DISTRIBUTION NETWORK CAPACITY INCREASE VIA THE USE OF DEMAND RESPONSE DURING EMERGENCY CONDITIONS: A COST BENEFIT ANALYSIS FRAMEWORK FOR TECHNO-ECONOMIC APPRAISAL

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ABSTRACT

This paper presents a scenario based Cost Benefit Analysis (CBA) framework for the assessment of a novel Demand Side Response (DSR) solution currently being tested in the UK, namely the Capacity to Customers (C_2C) method. The C_2C method is a network solution recently proposed by Electricity North West Limited (ENWL), which effectively increases network capacity during normal operation and offers several social benefits (i.e., power losses reductions and increased reliability, among others). This is achieved by pushing the network beyond its traditional security limits (e.g., dictated by the P2/6 engineering recommendations in the UK) while still meeting security constraints by resorting to DSR deployment during emergency conditions. Costly investments in traditional network reinforcements can thus effectively deferred (or even avoided), particularly in the face of uncertainty. However, the economic value of C_2C interventions is yet to be understood and quantified, which is the main driver for the development of the CBA framework presented in this work. This CBA framework is used to evaluate the potential application of C_2C interventions in real UK medium voltage distribution networks. The results show that the C_2C method can be economically (and socially) more attractive than traditional reinforcements under several conditions. The factors that increase or decrease this attractiveness of the C_2C method are also identified and discussed.

INTRODUCTION

In the UK, traditional planning practices for distribution networks at medium voltage and above recommend investing in sufficient network capacity to guarantee energy supply for all (or most) customers after credible contingencies occur (e.g., based on N-1 security considerations, or on specific indications/standards such as the engineering recommendations (ER) “P2/6”, among others) [1]. As a result, typically large investments are made to oversize the distribution networks to enable sufficient reserve capacity to meet the abovementioned security criteria. This reserve capacity is seldom used as it is strictly reserved for emergency conditions that rarely occur (e.g., in some cases once every five years or less frequently).

In order to address the above-mentioned issue, Electricity North West Limited (ENWL), which is one of the distribution network operators (DNOs) in the UK, has recently proposed a Demand Side Response (DSR) based solution, namely the Capacity to Customers (C_2C) method [2]. The C_2C method has the potential to (i) release part of the aforementioned untapped capacity for everyday use (effectively deferring or even avoiding costly network reinforcements) and (ii) provide a wide range of network benefits such as decreased power losses and increased reliability among others. However, these benefits have yet to be quantified and compared against the costs inherent to the solution (e.g., costs of C_2C related infrastructure, DSR payment and so forth) using proper cost benefit analysis (CBA) frameworks.

In the light of the above, this work presents a scenario based CBA framework specifically devised to capture the value of the C_2C method and systematically investigate the value of C_2C interventions compared with traditional reinforcement based practices (e.g., reinforcing the feeders and substations whenever demand is forecasted to exceed their secure capacity).

Based on the proposed methodology, the work carried out at the University of Manchester and presented in this paper investigates from a quantitative standpoint the technical and economic potential of the C_2C method throughout several real UK Trial networks where the method is currently being tested. Particular focus is placed on the potential of the C_2C method to increase network capacity and potentially deferring or even avoiding reinforcement requirements in the face of uncertainty, as well as on the potential of the method to reduce power losses.

The rest of the paper is structured as follows. Section II provides a detailed description of the C_2C method, especially the different characteristics of the method that must be captured by a proper CBA. Section III describes the CBA framework that is developed for the assessment of the C_2C method. Sections IV and V present the main results and conclusions of this study, respectively.

THE C_2C METHOD

Under current UK practices, typical distribution networks at the 6.6kV and 11kV levels comprise two or more radial feeders interconnected through a Normally Open Point (NOP) as shown in Fig 1. These networks are planned and operated based on supply-side control and preventive security. Based on this rationale, whenever a contingency occurs in one of the radial feeders, all customers in that feeder are disconnected while the fault and some of these customers are isolated from the rest of the feeder by the protections system (normally within three minutes). Afterwards, the NOP is closed manually (this takes roughly an hour) to supply the rest of the customers through the neighbouring feeder. This practice is analogous to N-1 security considerations and is put in place to comply with engineering recommendations P2/6 [1]. Due to these security considerations, both distribution feeders are significantly oversized to meet own demand as well as demand from neighbouring feeders. The resulting spare capacity is only used during emergency conditions that occur rarely; in some cases once every five years or less frequently. As a result, demand growth in one of the feeders may lead to costly reinforcements in one or both feeders or in the substation to provide security capacity that is seldom used.

