Mathematical & Computer Modelling

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Rachel Fletcher
OFGEM

11th.July 2008

Dear Rachel,

Consultation and impact assessment on EDF's proposal (UoS Mod 21)

Please find attached in response to your consultation document some comments and analysis regarding EDF's proposal on UoS charges for their SPN network. As you will be aware I have been providing consultancy to Scottish & Southern Energy, part of the G3 group, but I would like to stress that the views expressed are my own and may well not be shared by SSE or the other members of G3.

The views expressed are fairly general, largely concerning the methodologies involved. There is not sufficient detail in the EDF proposal or OFGEM's consultation document to validate any of the details of the power flow modelling, the charging calculations or the setting of the tariffs.

In interpreting the OFGEM document I have assumed that where OFGEM refer to £/MVA on the charts and the parallel text in Schedules 1 and 3, that the units should read £k/MVA or £/kVA. Since there is a difference of a factor of 1000, I am fairly certain this is what was intended. If I should be wrong then there would be other concerns which I would wish to raise regarding the proposal.

If you should wish clarification on any of the points raised, then please get in touch with me.

Yours sincerely

Robin Hodgkins

Application of a power flow scaling factor

EDF introduce a power flow scaling factor in order to reduce the very high charge rates calculated by the LRIC algorithm at low growth rates and high utilizations. EDF already experience low growth rates (OFGEM table 2) and have assets with high utilisation (OFGEM figure 6). Therefore the use of the raw LRIC algorithm would lead to excessive EHV locational charges at some nodes and, after scaling to allowed revenue as proposed by EDF, lead to negative charges for some EHV customers (OFGEM figure 5). Growth rates are likely to reduce further in the future thus exacerbating this problem. The LRIC algorithm also results in gross under charging at high growth rates, although none of EDF's growth rates currently fall into this category.

These features of the LRIC algorithm were recognised more than two years ago. As a result WPD used a single growth rate of 1%, thus avoiding the perverse variation with growth rate at high utilisations (OFGEM figure 3). G3 (SP, SSE, and CN) have proposed an empirical method. UU have proposed a method largely based on ICRP (with a homoeopathic dose of LRIC!) and now EDF propose power flow scaling.

An examination of the LRIC algorithm using infinitesimal increments (which numerically gives results almost identical to 1 kVA increments) shows that the charge rate tends to infinity at high utilisations as the growth rate tends to zero. Thus the anomalous and unacceptable results of LRIC are not some quirk of the method but arise from a flaw, or flaws, in its derivation.

One fundamental flaw in the derivation of the LRIC algorithm is the use of a fixed annuity period to convert the incremental costs in £/kVA into £/kVA p.a. The incremental cost represents the NPV change in the future cost of reinforcement due to an increment of load. The future cost of reinforcement is the purchase cost (plus any additional costs) of the asset to be reinforced. When a customer purchases a plasma TV over 3 years, or a car over 5 years, or a house over 25 years, the annual cost is based on the payment period. It is not based on the 7 year lifetime of the TV, or the 10 year lifetime of the car, or the 100 year lifetime of the house. Yet the proposed LRIC algorithm derives the annual charge by applying a constant annuity factor based on a 40 year asset lifetime, independently of the payment period. The payment period, often termed the cost recovery period, depends on the growth rate. Consider the case where the demand doubles each year, so one year after a first reinforcement a second reinforcement will be required. Only one payment will ever be made but LRIC applies an annuity factor of 7.4%. A gross undercharging at this high growth rate, not available to customers purchasing their TV, car, or house in the normal financial market.

This fundamental flaw in the derivation implies that any economic arguments for the applicability of LRIC are invalidated, not only at high and low growth rates, but at all growth rates since there is no a priori argument for asserting validity at any growth rate, although at some intermediate, but unknown, value between high and low growth rates, depending on utilisation, the value would correspond to a valid theory. This implies that simply applying a fix to that part of the results which are evidently in error does not provide any logical basis for asserting the charge rates are valid over any other part of the range. Therefore any modified method needs independent validation.

