Impact of C_2C Operation on DG Capacity in HV Networks

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Abbreviations

C_2C	Capacity to Customers
CHP	Combined Heat and Power
DG	Distributed Generation
DINIS	Distribution Network Information System
DSR	Demand-Side Response
ENWL	Electricity North West Limited
HV	High Voltage (6.6 kV or 11 kV)
IPSA	Interactive Power System Analysis
LV	Low Voltage (typically 400 V)
Ofgem	Office of Gas and Electricity Markets
OHL	Overhead Line
NOP	Normally Open Point
pu	Per Unit
PV	Photovoltaic

Contents

1 Introduction

Distribution networks must be equipped for a significant increase in future electrical demand, due to the continuing electrification of transport and heating to meet the UK's ambitious CO_2 emission targets [1]. Furthermore, the proliferation of distributed generation (DG) can sometimes be inhibited by lack of available network capacity. The challenges associated with these developments must be met in a cost-effective manner and without undue environmental impact. It is also important that future capacity can be delivered without compromising network protection or the security of supply.

The objective of the Capacity to Customers (C_2C) project, an Ofgem Low Carbon Network Fund project led by Electricity North West Limited (ENWL) in conjunction with several industrial and academic partners, is to test a combination of new automation technology, non-conventional network operational practices (i.e., increased network interconnection), and commercial demand-side response (DSR) contracts. These changes will allow ENWL to increase demand and generation connections on a selection of trial circuits – representing approximately 10% of its high voltage (HV) system – without resorting to conventional reinforcement measures. The project will thereby "release" inherent spare capacity in the HV system in order to accommodate the future forecast increases in demand and DG, whilst avoiding (or deferring) the cost and environmental impacts that are associated with traditional network reinforcement.

This paper documents work undertaken by the University of Strathclyde to quantify the ability of C_2C network operation to accommodate additional DG capacity. This has been achieved using simulation models based upon actual system data from a representative proportion of the C_2C trial circuits.

A DG "base case" is established which defines the maximum DG which can be connected to circuits without C_2C operation, i.e., when there is a requirement for DG to remain connected during N-1 conditions. Therefore, the additional DG which can be connected for C_2C operation – where DG may be disconnected during N-1 conditions – can be quantified.

The DG capacity improvement for each circuit, relative to the DG base case, has been determined for both "Radial C_2C" operation and for "Interconnected C_2C" operation, i.e., the effects of operating the network with a closed ring have been evaluated. Two complementary approaches for determining the range of DG capacity which is released by C_2C operation have been used for each circuit: distributed, uniform DG growth at existing network locations, and localised, non-uniform "point" DG connected at specific circuit locations. This process is summarised in Figure 1.

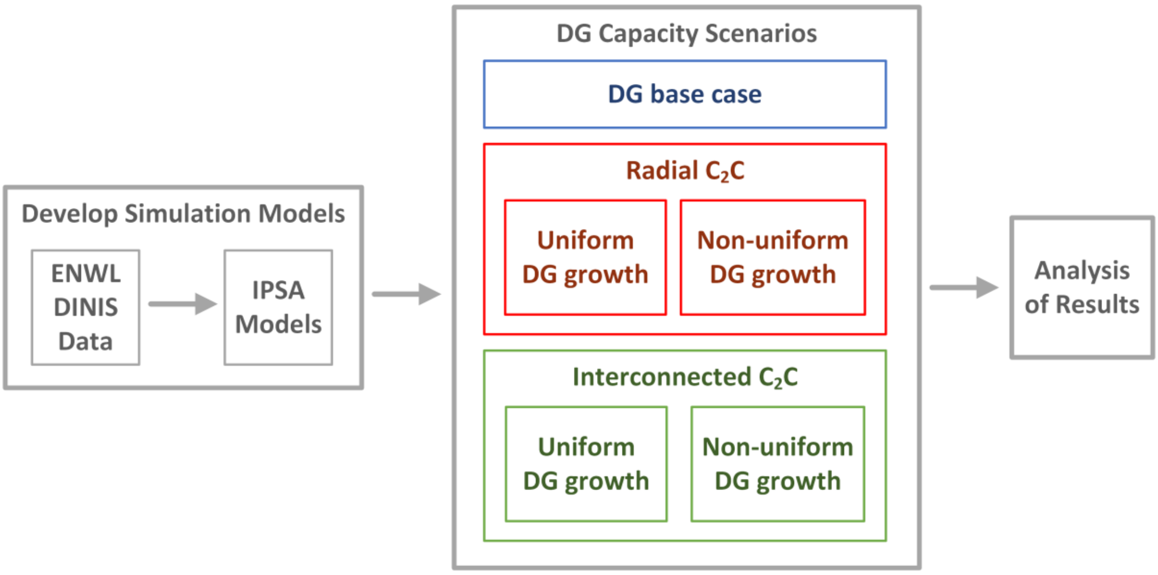

Figure 1: Overview of DG capacity analysis process

Section 2 describes the processes for determining the network DG capacity limits for various circuit configurations. Section 3 provides a simplified overview of the effects of C_2C on HV network DG capacity using hypothetical, but illustrative, simulated scenarios. The full results for a selection of actual HV circuits are presented in Section 4, and conclusions are drawn on these results in Section 5.

2 Methodology for establishing DG base case and C_2C capacities

2.1 Overview of methodology

Two complementary approaches have been used to quantify the potential increase in DG capacity released by C_2C operation:

1. Uniform growth in DG at all existing secondary substations. This approach is representative of distributed domestic photovoltaic (PV) connections.
2. Non-uniform growth, with DG at just one specific secondary substation on each feeder. This approach is representative of large new DG connections such as wind farms, combined heat and power (CHP), or biomass.

The DG base case, which is used as a reference for quantifying the increase in DG capacity released by C_2C operation, is described in Section 2.2. Sections 2.3 and 2.4 describe the methodologies for evaluating uniform and non-uniform DG growth respectively.

2.2 DG base case and assumptions

It is assumed that conventional network operation requires DG to remain connected during N-1 conditions. The N-1 circuit configurations used to determine the DG base case are illustrated in Figure 2. The initial connected DG capacity at each secondary substation is proportional to the initial connected demand (which is based on transformer ratings or maximum demand indicators), i.e., it is assumed that DG penetration is proportional to maximum demand levels. For example, it is assumed that domestic PV would generally be connected in proportion with existing domestic demand. DG is modelled to export constant power at unity power factor (see Appendix A for a discussion of the effects of other power factors). The DG connected at all secondary substations is increased until a thermal or voltage constraint occurs on the HV network. The particular N-1 configuration (from the two possible options) from Figure 2 which supports the lower total generation export is selected as the DG base case.

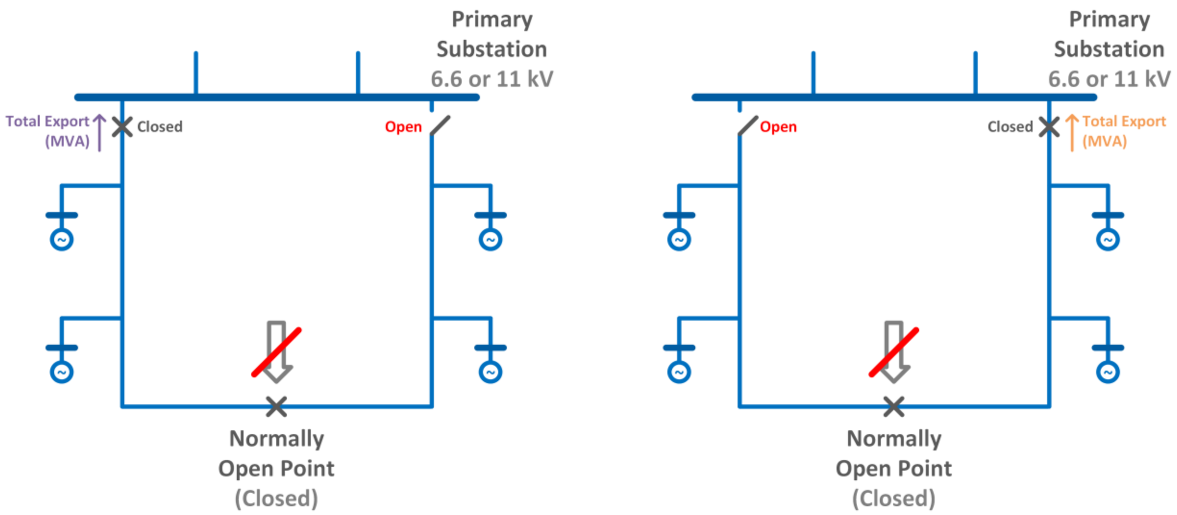

Figure 2: N-1 configurations for determining the DG base case

No demand is modelled for simulations involving the DG capacity. A maximum HV voltage limit of 1.012 pu is assumed based upon the present ENWL HV planning methodology for assessing DG connections[1].