In the light of this, ENWL recently introduced the C_2C method (currently under trial) at the medium voltage level (currently 6.6kV an 11kV levels). The C_2C method is a corrective control philosophy based on DSR specially devised as an alternative solution to costly network reinforcements, as well as a means for reducing social costs at the distribution level [2].

The C_2C method is expected to defer (or even avert) costly network reinforcements by releasing emergency capacity for use during normal network operations. This is achieved by allowing demand to grow beyond the security (post-contingency) limits imposed by security criteria (e.g., the P2/6 engineering recommendations in the UK) while still meeting security requirements by calling DSR to mitigate thermal and voltage issues that might have arisen after a contingency occurs. It is important to note that DSR would seldom be called as emergencies occur rarely and, even during emergency conditions, thermal or voltage issues are unlikely to occur unless the emergency condition extends to peak time. By allowing demand to grow beyond traditional security limits, the C_2C interventions would defer costly network reinforcements. Furthermore, considering that demand growth forecasts can be substantially uncertain under real life conditions and investments in reinforcement must be committed several years before demand is expected to exceed the secure network capacity due to the lead time needed to carry out the work (e.g., 3 years), C_2C interventions may avert reinforcements whenever demand does not grow as forecasted. Thus, C_2C interventions (with a low lead time of roughly a year) may be particularly valuable alternatives to costly reinforcements under practical conditions characterised by significant uncertainty.

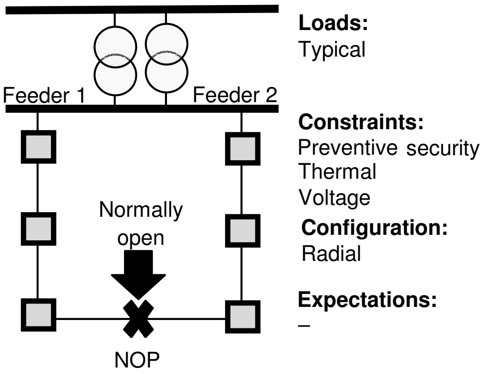

Fig. 1. Traditional network comprising two radial feeders

Besides network reinforcement deferral, the C_2C method is expected to minimise social costs by automating the NOPs and operating them normally closed, creating a ring (view Fig. 2). This network configuration is expected to bring about immediate power losses reduction. In addition, if a fault were to occur, all customers in both feeders would be disconnected for less than three minutes; however, apart from the customers that are isolated along with the fault, all other customers would be restored within three minutes (the time for the automatic switching scheme to operate, as mentioned above). As a result, the C_2C improves system reliability by reducing customer interruptions of longer than three minutes, which are the only interruptions regulated in the UK.

Hence, it is clear how the C_2C solution could offer a wide range of benefits for both customers and DNOs. Nevertheless, these benefits have yet to be quantified and compared against the costs inherent to the solution (e.g., costs of NOP automation, DSR capacity payments and so forth) using a suitable CBA framework as the one presented in the next section.

METHODOLOGY

In this work, a scenario based CBA framework has been specifically devised to capture the value of C_2C interventions compared with traditional reinforcements in the face of uncertainty. This framework is in line with

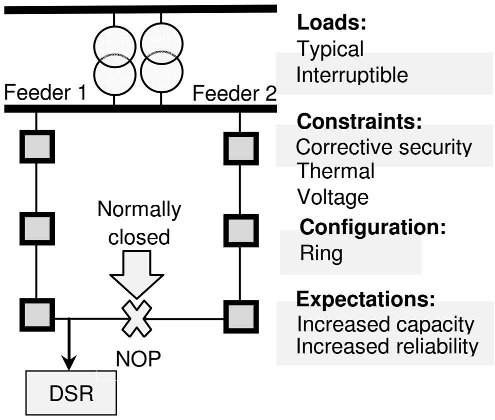

Fig. 2. C_2C networks

emerging UK regulations based on the new Revenues = Incentives + Innovations + Outputs (RIIO) price control scheme (from April 2015 to March 2023) [3].