In order to investigate this, the EDF method for the various scaling factors is compared against ICRP and LRIC Corrected as bench marks. ICRP can be regarded as giving a very long term charge rate. If the asset is many years away from requiring reinforcement, then the charge rate would be substantially less than the ICRP rate and when the time to reinforcement becomes small, then the charge rate would be expected to exceed the ICRP rate. LRIC Corrected implements the LRIC method by applying a variable annuity rate depending on the cost recovery period in order to remedy the fundamental flaw in LRIC. A derivation of this is given in the appendix 'Incremental Methods'. It is not claimed that this is a unique way of deriving a correct implementation of LRIC, but it does remedy this particular flaw and also matches the G3 empirical method in its functional form.

In order to simplify the comparison, the results have been normalised by setting the factor d (A/C) to unity, where d is the discount rate, A is the reinforcement cost, and C is both the capacity at which reinforcement is required and the capacity of the additional asset. An annual discount rate of 6.9% has been used and an annuity period of 40 years used for ICRP and for LRIC.

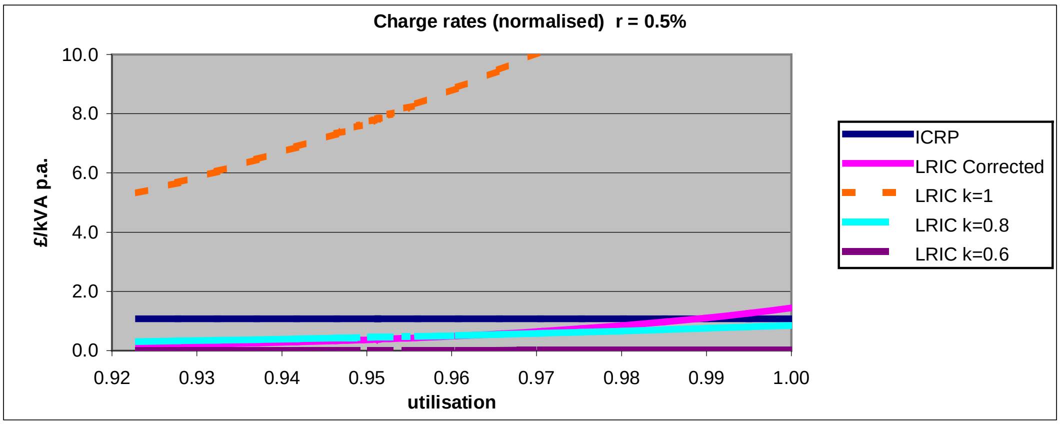
The following charts plot the normalised charge rate in £/kVA p.a. against the utilisation at various growth rates over the range declared by EDF. First consider the variation with growth rate and between methods as the utilisation approaches 100%. It is evident that at a growth rate of 0.5% or lower, the charge rate is reduced by the 0.6 scaling factor to a negligible value, tending to about 2% of the ICRP value. However, applying the 0.8 scaling factor gives about 85% of the ICRP value. The LRIC value (1.0 scaling factor) tends to about 16 times the ICRP value, with even larger ratios for lower growth rates, which is clearly erroneous and unacceptable.

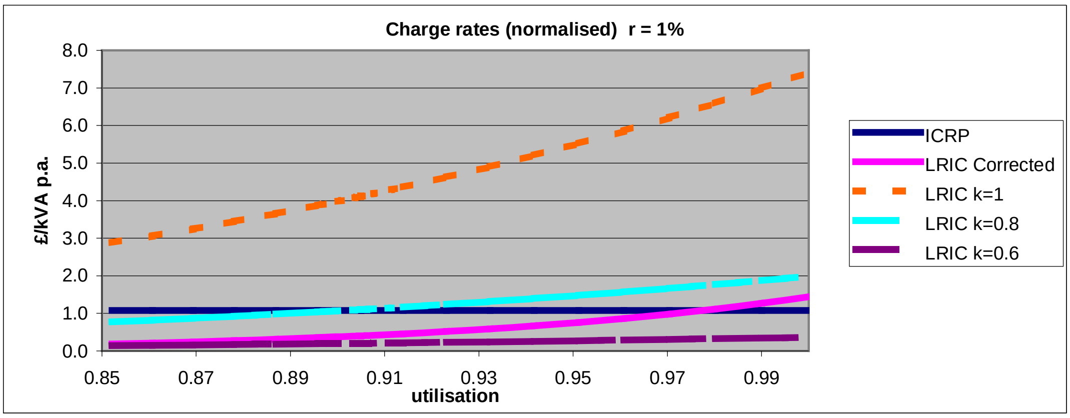
At a growth rate of 1% the damping effect of the 0.6 scaling factor is considerably reduced, giving rates about one third of the ICRP rate; the 0.8% scaling gives about 200% of the ICRP value and exceeds that of LRIC Corrected. By 2% growth rate the result from the 0.6 scaling factor now roughly equals ICRP whilst the 0.8 scaling factor remains at about 200% of the ICRP value. By 4% the excessive charge rates levied by the unscaled LRIC have reduced and all methods give somewhat similar results.