2.3 C_2C operation for uniform DG growth

All connected DG capacity, as established for the DG base case, is uniformly scaled up (using the same multiplicative factor at every DG location) until a thermal or voltage constraint is encountered anywhere in the modelled HV network. This is performed for Radial C_2C operation (Figure 3) and Interconnected C_2C operation (Figure 4) to establish their respective released DG capacities. For Radial C_2C operation, the released DG capacity could be limited by a constraint on either of the two feeders because this represents the level of DG growth where the first reinforcement investment would be required.

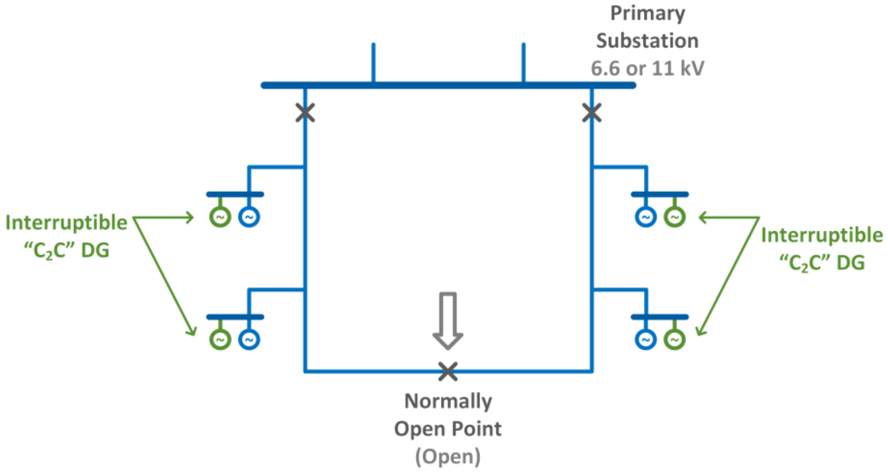

Figure 3: Representative DG locations for uniform DG growth of a system operating with Radial C_2C configuration

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[1] This is based on the LV voltage statutory upper limit of 230 V +10% in the UK, and an assumed distribution transformer ratio of 11000:250 (for 11 kV systems) [3]. Therefore, a 1.2% (0.012 pu) increase in HV voltage above nominal results in the maximum allowable LV voltage of 253 V.

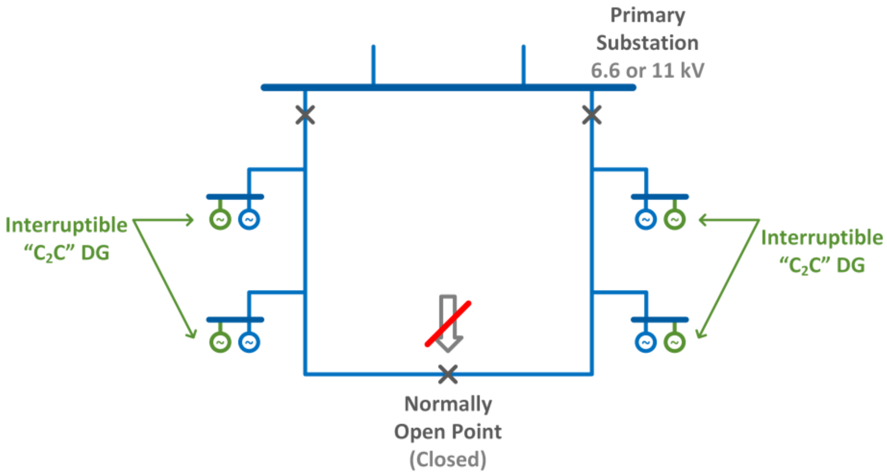

Figure 4: Representative DG locations for uniform DG growth of a system operating with Interconnected C_2C configuration

2.4 C_2C operation for non-uniform DG growth

Figure 5 illustrates representative locations for specific (or "point") DG connections. Two representative locations have been selected: the secondary substation at the NOP, and the secondary substation at the furthest extremity from the primary (e.g., at the end of the longest spur). Locations near the primary are not included in the evaluation of DG capacity, because DG connections near the primary are likely to show very high levels of released DG capacity due to the relatively small impedance between the point of connection and the primary substation and the associated small voltage rise.

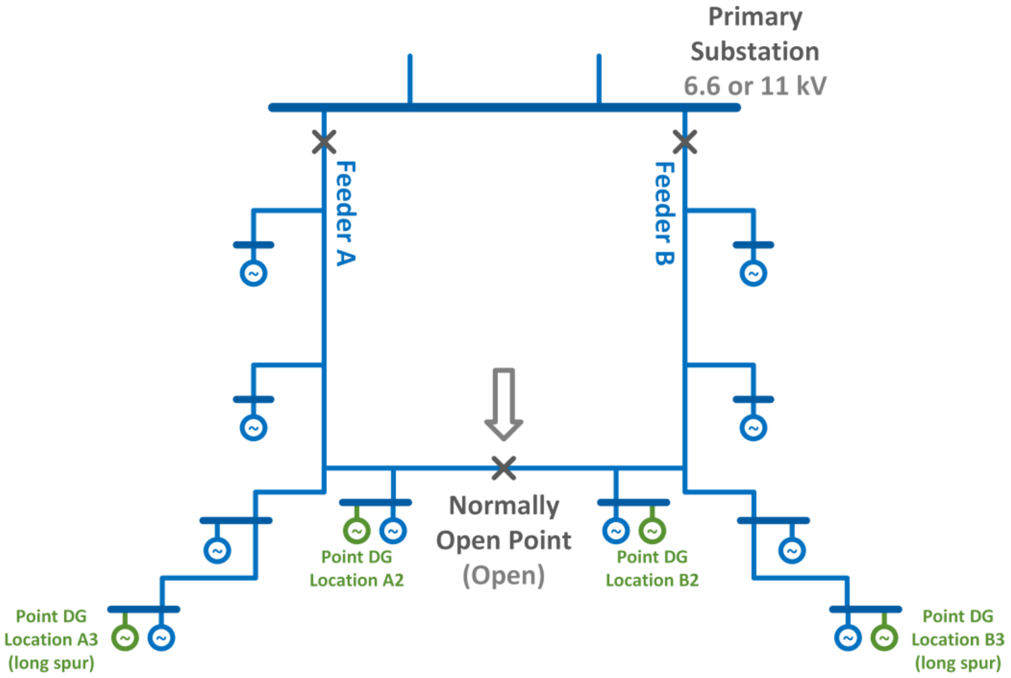

Figure 5: Representative point DG locations (shown for Radial C_2C)

Each “pair” of DG connections (A2 and B2, or A3 and B3 as shown in Figure 5) is tested together. This is because Radial C_2C operation requires a connection on each radial feeder to appropriately test the DG capacity which is released by the open ring circuit network; consequently, the same DG paired locations are tested for Interconnected C_2C operation.

Point DG connections are made in addition to the DG connected for the DG base case. The capacity of each pair of DG connections is increased by the same factor until a thermal or voltage constraint occurs anywhere on the two feeders.