The new RIIO price control is expected to incentivise DNOs that develop or implement novel distribution-level solutions that may lead to reduced investment costs or provide other benefits (e.g., the C_2C method). In this regard, the UK regulator (Ofgem) introduced a deterministic CBA framework (used as a foundation for the CBA approach used in this work) for DNOs to assess new asset investments based on "RIIO". According to Ofgem's CBA framework, DNO investment costs associated with the implementation of a distribution network solution should be assessed based on the Net Present Costs (NPC) criterion as denoted by (1) – (7) [4].

$$Capitalized\_Inv_y = 0.85 \times \sum_{n=1} Inv_{n(y),y} \tag{1}$$

$$Expensed\_Inv_y = 0.15 \times \sum_{n(y)=1} Inv_{n(y),y} \tag{2}$$

$$Dep_y = \sum_{y1=1}^{y} \frac{Capitalized\_Inv_{y1}}{Dep\_Lifetime} \tag{3}$$

$$RAV_y = Capitalized\_Inv_y - Dep_y - RAV_{y-1} \tag{4}$$

$$CC_y = RAV_y \times WACC \tag{5}$$

$$DNO\_Inv_y = Expensed\_Inv_y + Dep_y + CC_y \tag{6}$$

$$\mathrm{NPC} = \sum_{y=1}^{45} \frac{DNO\_Inv_y}{(1+d)^y} \tag{7}$$

where $Capitalized\_Inv_y$ and $Expensed\_Inv_y$ are shares of the investment costs ($Inv_{n,y}$) that can be recovered over time and immediately, respectively; Dep_y is the depreciation of all capitalized investments over the depreciation lifetime ($Dep\_Lifetime$), RAV_y is the regulated asset value, CC_y is the cost of capital, $WACC$ is the pre-tax weighted average cost of capital (4.2% for ENWL), DNO_Inv_y are the investment costs incurred by DNOs in a given year, the subscript $n(y)$ denotes the n-th intervention's investment associated to a network solution in year y, and the subscripts y and $y1$ denote time periods (years).

It is important to note that Ofgem's CBA assesses investment decisions by comparing them to a baseline via the Net Present Value (NPV) criterion. However, this approach has the disadvantage of concealing the characteristics of the baseline. Accordingly, the NPC criterion is used in this work for illustrative purposes only and without affecting the results of the CBA as the baseline is always presented to allow a direct comparison.

Following Ofgem's recommendations, the baseline should be a business as usual reinforcement based investment scheme for a forecasted scenario. As discussed previously, considering a single deterministic scenario may not be realistic as it disregards uncertainty, as well as the flexibility value of the C_2C method to defer or avoid investments whenever a scenario other than the forecast materialises. Thus, several potential future scenarios and associated baselines are considered in this study. The baseline for each scenario is formulated as a set of recommended lowest cost reinforcements available (for one or both feeders or the substation) for periods when demand reaches the maximum capacity of the system (considering lead time) under a given demand growth scenario. In order to illustrate this, assume a scenario where the maximum capacity of one (or both) feeders is forecasted to be exceeded in 5 years. The baseline would be to reinforce the associated sections of the feeders in year 2 (assuming a 3 years lead time) by upgrading the lines to the next available capacity level (cheapest reinforcement possible). Considering that ENWL proposed the C_2C solution as an alternative to traditional network reinforcements, all C_2C interventions are modelled as alternative solutions to the reinforcements recommended by the baseline. Following the previous example, a C_2C intervention would be performed in year 4 (assuming a 1 year lead time) instead of the reinforcement in year 2.

For the sake of precision, both the baseline and C_2C intervention are determined via greedy searches as shown in Fig. 3. This algorithm selects the cheapest available reinforcements (based on a CBA) whenever the system becomes unfeasible (e.g., security considerations are not met), and performs a full CBA based on (1) – (7) after decisions for the whole planning horizon ($y > 45$) have been selected.