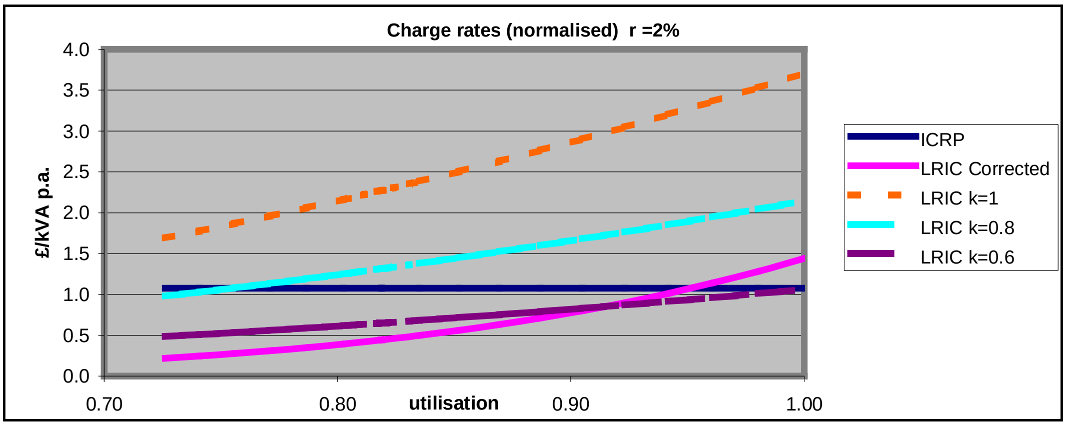
A feature, most readily seen on the chart for 4% growth rate, but present to a lesser extent at all growth rates, is that the ratio of the charge rates at the lowest utilisations plotted (corresponding to 16 years prior to reinforcement) to those at 100% utilisation are high, ranging from 36% at a growth rate of 0.5% to 63% at a growth rate of 4%. This implies that potential reinforcements 16 years or more distant still give rise to relatively high charge rates compared with those when reinforcement is imminent. Indeed the value of the charges recovered at say 30 years prior to reinforcement is equal in value by the time of reinforcement to the charges recovered in the final year. In contrast, LRIC Corrected shows a much more substantial variation with utilisation or with the number of years to reinforcement.

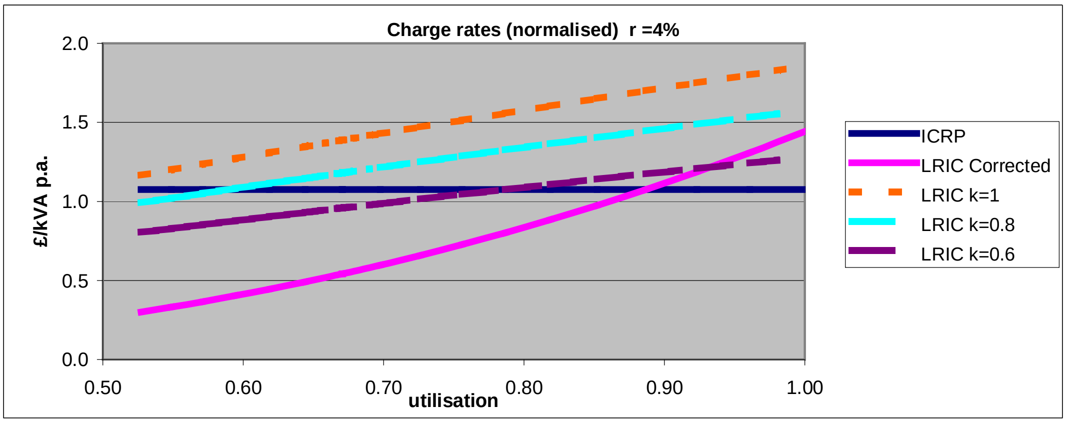
From the foregoing the following conclusions are reached:

- LRIC (unscaled) is erroneous and should on no account be used in its present form.
- The use of the 0.6 scaling factor reduces the charge rate by too great an extent at low growth rates (~0.5%) which occur in EDF networks.
- A scaling factor of 0.8 matches more closely the bench mark comparisons of ICRP and LRIC corrected.
- The variation of charge rate with utilisation (or time to reinforcement) is too small and gives undue weight to reinforcements well into the future.
- There is no logical basis or justification for the scaling of LRIC proposed by EDF.


Charge rates (normalised) r = 0.5%
£/kVA p.a.
10.0
8.0
6.0
4.0
2.0
0.0
0.92
0.93
0.94
0.95
0.96
0.97
0.98
0.99
1.00
utilisation
ICRP
LRIC Corrected
LRIC k=1
LRIC k=0.8
LRIC k=0.6


Charge rates (normalised) r = 1%
£/kVA p.a.
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.85
0.87
0.89
0.91
0.93
0.95
0.97
0.99
utilisation
ICRP
LRIC Corrected
LRIC k=1
LRIC k=0.8
LRIC k=0.6


Charge rates (normalised) r =2%
£/kVA p.a.
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.70
0.80
utilisation
0.90
1.00
ICRP
LRIC Corrected
LRIC k=1
LRIC k=0.8
LRIC k=0.6


Charge rates (normalised) r =4%
£/kVA p.a.
2.0
1.5
1.0
0.5
0.0
0.50
0.60
0.70
utilisation
0.80
0.90
1.00
ICRP
LRIC Corrected
LRIC k=1
LRIC k=0.8
LRIC k=0.6

A number of other factors need to be borne in mind:

- Growth rates are not known well into the future. The long term trend over the last few decades has been for the average growth rate to decline and this trend could be expected to continue due to higher prices, energy savings, and user own generation. Locational high growth rates very often decline within 5 or 10 years and extrapolation is likely to be unwarranted.
- There will always be cases where the nominal capacity has already been reached or exceeded. This is partly because companies do not wish to unnecessarily reinforce networks. Therefore steps, such as back feeding, may be taken (but not included in the analysis software) to manage networks without reinforcement. In other cases reinforcements are planned and either have not been completed or the software not yet updated. EDF scale according to the maximum utilisation. If this is greater than 100% then this can reduce the charge rates for assets at 100% utilisation. Furthermore if the maximum utilisation were to be incorrect, due to a data error or other factors, this would be unwarranted. A safer method would be to assign a 100% utilisation to all items nominally experiencing greater than 100% utilisation.
- Assuming that in carrying out the power flow analysis the base network is not updated with each reinforcement, then whenever further reinforcements are required these could be substantially incorrect and yet, given EDF's proposed charging algorithm, cause substantial increases to the charge rates.
- OFGEM express their concern that scaling dilutes incremental cost signals and alters their relativity. This assumes that the unscaled LRIC gives rise to correct cost signals. This is untrue. Incremental cost signals do decrease as the scaling factor decreases but correct values are not given by LRIC. However, the relativity should improve with scaling as the perverse variation of charge rate with growth rate exhibited by LRIC is dampened.
- It appears that a main reason why EDF choose the scaling factor of 0.6 is to avoid negative EHV charge rates at some nodes which would be required to balance high EHV marginal charge rates at other nodes if higher values of the scaling parameter were to be used (OFGEM figure 5). This presumably arises because EDF have split the *total* demand allowed revenue between voltage levels. This is undesirable and unwarranted. A preferable approach is to split the *residual* allowed revenue (after all other costs have been included) between voltage levels. It is this residual amount that is allowed by OFGEM to provide a rate of return and pay interest on investments. A proxy for this split is the asset investment at each voltage level. With this latter approach the problem of negative charges would not arise until the residual allowed revenue reduces to zero.
- In this context it is not clear whether EDF split allowed revenue between EHV and HV/LV or whether it is split between 132kV, 33kV, etc. The latter approach minimises cross-subsidies.