3 Theoretical analysis of DG capacity

This section provides a simplified overview of the effects of C_2C operation on HV network DG capacity using hypothetical, but illustrative, simulated scenarios. The differences and subtleties between Radial C_2C and Interconnected C_2C operation, in terms of DG capacity released, are highlighted.

3.1 Simplified HV network and assumptions

Figure 6 illustrates a simplified, but representative, HV network with the following properties:

- A simplified 11 kV network comprised of two feeders, with two secondary substations per feeder.
- A thermal rating of 5 MVA has been used for all branches.
- The maximum voltage permitted at any point in the HV network is 1.012 pu.
- Initially, a 500 kVA generator, with unity power factor, is connected at each secondary substation. This represents an arbitrary, nominal level of connected generation.
- Initially, all branches have the following positive sequence impedances: R = 0.1 pu, X = 0.1 pu (on a 100 MVA base). The branch associated with the NOP (if connected) has the same impedance as all other branches.
- No load is connected.

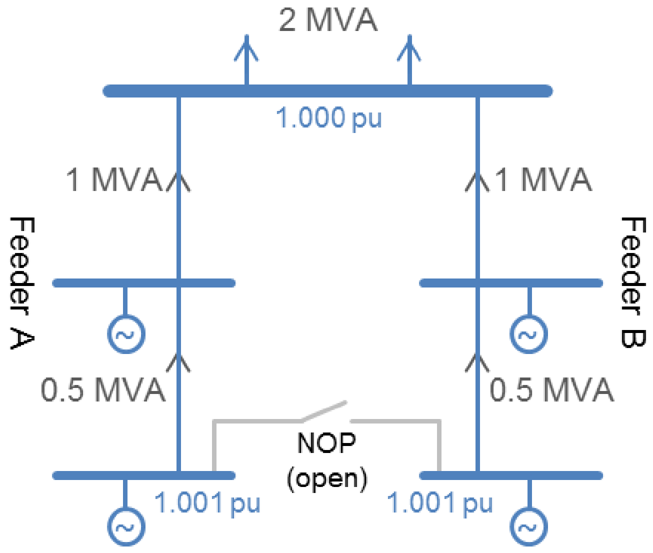

Figure 6: Simplified HV network

For simplicity, the examples given in this section do not include the effects of different branch thermal ratings, which is relevant in actual HV networks. The relevant branch power flows and bus voltages are indicated on Figure 6 and throughout this section.

Three scenarios are considered with reference to the simplified HV network, as illustrated in Figure 7:

1. Symmetric feeder impedances and symmetric DG: both feeders are identical, i.e., have the same branch impedances and connected DG.
2. Asymmetric feeder impedances and symmetric DG: the impedances of the branches of feeder A are increased to: R = 0.5 pu, X = 0.5 pu; this emulates an increase in feeder length. The connected DG is identical. The NOP branch is shown as being longer in Figure 7, but it is not modelled as being longer.
3. Symmetric feeder impedances and asymmetric DG: the capacity of each of the generators connected to feeder A is doubled to 1 MVA. All branch lengths (i.e., impedances) are equal.

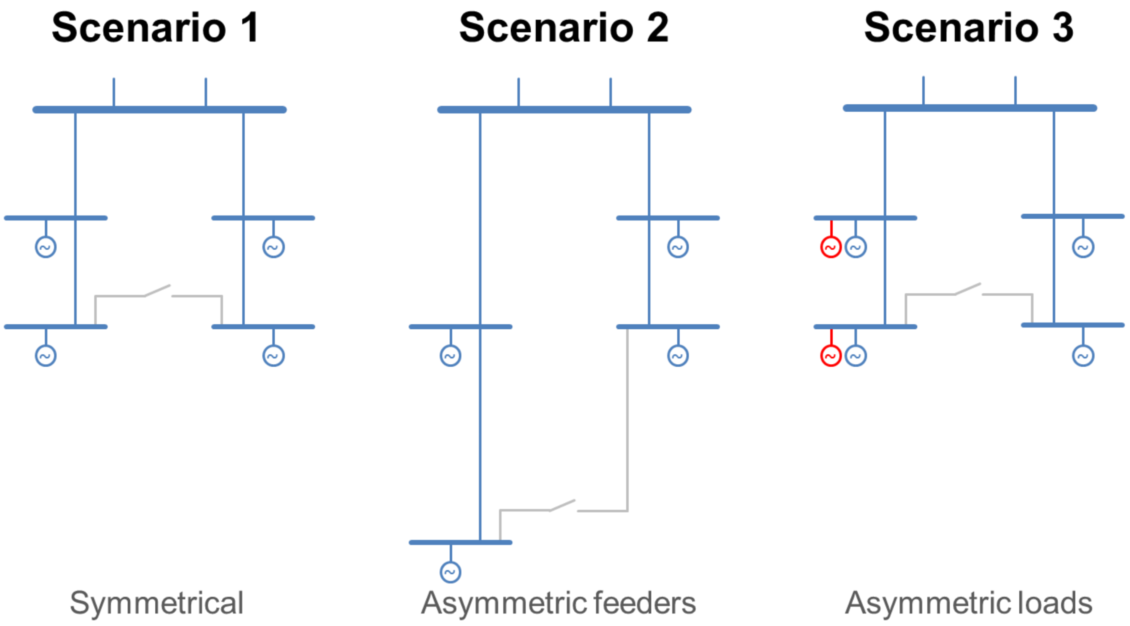

Figure 7: Scenario circuit configurations

3.2 Comparison of radial and interconnected operation under different scenarios

This section illustrates the effect of moving from radial to interconnected operation only, and describes the resulting effect on network power flows and bus voltages. The circuits are not at maximum loading, i.e., C_2C operation has not been applied to the circuit.

3.2.1 Scenario 1 – Symmetric feeder impedances and symmetric DG

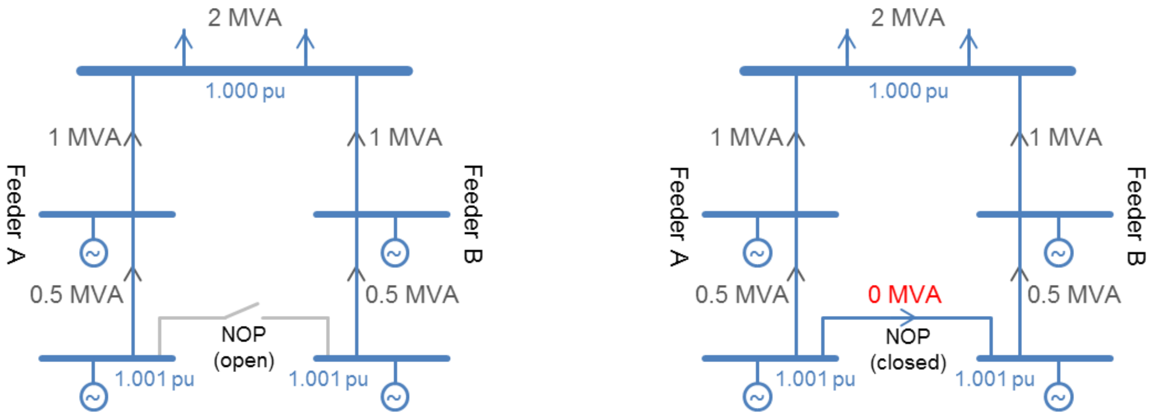

Figure 8: Scenario 1 – radial (left) and interconnected (right)

Due to symmetrical impedances and connected DG, closing the NOP has no effect; there is no power flow through the branch associated with the NOP, as shown in Figure 8.

