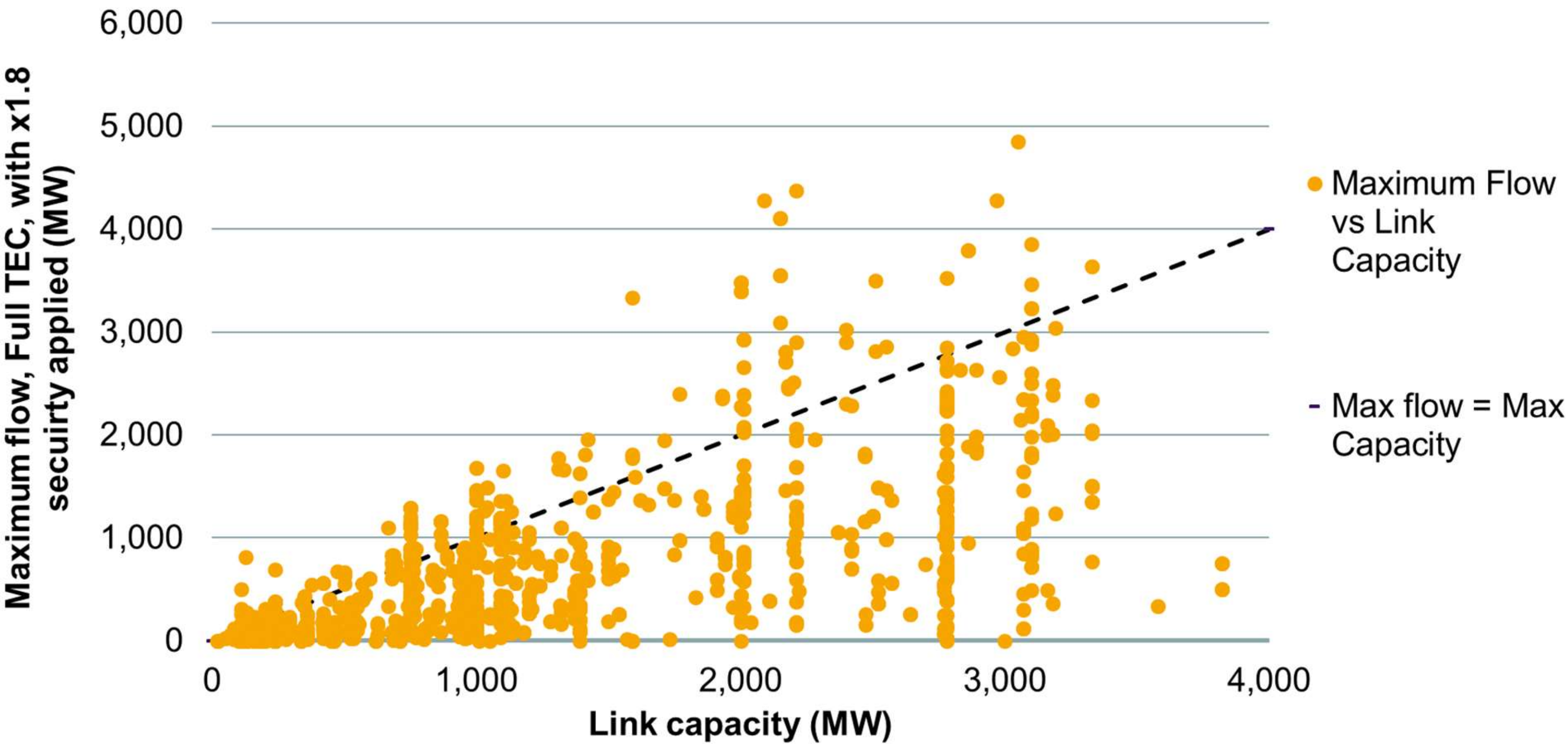


Maximum flows on the lines increase significantly, but are still, on average, below capacity. Flows represent 52% of network capacity, and MW-km costs are 51% of the full capacity cost.

Locational Onshore Security Factor

Test 2: Maximum contracted TEC used in secure Transport Model

Repeating the analysis, with injections based on the maximum contracted TEC of all generators (including wind) and the x1.8 security factor still applied:

