# CAPACITY VALUE OF DISTRIBUTED GENERATION FOR NETWORK CAPACITY PLANNING

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## ABSTRACT

*Installed capacities of distributed generation are projected to increase substantially in Great Britain and many other power systems. This paper will discuss the definition of capacity value of DG arising from its ability to support additional demand without the need for new network capacity, in analogy with the definition of Effective Load Carrying Capability (ELCC) at transmission level. This calculated ELCC depends on the precise detail of its definition; in particular in a demand group fed by a pair of circuits where the double outage state dominates the calculated reliability index, the ELCC will be very small unless the generator can run in islanded mode. Finally, requirements for use in practical planning studies and development of formal planning standards will be discussed.*

## INTRODUCTION

Installed capacities of distributed generation (DG), i.e. generation embedded in distribution networks, are projected to increase substantially in Great Britain (GB) and many other power systems. This is largely due to incentives to encourage the uptake of low carbon technologies at all voltage levels of the power system, from domestic properties to higher distribution voltages. A general survey of methods for analysis of the consequences of installing DG may be found in [1].

One key benefit which DG potentially brings in distribution networks is reduction in the incoming circuit capacity required from higher voltage levels to the demand group containing the DG. In practice, this is often viewed in terms of the number of years by which the DG can defer upgrades which are driven by load growth. This has been studied by various means in the literature, including formal optimisation methods for network design (see [2] and references therein), and Monte Carlo simulation of network outages [3]. Related work on use-of-system pricing based on contribution to deferring upgrades may be found in [4].

It is widely accepted that the only systematic framework in which DG's contribution to demand security can be assessed is probabilistic risk modelling. This recognises the random nature of outages, and provides the necessary means for considering coincident events of different natures (for instance in order to have a supply shortage, it might be necessary to have high demand, low available DG capacity, *and* an incoming circuit outage) and multiple resources (including incoming circuits, DG and low voltage interconnection).

The present network planning standard in Great Britain (Electricity Network Association Engineering Recommendation P2/6, [5,6]) states that peak demand in a demand group must be less than the incoming circuit capacity in a defined outage state; the degree of redundancy required may be N-1 and N-2 depending on the peak demand of the demand group under study (N-i means that all demand must be met with i circuits on outage.)

A calculation method is supplied for determining the amount by which a network operator can reduce this need for incoming circuit capacity when performing assessments under P2/6 for a network with DG. The tables for DG contribution within the P2/6 standard (essentially the current specified capacity value) are not derived with respect to a full probabilistic analysis of a preferred reliability index; the consequences of this will be described more fully in the next section. Given an appropriate specification of a reliability index such as Expected Energy Not Supplied (EENS, the customary index in similar studies in GB), quantifying DG's contribution is essentially a matter of defining and calculating an appropriate capacity value metric.

Concepts of capacity value are well studied in the transmission-level reliability literature; a recent survey may be found in [7]; the capacity value of an additional generator (or ensemble thereof) is made specific using metrics such as Effective Load Carrying Capability (ELCC, the additional load which can be supported by the additional generation without increasing the risk index), or Equivalent Firm Capacity (EFC, the completely firm generating capacity which would give the same value of risk index if it replaced the additional generation). It is important to note that due to the different ways one can make the concept specific (e.g. EFC and ELCC) there can be no one definitive capacity value of a generator – however, for a given engineering question, the appropriate capacity value definition is usually clear.

This paper will explore how concepts of capacity value may be used to visualise the contribution of DG to distribution network reliability within the framework of a P2/6-like standard; future work will investigate the development of practical planning standards based on the insights gained. In this paper we will generally use ELCC, representing the additional load that may be supported due to the presence of generating capacity. Firstly, the present P2/6 standard will be described, and then ELCC and the underlying reliability metric defined. An illustrative case study will be presented, and finally conclusions draw (including discussion of further work required for use of the work in practical planning and standards development).

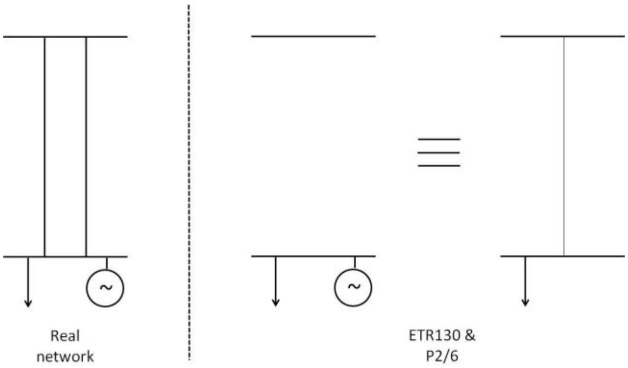


Fig 1. Comparison between a real network and the method used for assigning a capacity value to DG within P2/6.

## CAPACITY VALUE DEFINITIONS

### Test example

The real network example considered throughout this paper is illustrated in the left half of Fig. 1. A grid supply point (GSP) is connected by two circuits to a demand group which contains generation.