3.2.2 Scenario 2 – Asymmetric feeder impedances and symmetric DG

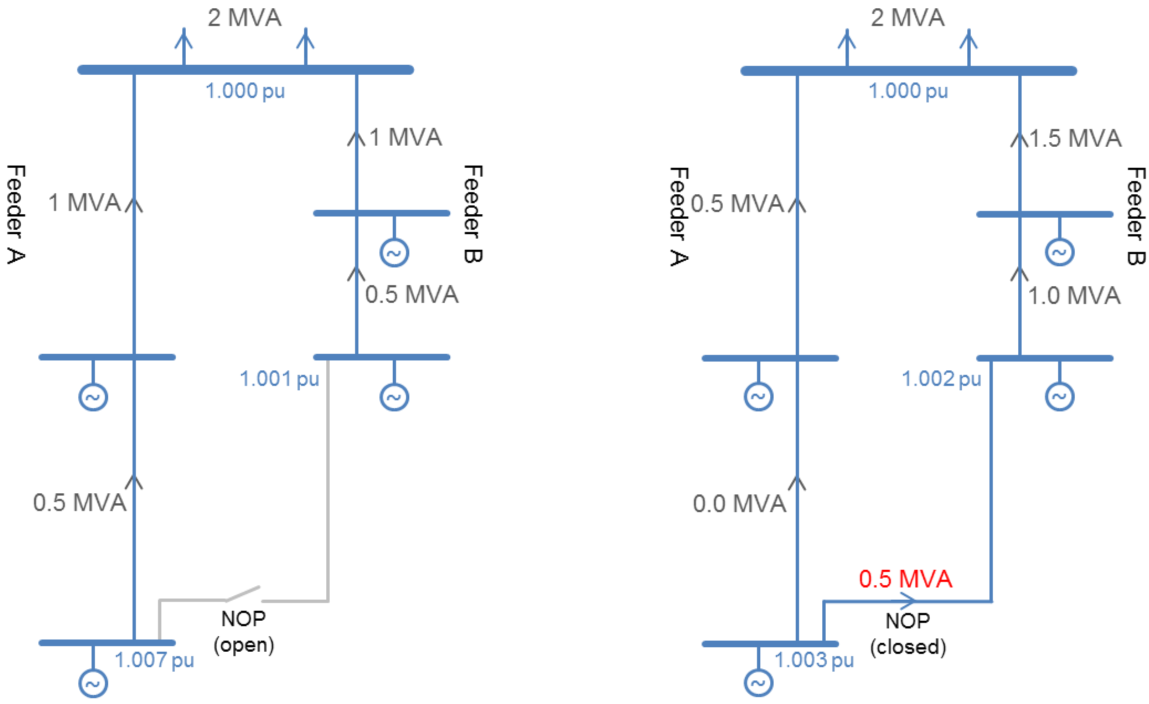

Figure 9: Scenario 2 – radial (left) and interconnected (right)

For radial operation, the maximum voltage on feeder A is higher than scenario 1 due to the increased impedance: an increase from 1.001 pu to 1.007 pu at the extremity of the feeder. The voltage increases from the primary substation along the feeders due to the fact that power is being transferred from DG connected throughout the network to the primary substation (no load is connected).

For interconnected operation, a proportion of power generated on feeder A is supplied to feeder B (the electrically shorter feeder) via the NOP. Consequently, the power flows in feeder A are reduced compared to radial operation. The worst case secondary substation voltage is improved compared to radial operation, from 1.007 pu to 1.003 pu.

3.2.3 Scenario 3 – Symmetric feeder impedances and asymmetric DG

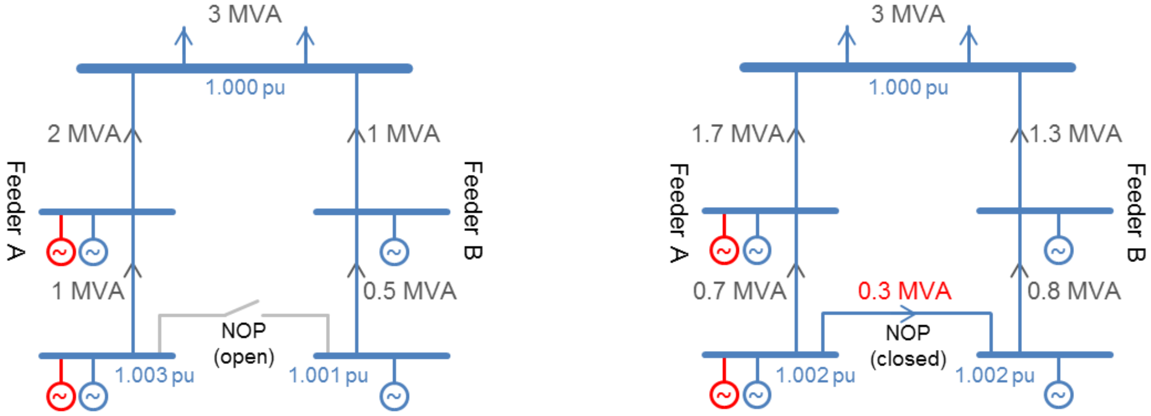

Figure 10: Scenario 3 – radial (left) and interconnected (right)

In this case, closing the NOP allows feeder B, which had less connected DG prior to interconnection, to export a proportion of the power generated on feeder A via the NOP.

3.3 Maximum capacity released under different scenarios for C_2C operation

This section assesses the maximum capacity released for each scenario, for both Radial C_2C and Interconnected C_2C configurations. All generators are scaled up in a uniform fashion until a thermal or voltage constraint occurs, as described in Section 2. In the following system diagrams, a red box around a branch’s power flow label or around a busbar voltage label illustrates the presence of a thermal or voltage constraint, respectively.

3.3.1 Scenario 1 – Symmetric feeder impedances and symmetric DG

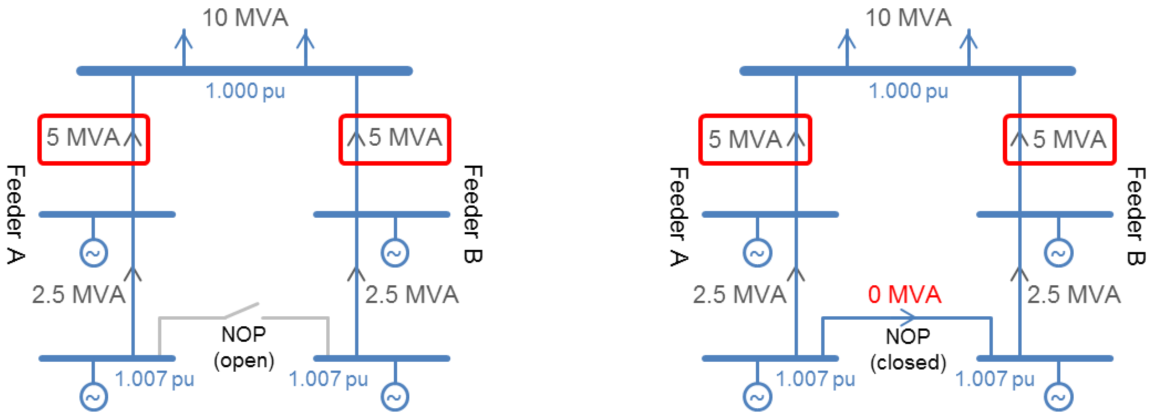

Figure 11: Scenario 1 – Radial C_2C (left) and Interconnected C_2C (right)

Figure 10 shows the maximum DG capacities for Radial C_2C and Interconnected C_2C for the case that feeder impedances and the connected DG are symmetrical.

Closing the NOP has no effect on the maximum DG capacity of the ring circuit, which is 10 MVA in both Radial C_2C and Interconnected C_2C configurations, with the feeder section between the primary and the first secondary substation being thermally constrained in both cases.