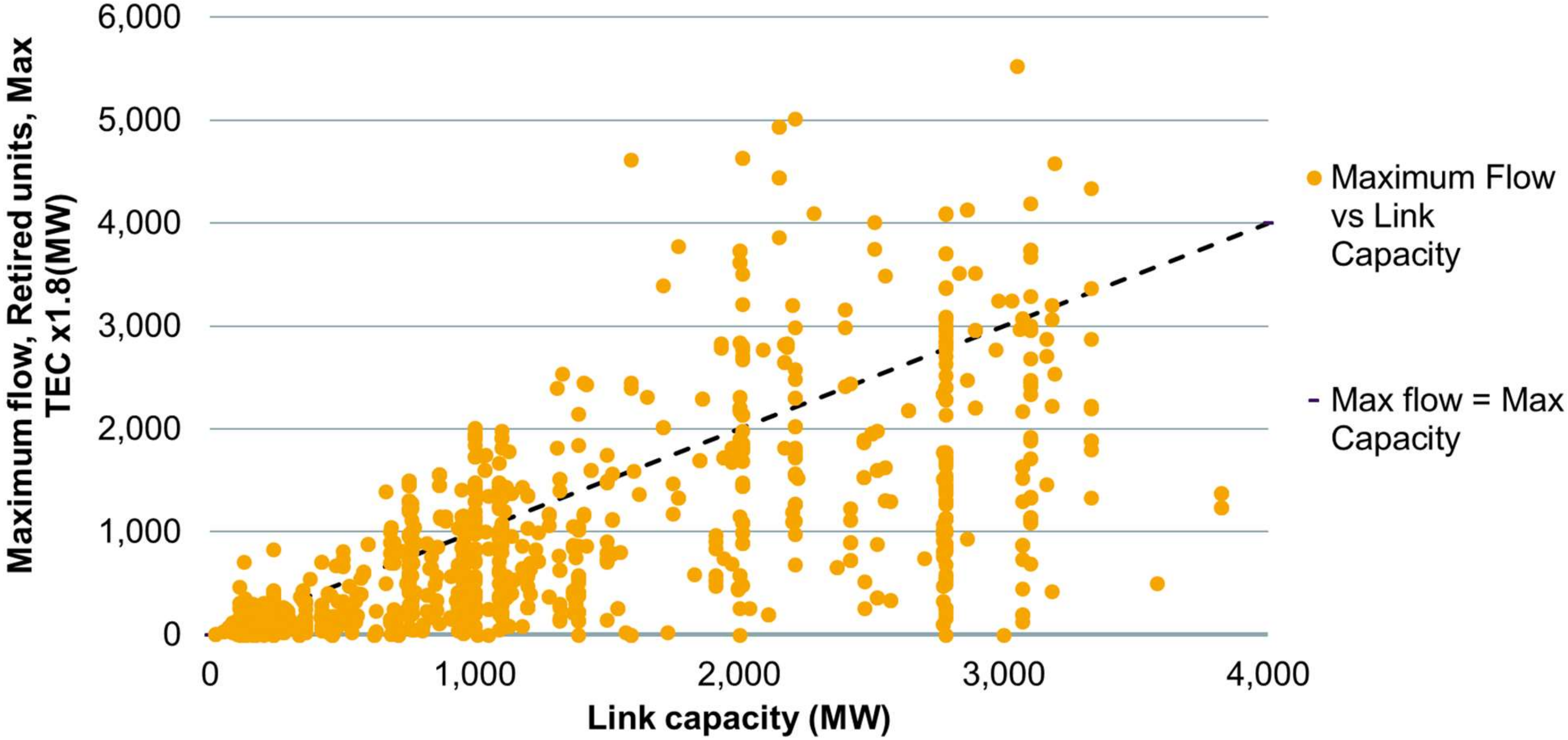


As in Test 1 flows increase but are still below capacity on average. Flows are 57% of network capacity, and MW-km costs are 61% of the full capacity cost.

Locational Onshore Security Factor

Test 1 and 2 combined

We also combined Test 1 & 2 to explore whether using maximum contracted TEC for all existing and retired units (to 2005), and the 1.8 security factor, explained the discrepancy:



Flows are 72% of capacity on average, and MW-km costs are 79% of the full capacity cost. These two factors could account for the majority of the extra capacity on the network.

* Peak demand is not scaled in this run to avoid double counting

Locational Onshore Security Factor

Application in final tariffs

Results for the baseline and 3 tests are summarised below

Run description (all runs based on 2019/20 Transport Model)	Total generator injections (GW)	Flows as % of line capacity	Costs as a % of cost of line capacity	Notes
Baseline, with 1.8 security factor	89	43%	41%	
Test 1: Retired units restored, Peak demand scaled to historic levels, 1.8 security factor	147	52%	51%	Relatively low increase in flows/costs due to proximity of retired units to demand
Test 2: Max contracted TEC used for all generation injections, 1.8 security factor	145	57%	61%	Flows/costs higher than Test 1 despite lower injections, due to remoteness of low load factor wind units
Test 1 and Test 2 combined*	183	72%	79%	2/3 of cost discrepancy removed.

Conclusion: Both tests account for a proportion of the spare capacity in the Transport Model.

Test 2 suggests that the locational security factor (or some other part of the tariff calculation) may need to be adjusted to account for the network being sized to accommodate the maximum capacity of all connected generators.

* Peak demand is not scaled in this run to avoid double counting

Alternative benchmarks for the expansion constant

Locational Onshore Security Factor

Application in final tariffs

Though the 2019/20 expansion constant in the Transport and Tariff Model is £14.55/MW-km. The locational tariffs also include adjustments for:

a) the locational security factor (1.8)

b) the expansion factors (MW-km marginal costs increased based on different voltages and types of link)

Source	Annual £/MW-km	Notes
Expansion Constant	14.55	Cost per MW-km of 400kV OHL
Expansion Constant * Avg. Expansion Factor	21	Weighted average cost per MW-km, taking into account the different transmission link types on the system (voltages, cable vs OHL)
Expansion Constant * Security Factor	26	Allowing for 1.8x contingency
EC * EF * SF	38	Cost per MW-km, allowing for contingency and different transmission link types

When benchmarking against other studies / data sources, it is important to note the above differences and compare on a consistent basis.