As is the practice in distribution planning in GB, each level of the network is considered in isolation, i.e. when planning the circuit capacity required between the GSP and the demand group the GSP is assumed to be able to supply any amount of power with perfect reliability, and reliability of lower voltage network within the demand group is not considered.

### Capacity value calculation within P2/6

The method for assigning a capacity value to distributed generation within the present P2/6 standard is illustrated in the right hand panel of Fig. 1. EENS is calculated with the DG but with no incoming circuit capacity, and the DG is then deemed equivalent in reliability terms to a single incoming circuit which gives the same level of EENS. These calculations are performed assuming peak demand equal to the installed capacity of the DG. Capacity values as a percentage of maximum output are supplied, in Table 2 of P2/6, for generic units of a range of generator technologies. Alternatively, a standard spreadsheet implementation of the method is available [8].

This approach, on which the DG contributions laid down in P2/6 are based, thus does not at any point involve a reliability analysis for a realistic network scenario with both incoming circuits and DG of different capacities. There is thus a concern that the capacity values allocated to the DG might be excessive, and expose customers to loss-of-supply risks in excess of those which would be experienced in a system with the same planning standard but without any generation in the demand group.

### Defining Expected Power Nor Supplied (EPNS)

The Expected Energy Not Supplied may be defined as

$$[\mathrm{EENS}] = \delta t \sum_t \mathrm{E}[(D_t - X_t - Y_t)_+] \qquad (1)$$

where $X_t$, $Y_t$ and $D_t$ are respectively random variables representing the available incoming circuit capacity, available embedded generation, and demand at period $t$ within the future time window across which the EENS is to be calculated. $\delta t$ is the duration of each period, and $(x)_+$ takes the value $x$ if $x > 0$ and $0$ otherwise. EENS is thus the length of each period, multiplied by the sum over periods of expected shortfalls. Provided that there are no technologies such as storage which create explicit linkages between periods, the EENS may [9] be reformulated as

$$\begin{aligned}[\mathrm{EENS}] &= \Delta t[\mathrm{EPNS}] \\ &= \Delta t \times \mathrm{E}[(D - X - Y)_+]\end{aligned} \qquad (2)$$

where $X$, $Y$ and $D$ are now the available capacities and demand at a randomly chosen time interval within the time window under study, and $\Delta t$ is the length of the time window. This alternative formulation will prove much more convenient for specifying the capacity value definitions and theoretical results which follow.

In a situation where there are two incoming circuits of equal capacity, the EPNS may be expressed as

$$\begin{aligned}[\mathrm{EPNS}] = {} & p_{\mathrm{N}-1}\mathrm{E}[(D - c - Y)_+ \mid \mathrm{N}-1] \\ & + p_{\mathrm{N}-2}\mathrm{E}[(D - Y)_+ \mid \mathrm{N}-2]\end{aligned} \qquad (3)$$

where $p_{\mathrm{N}-i}$ is the probability of an $i$ circuit outage, and '$\mid \mathrm{N}-i$' means that the expectation value is taken conditional on an $i$ circuit outage (this accounts for the possibility that the generation may not be able to contribute fully if at all with no incoming circuit capacity), and it is assumed that all demand may be met at any time when all circuits are available.

### Defining Effective Load Carrying Capability (ELCC)

At transmission level, the ELCC of additional generation is defined as the additional peak demand which may be supplied when this additional generation is connected, while maintaining the original level of a chosen risk index [7]. An analogous definition of the ELCC of embedded generation may be made in this distribution problem, with the incoming circuit capacity taking the role that existing generation plays in transmission level calculations, the simplest version of this being:

$$\mathrm{E}[(D-X)_{+}] = \mathrm{E}[(D+[\mathrm{ELCC}]-X-Y)_{+}] \quad (4)$$

There are in fact three decisions which must be made when specifying this definition, which create alternative equations for the ELCC:

- Whether to add a block of firm demand equal to the ELCC (as above), or whether to rescale the distribution of demand defining ELCC in terms of a chosen measure of peak demand level. This is a comparatively minor issue, and any difference the choice of definition makes is likely to be dominated by modelling uncertainties.
- Whether in the ELCC calculation to work with EPNS in absolute terms (i.e. in MW) as above, or whether to work with EPNS as a percentage of mean demand.
- Whether to calculate unconditional expectation values (as above), or whether to calculate the expectation values conditional on a particular outage state of the circuits.

We believe that most readers will find this definition of ELCC an intuitively reasonable way of quantifying the contribution of the generation to demand security, however it has some consequences which are not immediately obvious and which will be described next; these are in contrast to the nature of transmission level calculation in which (unlike the distribution of available circuit capacity in this paper) for a system of substantial size the distribution of available existing generating capacity may be approximated well by a smooth continuous distribution.

## Observations on the definition of ELCC

**Evolution from N-1 standard without generation**

In a demand group without embedded generation, the existing P2/6 standard would require that 100% of demand can be met at all times with just one of the two circuits available.

If generation is added, and it cannot support demand in islanded mode, then this DG does not make any contribution to reducing EPNS conditional on being in the N-2 circuit state. On the other hand, if demand is increased by more than the minimum possible available output from the DG, then the EPNS conditional on being in the N-1 circuit state must become non-zero.