3.3.2 Scenario 2 – Asymmetric feeder impedances and symmetric DG

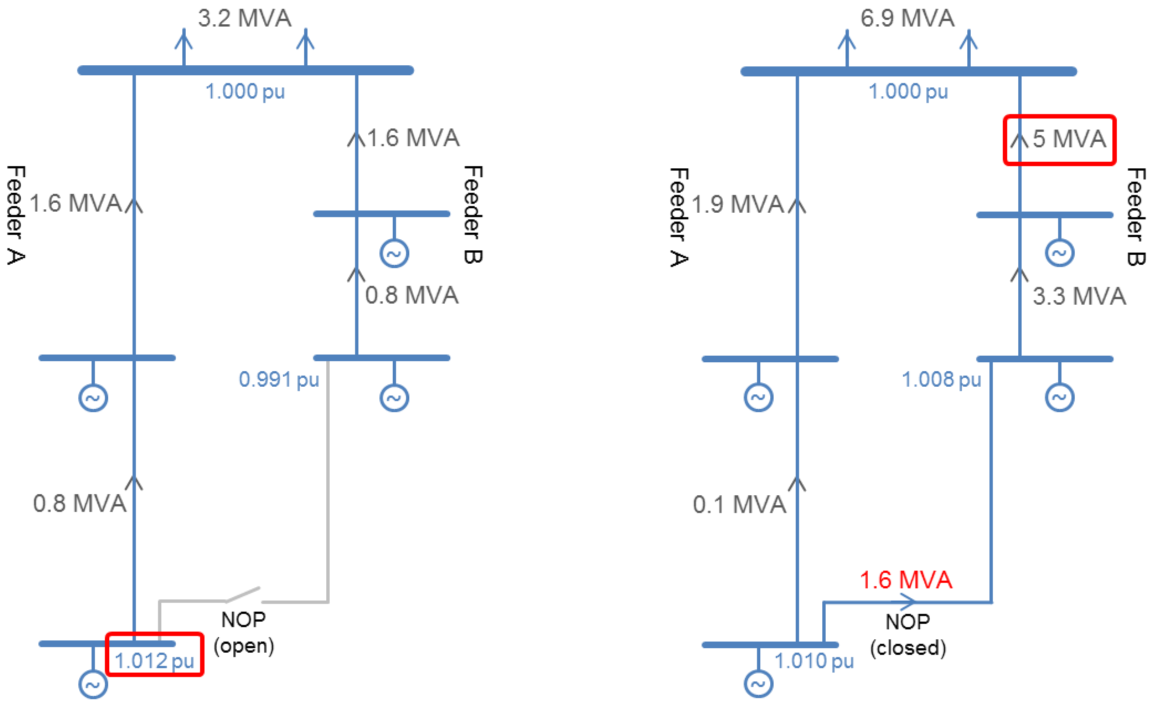

Figure 12: Scenario 2 – Radial C_2C (left) and Interconnected C_2C (right)

When the impedance of feeder A is greater than that of feeder B, for Radial C_2C operation, feeder A experiences an over-voltage constraint at its extremity due to its higher impedance. The total DG capacity released by Radial C_2C operation is 3.2 MVA, which is significantly lower than for the theoretical maximum of 10 MVA for symmetric feeders (scenario 1).

For Interconnected C_2C operation, the asymmetry of the feeder impedances increases the power flow through feeder B and thereby "accelerates" the occurrence of a thermal constraint in the first branch of feeder B. However, Interconnected C_2C operation mitigates the voltage constraint at the extremity of feeder A. Therefore, the maximum DG demand released by Interconnected C_2C operation, 6.8 MVA, is significantly higher than the maximum DG capacity for Radial C_2C operation of 3.2 MVA. This is due to the methodology adopted for evaluating Radial C_2C operation, as described in Section 2.3, which defines the DG capacity as the value just before reinforcement is required on either of the radial feeders.

3.3.3 Scenario 3 – Symmetric feeder impedances and asymmetric DG

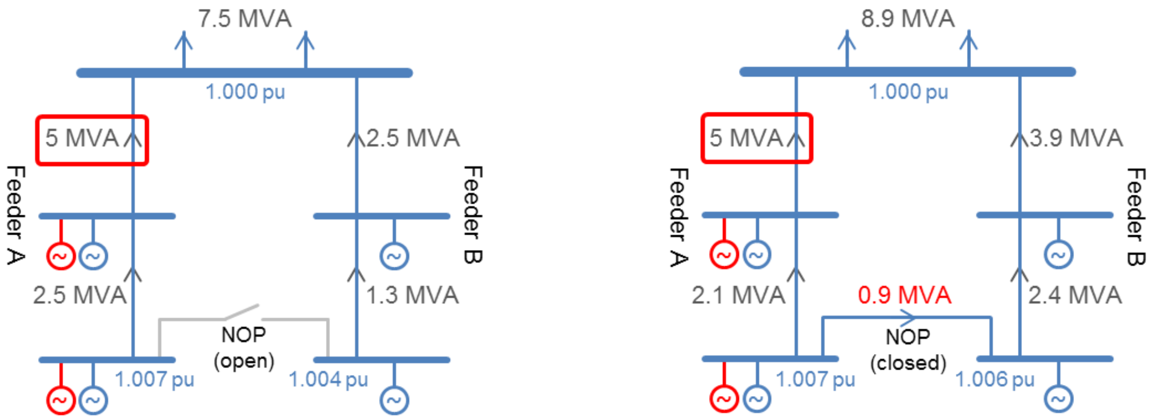

Figure 13: Scenario 3 – Radial C_2C (left) and Interconnected C_2C (right)

With the asymmetry in the DG, as shown in Figure 12, for Radial C_2C operation, the maximum DG capacity is limited by feeder A, which has a greater level of DG connected. Therefore the maximum Radial C_2C capacity is 7.5 MVA. Note that the thermal capacity of feeder B is relatively underutilised.

For Interconnected C_2C operation in this scenario, the total DG capacity is still limited by the first branch of feeder A. However, feeder B exports a proportion of the power generated on feeder A due to the impedances of the interconnected system. The maximum DG capacity released by Interconnected C_2C operation, 8.8 MVA, is therefore higher than for Radial C_2C for this scenario.

3.4 Overview of results for the simplified HV network

Table 1 summarises the maximum DG capacity released by Radial C_2C and Interconnected C_2C for each scenario, using the simplified HV network.

	Scenario 1	**Scenario 2**	**Scenario 3**
Feeder impedances	Symmetric	Asymmetric	Symmetric
DG arrangement	Symmetric	Symmetric	Asymmetric
Radial C_2C	10 MVA	3.2 MVA	7.5 MVA
Interconnected C_2C	10 MVA	6.8 MVA	8.8 MVA

Table 1: Summary of maximum released DG capacity

The following can be concluded:

- If the two feeders comprising the ring circuit are perfectly symmetrical (scenario 1), which is highly unlikely in practice, there is no difference in the maximum DG capacity released by Radial C_2C or Interconnected C_2C; electrically, closing the NOP has no effect on DG capacity.
- If one of the feeders comprising the ring circuit has a higher impedance (scenario 2), or if one of the feeders comprising the ring circuit has more DG connected (scenario 3), Interconnected C_2C operation will cause a redistribution of power flows and a reduction in the maximum voltage rise – and will thereby generally release more DG capacity than Radial C_2C.

For simplicity, the effects of combinations of feeder impedance and DG asymmetry are not demonstrated in this section. However, in general, Interconnected C_2C operation results in a lower worst case voltage rise at secondary substations than Radial C_2C, because of the lower equivalent impedance between the primary and secondary substations. Therefore, unlike demand capacity which is generally limited by thermal constraints [2], Interconnected C_2C is generally able to release more DG capacity than Radial C_2C because radial circuits are typically constrained by voltage rather than thermal capacity.

4 Results for ENWL C$_2$C Trial Circuits

4.1 Uniform DG growth

Figure 14 illustrates the distributions of released DG capacity from the analysis of simulations of 36 C$_2$C trial circuits, as percentage increases relative to the DG base case, both Radial C$_2$C and Interconnected C$_2$C operation. The distributions of these results are visualised using box plots, where the coloured box illustrates the range between the first and third quartiles (Q1 and Q3, respectively), and the median value (Q2) is shown as a black line within the coloured box. The ends of the "whiskers" represent the extreme values within 1.5x the interquartile range, i.e., within $1.5 \times (Q3 - Q1)$. Any outliers, defined as lying outside 1.5x the interquartile range, are represented as blue crosses. The mean values are represented by black dots and are labelled.