Zonal and nodal analysis

EDF propose using an AC nodal analysis with average growth rates for each zone. In principle a full nodal analysis should be capable of identifying the effects of incremental changes in loads at each load point. However, this is not what EDF propose. The proposal states that the requirements for reinforcement are determined from the appropriate N-1 and N-2 contingency analysis using AC load flows based on average load growths for the network being analysed. However, the sensitivity analysis is carried out only for the load flow under normal operating conditions. This would appear to nullify the potential advantages of the full nodal analysis. No studies are quoted to indicate that the results from this method are any better (in the sense of corresponding to the case where the sensitivity analysis is carried out for each contingency case) than treating all the loads as having the same sensitivity coefficients. Consider the following highly simplified case consisting of three identical branches with two identical loads supplied from supply points at either end of the line.

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S1 |------------------ L1 ---------------- L2 ------------------| S2
        B1                         B2                B3
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Under normal operating conditions the load in Branch 1 is L1, the load in B2 is zero, and the load in B3 is L2. Under contingency 1, loss of either S1 or B1, the load in B2 is L1 and the load in B3 is L1 + L2. The other critical contingency condition is loss of S2 or B3 when the load in B1 is now L1 + L2 and the load in B2 is L2. It is easy to see that the sensitivity coefficients for both contingency conditions are the same for both load points. However, the sensitivity coefficients derived from the single normal load flow would assign a zero sensitivity factor to L2 for contingency 1 and a zero sensitivity factor to L1 for contingency 2. In this case assigning the same sensitivity factor to both load points is the correct treatment.

It is easy of course to produce counter examples, especially if reinforcements are required on T branches. However, the simpler analysis would seem to be generally more applicable to supply point reinforcements. A full nodal analysis would of course require substantial additional computation, cause potential additional volatility, and maybe render the validation of the results unmanageable.

Given the unsupported validity of the sensitivity coefficients, the future unpredictability of nodal growth rates, and potential volatility of the analysis, it seems reasonable to use zonal growth rates which would be expected to reduce volatility and show somewhat better predictability.

Size of increment

Ideally where results can be expressed analytically, as for LRIC, it is desirable to use an infinitesimal increment thus using differentiation rather than an arbitrary finite increment. The results would correspond to the 1 kVA increment for the level of demands and generation analysed. If a discrete increment is to be used then the natural choice would be the expected increment in demand in the next year, since it is annual charges that are being derived. A fixed increment of say 1 MVA would not be sensible for a 2 MVA transformer. However, the AC power flow modelling cannot be expressed analytically. In this case the smallest increment should be used which gives stable results. In some cases the effect of a small increment, such as 1 kVA may be swamped by rounding errors or small perturbations of the AC flow and a significantly larger increment may be required.

The use of an infinitesimal or small increment implies that the same result can be used when calculating generator benefits resulting from offsetting demand. However, EDF do not calculate generator reinforcement costs as fault levels (and reverse power calculations?) are not included. If these were included (as planned in the future) then it needs to be recognised that demand and generation are inherently unsymmetrical. The largest proportion of the increase in demand at EHV is due to relatively gradual increases in demand at lower voltage levels. However, increases in generation at lower voltage levels have little effect on fault levels at higher voltages due to the intervening impedance of the network and transformers. Therefore it is only the impact of discrete larger generators at EHV which need to be considered. A further issue is that even when there is zero generation the fault level capacity could already be exhausted; thus algorithms such as LRIC Corrected are not directly applicable.