As a consequence of this argument, if in the absence of the DG all demand can be met always with just one circuit and it cannot support some demand in islanded mode, the ELCC of the generation is inevitably its credible minimum available output.

**Potential dominance of EPNS by N-2 state**

Statistics from the National Fault and Interruption Reporting Scheme [NAFIRS] indicate that the probability of being in the N-2 state may only be about a factor of 5 lower than that of being in the N-1 state. On the other hand, EPNS conditional on being in the N-2 state is the mean demand if islanded operation is not possible, while EPNS conditional on being in the N-1 state will be usually be much smaller (realistically, single circuit capacity would not be substantially lower than maximum possible demand, and hence conditional in N-1 there is a small probability of shortage of circuit capacity, and that shortage could be only small).

As a consequence, if a definition of ELCC is made in which the N-2 circuit state contributes to the comparison of reliability with and without the generation, if the contribution to EPNS from the N-2 state dominates that from the N-1 state then the ELCC of the generation will necessarily be very small.

## CASE STUDY

The above methodology can be illustrated by a case study based on a typical 2-circuit network. Table 1 shows relevant parameters for this network. The probability density of $D$ is taken to be symmetric about its mean and triangular in shape.

| | | | |
|---|---|---|---|
| Failure rate for each circuit | 0.3 / year | Mean repair time | 3 hours |
| Proportion affecting both circuits | 20% | Mean $D$<br>Max $D$<br>Annual increment. | 90 MW<br>120 MW<br>+ 1.0 MW |
| $c$ for each circuit | 120 MW | $Y$ | 10 MW with 90% availability |

Table 1 – Case study parameters

It can be seen that, in Year 0, a single circuit can just support maximum demand. By Year 5, there is a possible shortfall of 5 MW under (N-1) conditions, increasing to 10 MW by year 10. Under these circumstances, without consideration of the DG the network would be in breach of the industry design standard P2/6 at (N-1).

Using the earlier formulae with the data in Table 1, the EPNS in Year 5 without generation contains contributions of 0.0038 kW arising from the (N-1) state, and 3.90 kW arising from (N-2). Since 99.9% of the contribution to EPNS comes from the (N-2) case, (by Year 10, the equivalent proportion is 99.2%), it is clear that any value of the generation in terms of reduction of EENS comes almost entirely from the (N-2) situation, which will thus be the focus of the analysis which follows.

Whether the generation can decrease EPNS significantly thus depends on whether it can continue to operate in islanded mode, or at least in semi-islanded mode (alongside infeed at lower voltages independent of the two faulted incoming circuits). If it cannot so operate, then its capacity value is very close to nil. However, if it can continue to operate, then its ELCC as defined in (4) is 90% of 10 MW (to allow for unavailability), or 9 MW.

For any given practical example, it would be necessary to determine whether the generation could continue to operate under (N-2) conditions, or whether appropriate capital investment to enable it to do so could be justified.

## CONCLUSIONS AND FURTHER WORK

This paper has proposed Effective Load Carrying Capability (ELCC) as a metric for visualising the contribution of distributed generation to reliability of supply within the framework of the Great Britain P2/6 distribution network planning standard. This is in analogy with definitions of capacity value used at transmission level.

Within this immediate application of visualisation of generation's contribution within reliability calculations, further work will include additional exploration of how quantitative results depend on the definition of ELCC chosen, and in particular on the relative contributions of different circuit outage states within alternative ELCC definitions. Case studies will be supported by theoretical analysis based on closed form results for instructive limiting cases of (3) and (4) in analogy to [9]. In particular, these studies will illustrate the circumstances under which the DG capacity value definition underlying P2/6 might overestimate the contribution which DG can make within the reliability calculations performed.

More broadly, we will also explore the insights which this form of analysis can bring in developing practical planning standards. Understanding the quantification of the contribution of DG within relevant reliability calculations will certainly be of value in guiding discussions over standards. There is a natural desire to define a standard directly in terms of circuit capacities and capacity values of other resources rather than via a full probabilistic calculation, in analogy with the present P2/6 standard. However, it is as yet unclear how this might be done in a systematic way, as systematically defined capacity values of different resources do not combine by simple addition except in certain limiting cases (e.g. very small resource capacity).

If no systematic way can be found to define such a standard (i.e. based on circuit capacities and capacity values), then a natural conclusion may be that a full probabilistic standard is required. This links to broader questions of how to introduce highly relevant mathematical methods such as probabilistic reliability analysis into widespread field application; these have not traditionally formed a core part of a planning engineer's skill set (whether in university education or in the distribution industry), but it is desirable for engineers to be able to take full ownership of the analysis which they use to take decisions.

Further technical modelling questions include developing probabilistic representations of a full range of resources including low voltage interconnection between demand groups; whether one can create meaningful generic models for a given class of generator (such as wind or waste incinerator) given the diversity within such classes; and questions of uncertainty analysis arising from the need to make planning decisions based on limited quantities of directly relevant data.

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