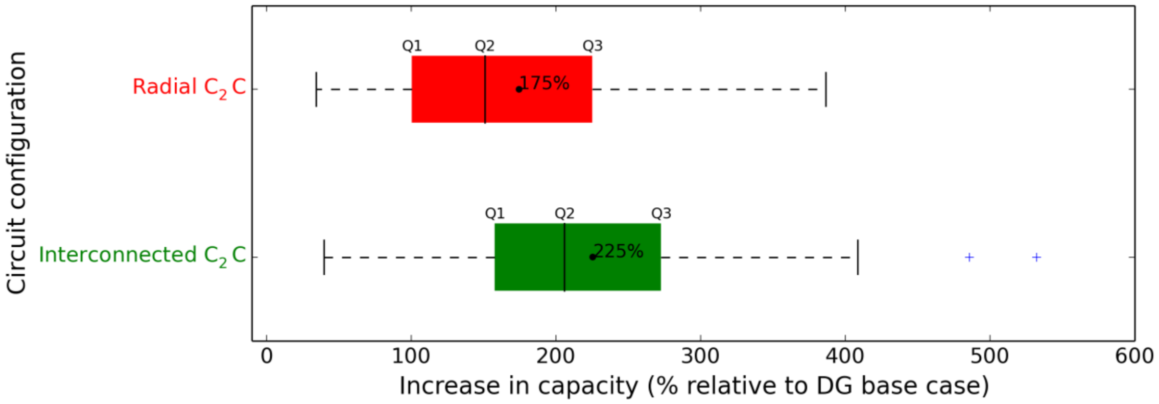

Figure 14: Summary of DG capacity released by C$_2$C operation for uniform DG growth

The maximum DG capacity values, for a uniform growth in DG which can be connected before a constraint is encountered are presented in as a percentage increase in Figure 15 and in MVA in Figure 16. The types of constraints encountered are documented in Appendix A.

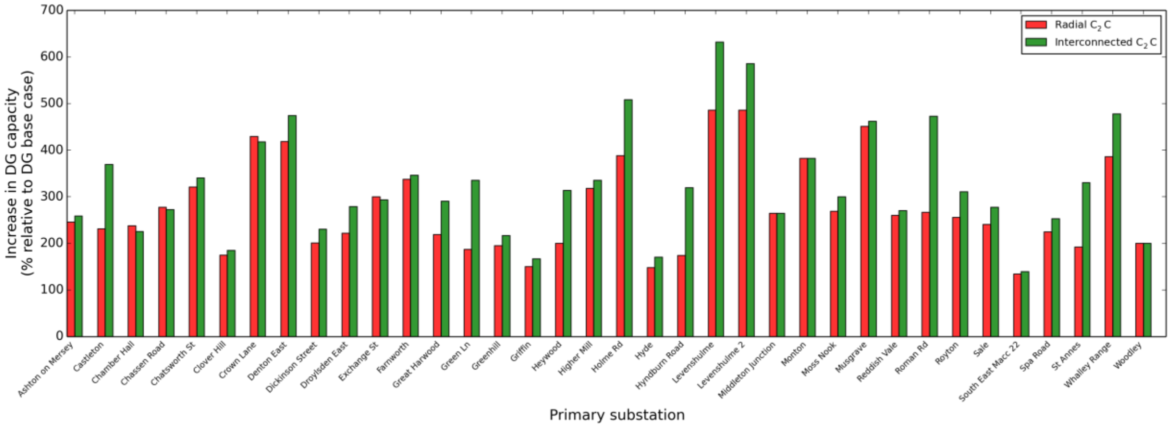

Figure 15: Maximum DG capacity values for uniform DG growth

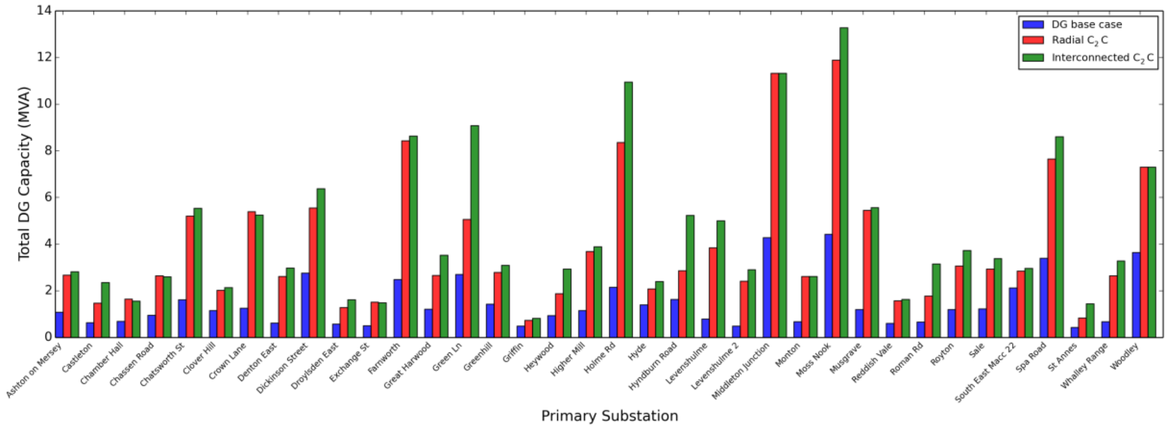

Figure 16: Maximum DG capacity values for uniform DG growth (in MVA)

The results demonstrate that C_2C operation provides a significant increase in DG capacity compared to connections based on an N-1 planning approach – an average of approximately 175-225% assuming a uniform growth in DG (where 100% represents a doubling of DG capacity). The requirement for DG to remain connected during N-1 conditions for the DG base case limits the maximum DG capacity, and C_2C operation thereby releases significant additional DG capacity.

There is significant variability in the released DG capacity (40-400% for Radial C_2C), which is dependent on the specific feeder impedances and DG locations. For example, for the “Griffin” circuit, which includes a relatively long overhead line spur, application of C_2C operation releases up to approximately 0.33 MVA (67%) of additional DG capacity; a relatively short cable network such as the “Dickinson Street” circuit is able to release up to approximately 6 MVA (100%) of additional DG capacity.

On average, Interconnected C_2C operation releases greater DG capacity (225%) than Radial C_2C operation (175%). This is due to the fact that, for Radial C_2C operation, a constraint on either radial feeder limits the capacity of both feeders as specified in Section 2.3. Furthermore, as illustrated in Section 2, Interconnected C_2C operation generally benefits from lower voltage rises due to the lower equivalent impedance of the feeders. For example, the “Green Lane” circuit releases significantly more additional DG capacity for Interconnected C_2C operation (235%) compared to Radial C_2C operation (87%) because closing the NOP mitigates a voltage constraint at the extremity of one of the feeders.

In some cases, Radial C_2C operation releases slightly more DG capacity than Interconnected C_2C, such as for the “Chamber Hall” and “Crown Lane” circuits, as shown in Figure 15. This is because in these cases Interconnected C_2C operation raises the voltage on one “side” of the NOP (compared to radial operation). The voltage increase at the NOP leads to a slight increase in the voltage at circuit extremities which are spurred from near the NOP. Consequently, less generation can be accommodated before the voltage reaches the upper voltage limit of 1.012 pu and the DG capacity for Interconnected C_2C is less than that for Radial C_2C. However, the difference in voltage at the NOP and the resulting difference in released DG capacity are relatively small.

Many of the scenarios shown in Figure 16 may require reinforcement of the primary transformers to accommodate the maximum theoretical C_2C DG, especially if other circuits connected to the same primary substation were to accommodate similar levels of DG. For example, the “Middleton Junction” primary has a firm capacity of 23 MVA and Figure 16 illustrates that the circuits under study at Middleton Junction could export up to 11 MVA when maximum DG is connected. If other circuits connected to the same primary substation were to accommodate similar levels of DG, it is clear that the primary transformers may need upgraded to accommodate such growth.