Locational Onshore Security Factor

Application in final tariffs

Alternative estimates for GB expansion constant:

Source	Annual £/MW-km	
NGET (2011) "ideal pricing" idealised reinforcements	58	
NGET (2011) average pricing from TO revenues (NGET, SPT, SHETL)	41, 58, 32	
NGET (2011) Actual pricing, from specific projects (2009 ENSG Report)	100 – 240	
NERA-Imperial (2014/16) –based on ENSG process	60	
NERA-Imperial (2016) – LRMC estimate	180	Modelled
IET/PB (2012) (excluding substations) Lifetime cost: £580-750/MVA-km	38 - 50	Based on 400kV OHLs, but approx. half of costs due to power/energy losses
IEA (2014) for WECC $746-$3318/MW-km (before annuitisation, includes 25% contingency), Substation costs: $10,700-$24,000/MW	38 – 169 Substation costs: 13 – 29	Based on data for WECC (Western US). Substation MW per km based on GB estimates. Annuitisation based on NG assumptions.
NERA (2004) – based on £9.51/MW-km	6.47	Uses NG's £9.51/MW-km expansion constant, then downrates for 1993-2005 data that network was upgraded rather than expanded

Values are generally higher than the current GB expansion constant (£14.55/MW-km). Results are not all directly comparable to this figure due to different basis and components assumed.

Locational Onshore Security Factor

Application in final tariffs

An alternative approach to a “bottom up” derivation of the expansion constant (based on cost on individual assets), is a “top down” approach.

As NERA/Imperial (2016) argue: *“the current TNUoS charging methodology recovers only a very small proportion of total MAR through the locational element of the charge … this calls into question the efficacy of the locational elements of the charge in signalling the impact that network users have on transmission costs.”*

The top down approach we have employed assesses the proportion of the TO’s spending (or “MAR”, maximum allowed revenue) that represents the costs associated with users increasing or decreasing their use of the system.

Locational Onshore Security Factor

Application in final tariffs

The TO's spend is divided into four categories:

1. **Load-related expenditure (LRE):** investment on the network to accommodate changes in the level or pattern of electricity generation and demand.
2. **Non-Load related expenditure (NLRE):** mainly capital investment on replacement and prevention maintenance (refurbishment) to keep assets in good condition, but also other capital expenditure directly related to maintaining a reliable network, such as investments to improve flood defences.
3. **Non-operational capital expenditure (Non-op capex):** expenditure on equipment not directly related to transmission operations, for example, IT capital expenditure.
4. **Controllable operational expenditure (Opex):** this is day-to-day spending on activities required to maintain and operate the transmission networks.

At a minimum, we would expect that LRE would include relevant costs. In fact, all categories with the exception of non-op capex are likely to contain some relevant expenditure.

Locational Onshore Security Factor

Application in final tariffs

Based on RIIO-ET1 2018-19 annual report (combination of actual and forecast values for 8 year RIIO period 2013/14 to 2020/21)

TSO	MW-km (Transport model)	Total Expenditure (totex) £m ex. non-op capex (8 years)	Load Related Expenditure (LRE) £m (8 years)	Totex cost £/MW-km p.a. excl. non-op capex	LRE Cost, £/MW-km p.a.
NGET	9.76m	10,048	3,330	128	42
SPT	2.45m	2,174	1,159	171	59
SHET	0.88m	3,367	2,696	308	382
Total	**13.09m**	**15,589**	**7,185**	**149**	**69**

With just LRE included, costs over the 8 year RIIO period average about £69/MW-km p.a. This is consistent with the expansion constant x security factor (£26/MW-km) as it uses a MW-km figure that factors in expansion factors and includes all LRE costs (including investment in redundancy to secure the network).

This approach suggests the expansion constant does not represent the full cost associated with network capital investment.

Source: https://www.ofgem.gov.uk/system/files/docs/2019/03/riio_et_2018_19_annualreport_final_version_published.pdf

Locational Onshore Security Factor

Application in final tariffs

Limitations and approximations of this approach.

- Will not be stable, predictable if employed year-year due to fluctuations in spend, particularly due to the lumpiness of capital investments.
- Not truly forward looking, as assesses spend on existing assets on the system.
- Some Non-Load Related expenditure – e.g. maintenance of new assets – is likely to be affected by incremental changes (in medium-long term), so could be included.
- 2019/20 transport model was used to determine MW-km, but period covers all years from 2013/14 to 2020/21.

Use of our work

Interpretation and Limitations

The results presented in this workbook are dependent on the assumptions used and the modelling methodology applied. In particular, forecasts are subject to significant uncertainty and actual outcomes may differ materially from the forecasts presented. LCP can therefore accept no liability for losses suffered, direct or consequential, arising out of any reliance on the results presented.

The results should be interpreted in the context of the approach taken and the limitations associated with this approach.

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