The methodology is built upon the outputs of several recommendations from experts and technical studies of the prospective system before and after implementing a given solution. This information comprises:

- The maximum capacity of the system, which is estimated based on P2/6 engineering recommendations for the feeders and classical N-1 security criteria for the substation.
- Annual power losses from AC power flows.
- Potential network reinforcements based on credible upgrades of one or both feeders and the substation.
- Possible demand growth scenarios in the zone and reliability performances recommended by ENWL.

The scenario based CBA framework allows the assessment of network solutions under uncertainty and includes the quantification of losses and system

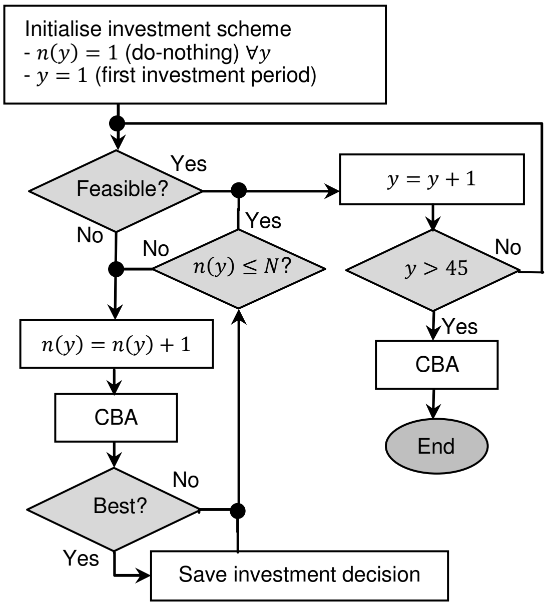

Fig. 3. Flow diagram of the greedy search engine

reliability, which are required to properly capture the value of the C_2C method to increase system capacity and decrease social costs.

CASE STUDY

In order to illustrate the key characteristics of the C_2C method compared with traditional reinforcement practices, assume that ENWL's "Green Lane" 11kV network is close to maximum capacity (i.e., 3% feeder headroom and 12% substation spare capacity). Accordingly, the DNO is considering whether to reinforce the network based on business as usual practices or perform a C_2C intervention. Note that this is a hypothetical situation as this is one of the Trial networks where the C_2C method is currently being tested. Further assume that (i) the price of DSR is 22k£/MWp for flexible capacity provided during peak time, (ii) costs for NOP automation are 19k£, (iii) reinforcement and C_2C intervention lead times are 3 years and 1 year, respectively; and (iv) the costs associated with reinforcing the network (both feeders) and the substation are 276k£ and 338k£, respectively.

ENWL envisions three potential demand growth scenarios for the area (view Fig. 4). Scenario 1 depicts a case where demand growth increases significantly in the next few years, which could be caused for example by the electrification of services such as transports and heating. Scenario 2 assumes that demand growth would halt during a few years before restarting, which may be attributed to regulatory uncertainties that may discourage electrification of services. Scenario 3 depicts a case in which after increasing for a few years, demand reverts to current levels. This scenario can represent a case where due to significant uncertainty, demand does not grow as expected, which could lead to network reinforcements that would provide capacity that would only be needed to meet security criteria for a short period if ever.

Based on the methodology, the baseline and recommended C_2C interventions for the above-mentioned scenarios are as shown in Table I and Table II. The value of the different schemes based on the NPC criterion and social impacts (i.e., losses and customer interruptions - CI) are shown in Table III.

The resutls exemplify the circumstances that increase or decrease the economic attractiveness of the C_2C method. On the one hand, the C_2C interventions are an attractive alternative to traditional reinforcement

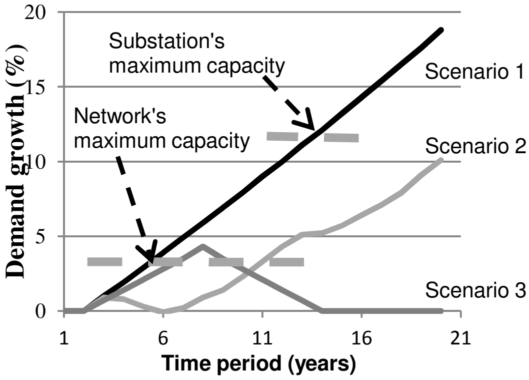

Fig. 4. Demand growth scenarios considered for the study

TABLE I. DESCRIPTION OF THE BASELINE

Scenario	Actions:
1	Reinforce the network in year 3 and the substation in year 11.
2	Reinforce the network in year 8.
3	Reinforce the network in year 4.