4.2 Non-uniform DG growth

Figure 17 illustrates the maximum DG released for non-uniform (“point”) DG growth at specific circuit locations, alongside the results for uniform DG growth presented in Figure 14. On average, Interconnected C_2C operation releases greater DG capacity than the corresponding Radial C_2C scenarios.

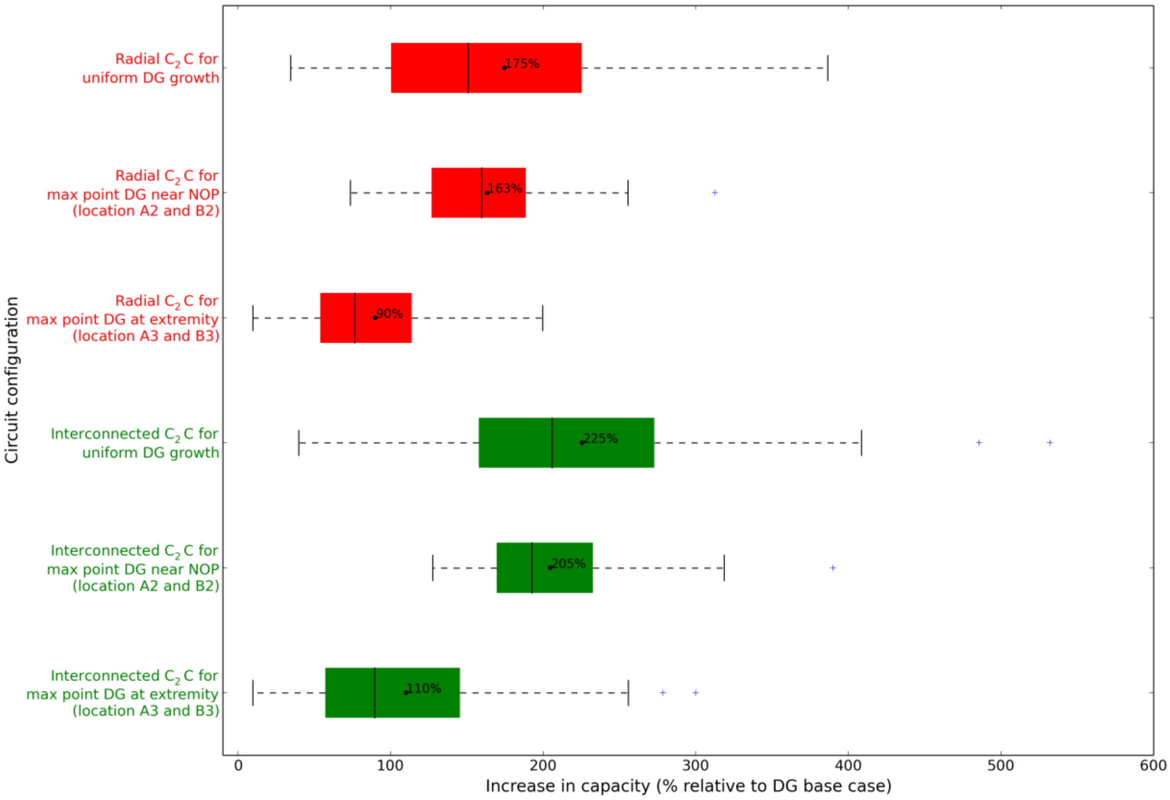

Figure 17: DG capacity released by C_2C operation

On average, DG growth concentrated at locations near the NOP (A2 and B2 in Figure 17) results in slightly lower released DG capacity compared to uniform DG growth. However, there is also lower variation in the results across different circuits for locations A2 and B2 (approximately 90-260% for Radial C_2C) compared to the distributions for uniform DG growth (approximately 40-400% for Radial C_2C). This is because uniform DG growth includes some DG growth at circuit extremities and is therefore more sensitive to the topology of each circuit, thus leading to greater diversity of the results. The impedances between the NOP and the primary are relatively similar across the modelled circuits, therefore point DG growth near the NOP does not exhibit such a high sensitivity to circuit topology and the range of the results is narrower.

At the extremities of circuits, large DG connections are unlikely to be feasible due to voltage constraints caused by the relatively high impedance between the point of connection and the primary. This is illustrated by the results for locations A3 and B3 in Figure 17; on average, these locations release approximately half of the corresponding DG capacity released assuming uniform DG growth, for both Radial C_2C and Interconnected C_2C operation.

5 Conclusions

This paper has described the methodology for evaluating the HV network DG capacity benefits of C_2C and the results corresponding to the simulation of 36 C_2C trial circuits. A DG base case has been established which represents the maximum DG that can be connected to a pair of radial HV circuits, without deploying C_2C, i.e., assuming that DG must remain connected during N-1 conditions. The additional DG capacities, relative to the DG base case, which can be achieved by the deployment of Radial C_2C operation and Interconnected C_2C operation have been evaluated.

Two complementary methods of modelling additional, interruptible C_2C DG capacity have been investigated:

1. Uniform DG growth, perhaps reflective of a high penetration of PV, which is relatively evenly distributed throughout existing secondary substations.
2. Non-uniform “point” DG, which may be reflective of relatively large localised generation such as a wind farm, CHP, or biomass.

From the results, the following can be concluded:

- C_2C operation has the potential to accommodate a significant increase in DG connections on HV circuits.
- For either Radial C_2C or Interconnected C_2C operation, the released DG capacity is highly dependent on the circuit topology and the relative modelled DG location.
- Interconnected C_2C operation will typically release more DG capacity than Radial C_2C operation, although there are exceptions to this.
- Assuming uniform growth in DG, Radial C_2C operation can, on average, release 175% additional DG capacity; Interconnected C_2C operation can release 225% additional DG capacity. If such extreme uptake of interruptible DG connections was to occur in HV circuits, and ignoring load connected to the circuit which would “negate” some of the exported power, other system factors such as primary transformer ratings may need to be considered.
- Assuming non-uniform DG growth, with point generators connected near the NOP location on each feeder, C_2C operation is able to release significant DG capacity; however this would be lower than the DG capacity released by uniform DG growth for both Radial and Interconnected C_2C operation.
- Assuming non-uniform DG growth, with point generators connected at the extremity of each feeder, significantly less DG capacity compared to uniform DG growth, for both Radial C_2C and Interconnected C_2C operation, can be released due to the higher impedances between the point DGs and the primary substations. However, even this evaluation of the additional DG at the circuit extremities facilitated by C_2C operation still permits approximately a doubling of connected DG, compared to the DG base case, whether operating radially or interconnected.
- For point DG connections relatively far from the primary, there is greater variation in the released capacity for each circuit compared to connections at (or near) the NOP. This is because the results depend on the topology of each circuit which varies significantly.

Appendix A: Effects of modelled DG power factor

A.1 DG capacity released

The selection of DG power factor slightly affects the results for released DG capacity. This is illustrated in Figure 18 for a power factor of 0.95 lagging, which results in a slight decrease in the average released DG capacity, compared to unity power factor as assumed in Section 2.2.

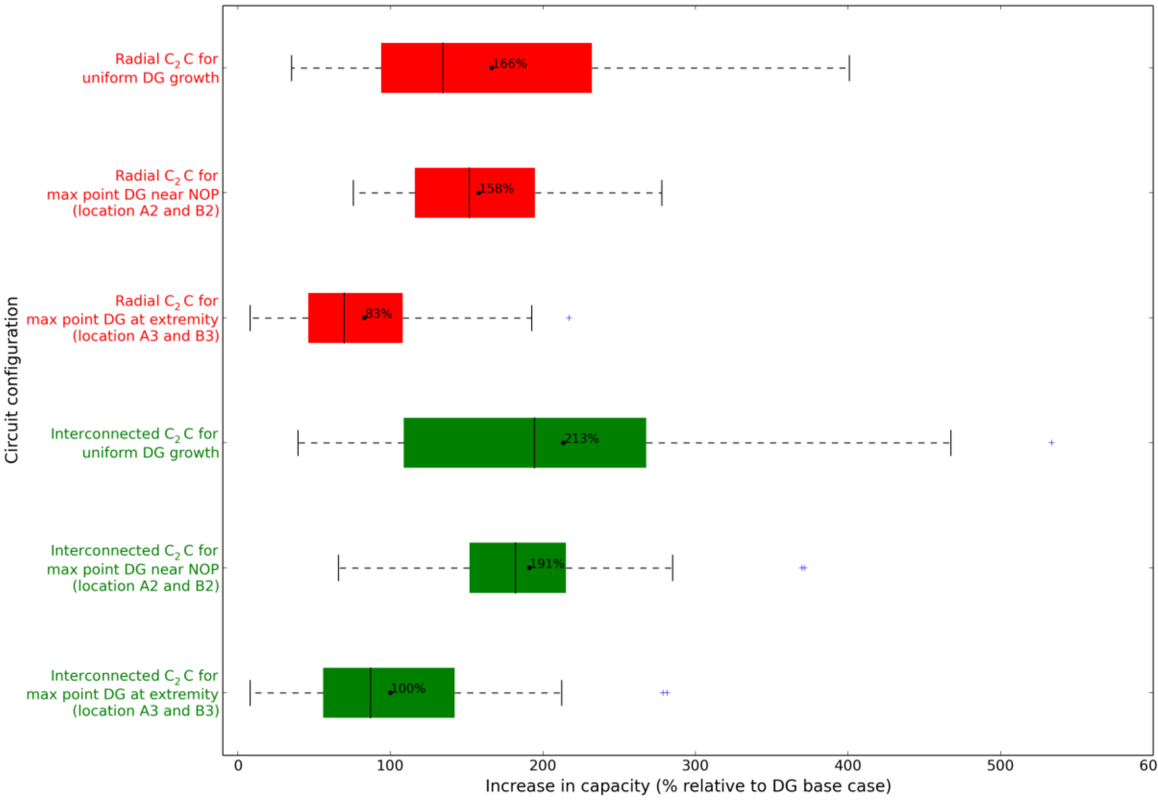

Figure 18: DG capacity for 0.95 lagging power factor

Similarly, a 0.95 leading power factor results in an increase in the average released DG capacity, compared to unity power factor, as shown in Figure 19. This is due to the fact that the increase in the reactive power flowing out of the primary causes an increased voltage drop which partly mitigates the voltage rise at the DG terminals, which in turn allows more DG capacity to be accommodated in some cases.

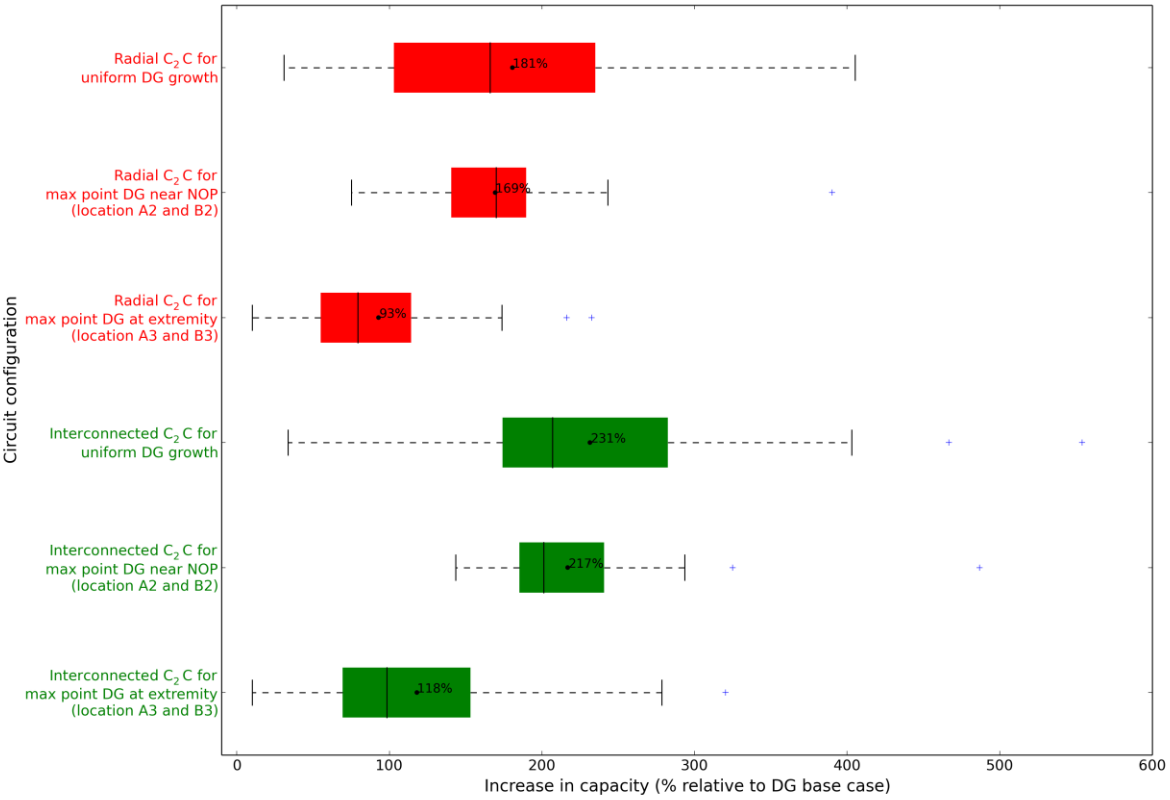

Figure 19: DG capacity for 0.95 leading power factor

A.2 Constraint types for unity DG power factor

The types of constraints – voltage or thermal – experienced for maximum connected DG, assuming uniform DG growth, are summarised in Table 2. For the DG base case, all constraints are due to voltage constraints (where the HV voltage is greater than 1.012 pu), and are typically experienced at DG locations relatively far from the primary. This can be attributed to the relatively large electrical distance between remote DG connections and the primary substation during the worst case N-1 conditions. The flow of the power exported from the DG through the associated impedance causes the voltage to rise above the nominal voltage at the primary.

	Voltage	Thermal
DG base case	100%	0%
Radial C_2C	89%	11%
Interconnected C_2C	86%	14%

Table 2: Summary of constraint types for uniform growth in DG

At unity power factor, there is almost no difference in the types of constraints experienced between Radial C_2C and Interconnected C_2C. For the “Dickinson Street” circuit, Interconnected C_2C operation results in a thermal constraint rather than the voltage constraint experienced for Radial C_2C operation (resulting in an overall increased proportion of thermal constraints from 11% to 14%). This is due to the change in power flows resulting from closing the NOP, which leads to a thermal constraint at a higher level of released DG capacity, because the voltage constraint is mitigated.

A.3 Constraint types for lagging and leading DG power factors

As can be observed in Table 3, a leading DG power factor results in a greater proportion of thermal constraints than voltage constraints, compared to unity or lagging power factor. As noted in Appendix A, this allows more DG capacity to be released, i.e., it leads to better utilisation of the HV circuits. Conversely, a lagging power increases the proportion of voltage constraints and generally reduces the released DG capacity.

	DG base case		**Radial C_2C**		**Interconnected C_2C**	
Power factor	**Voltage**	**Thermal**	**Voltage**	**Thermal**	**Voltage**	**Thermal**
Unity	100%	0%	89%	11%	86%	14%
0.95 lagging	100%	0%	94%	6%	92%	8%
0.95 leading	100%	0%	89%	11%	81%	19%

Table 3: Summary of constraint types for uniform growth in DG, at different power factors

References

[1] HM Government, *Climate Change Act 2008*. UK, 2008.

[2] V. Turnham, S. M. Blair, C. D. Booth, and P. Turner, “Increasing Distribution Network Capacity using Automation to Reduce Carbon Impact,” in *12th IET International Conference on Developments in Power System Protection (DPSP 2014)*, 2014, pp. 6.1.2–6.1.2.

[3] M. Hird, N. Jenkins, and P. Taylor, “An Active 11 kV Voltage Controller: Practical Considerations,” in *17th International Conference on Electricity Distribution (CIRED)*, 2003.