TABLE II. DESCRIPTION OF THE C_2C INTERVENTIONS

Scenario	Actions:
1	C_2C intervention in year 5.
2	C_2C intervention in year 10.
3	C_2C intervention in year 6.

TABLE III. CUMULATIVE NPC AND ANNUAL LOSSES ASSOCIATED WITH THE INVESTMENT SCHEMES

	NPC (k£)		Losses (MWh/year)		CI	
	Baseline	C_2C	Baseline	C_2C	Baseline	C_2C
1	275	266	213	188	260	130
2	23	109	184	162	260	130
3	26	20	155	136	260	130

practices whenever reinforcements are imminent and costly (i.e., in Scenario 1 where both the network and substation are reinforced) or the additional capacity from reinforcing the network is only needed for a short period (if ever) and thus C_2C costs are low (i.e., Scenario 3 where demand and the associated DSR costs decrease). As discussed previously, this scenario captures the flexibility value of the C_2C method to avert reinforcements when demand does not grow as forecasted (i.e., investment decisions are subject to high uncertainties). On the other hand, the C_2C method may not be attractive when only less costly reinforcements are expected in the long-term (Scenario 2).

It can also be observed that the C_2C intervention offer significant reliability improvements and losses reductions. Reliability improvements are currently fixed at 50% as it is considered that protections would isolate 50% of customers in one feeder along with the fault during emergency conditions, the NOP can be operated manually within one hour, and the automated NOP can restore the service within three minutes. These assumptions will be improved based on real data from the Trial systems as it becomes available. In this case, the C_2C method reduces losses further than the reinforced network (view Fig. 5). The C_2C method is indeed expected to redue power losses compared to the original network comprising two radial feeders. However, the C_2C method may not offer lower losses than a reinforced network.

In order to offer a more general view of the above-mentioned characteristics of the C_2C method, the case study was repeated based on information from other existing Trial networks (see Table IV for results corresponding to Scenario 3). The results are consistent with the conclusions drawn from the Green Lane case and highlight that, even though the C_2C method is likely to reduces power losses compared to the original radial network, it would likely result in higher losses than the reinforced network (in some cases significantly more). Thus, even though the method lead to a reduction in power losses (and associated emissions) in the short-term, in some cases it can result in higher losses than the baseline in the long-term.

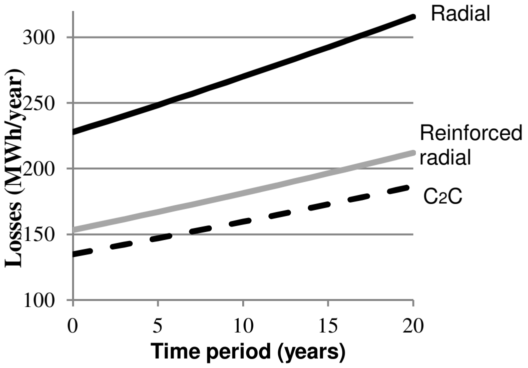

Fig. 5. Power losses associated with the different solutions

TABLE IV. PERFORMANCE OF C_2C AGAINST BASELINE

System	NPC savings (%)	Losses reduction (%)	CI reductions (%)
Ashton	30	-29	50
Exchange	31	-24	50
Green Ln	26	12	50
Heywood	30	-58	50
Hyndburn	30	-1	50

CONCLUSION

This work evaluated a DSR based corrective control philosophy, namely the C_2C method, in the context of several existing UK networks from a technical and economic perspective using a bespoke methodology.

The results highlight that the C_2C method is an attractive alternative to traditional reinforcement practices whenever reinforcement costs are imminent and significant, and investment decisions are subject to significant uncertainty. Furthermore, the C_2C method can offer several social benefits, particularly in the short-term. On the other hand, the C_2C interventions are unlikely to be economically attractive if investment costs are low and far in the future, and investment decisions are not influenced by uncertainty. Moreover, under some circumstances, the C_2C method may lead to higher power losses than network reinforcements in the long-term.

In the light of this, proper CBA frameworks as the one presented in this work are critical to facilitate the proper implementation of the C_2C method under conditions that facilitate both economic and social benefits.

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