Cost drivers

Fault levels would be expected to be the largest source of reinforcement costs when evaluating EHV charges for generation. However, as described above, new methodologies need to be developed to assign charge rates. Furthermore, the generation community believes that such charges discourage generation and that DNOs should be proactive in improving networks. At present OFGEM do not make allowance for this. This issue needs to be reviewed urgently with government, generators, and DNOs prior to the next price review.

Revenue reconciliation

No arguments are put forward for the proposed split of allowed revenue between voltage levels regardless of required reinforcement cost and other costs attributable to each voltage level. It would be desirable rather to split the residual allowed revenue thus not limiting actual or forward looking costs. It would be hoped that OFGEM would review or remove the split between Demand and Generation allowed revenue at the next Price Review.

Transparency and Predictability

The proposed method is not only complex in concept but depends upon detailed complex analysis. As described earlier no studies appear to have been carried out to support the accuracy of the method and with this level of complexity there will almost certainly be data errors and analysis errors which will be extremely difficult to detect and remove. The level of information provided in the OFGEM document and the EDF proposal do not provide enough information for any actual values to be checked. Some thought needs to be given as to the information to be provided to customers to enable them to satisfy themselves as to the accuracy and fairness of the method. EDF have expressed themselves to be wary of 'paralysis by analysis'. Maybe the tipping point has been passed.

Appendix - Incremental Methods

Several approaches could be adopted to setting the demand charge rates. The 'pure' incremental approach sets a zero charge whenever the spare capacity is sufficient to accommodate the estimated increment in future demand. If the charge rate is continuously reset in time then this sets a zero charge until the spare capacity reduces to zero. If charge rates are set annually then a zero charge is set until the year is reached when there is insufficient capacity to accommodate that years estimated growth in demand.

Once the demand reaches capacity then charges are applied. In a monopoly situation a utility needs to recover the cost of the required reinforcement. The charge now set is that just sufficient to reduce the underlying growth in demand to the available capacity. As the underlying demand grows further, then the charge rate is correspondingly increased. The revenue is nominally invested at the discount rate and this process continues until such time as the value of the accumulated revenue is sufficient to pay for the required reinforcement.

This model assumes knowledge of the price reflectivity. This could be very low as the EHV demand on some network groups may be only a small proportion, or even zero, of the total demand. Furthermore, the reinforcement charge rate is only a proportion of the total DUoS charge rate and changes in energy costs will interfere with the cost message. In principle if the price reflectivity is zero, then, assuming charges are set annually, the charge rate in the reinforcement year recovers all the reinforcement cost in that one year.

Not only could this give rise to very large charge rates, it fails to give advance notice of the impending need for reinforcement. This is an inevitable consequence of the 'pure' incremental approach when faced with 'capital indivisibility'. However, an important aim of introducing an improved methodology is not only to encourage growth in demand to take place where it can be accommodated without further investment, but, perhaps more importantly, to encourage generation to locate where increases in demand would otherwise require reinforcement to take place. These factors indicate that some level of advance signalling is required.

In determining the time period over which advance signalling is appropriate several factors need to be taken into account. The LTDS produced by each DNO currently forecasts demand for 5 years ahead. Given the time required for potential generators to consider their options, draw up plans, gain planning permission, and implement the schemes, this is considered a somewhat inadequate time scale for future planning. On the other hand, forecasts in demand become increasingly inaccurate as they are extrapolated into the future (long term forecasts, assuming current energy savings measures are effective and embedded generation, particularly at LV grows as targeted, suggest an average zero growth in demand beyond about 10 years). Furthermore, whilst the initial reinforcement resulting from growth in demand can be forecast with some confidence, subsequent reinforcements depend quite sensitively upon the order and nature of earlier reinforcements (planning engineers may increase the magnitude of an earlier scheme to avoid the necessity of some future reinforcements). Therefore basing charge rates on forecast growth and reinforcements a long time into the future could introduce very substantial errors and consequent inefficient investment decisions. G3 have proposed a time period of 10 years as it is believed that this gives adequate time for planning without incurring too large errors in demand forecasts and reinforcement schemes.

There is no unique way of modifying the 'pure' incremental approach to set charge rates in advance of the reinforcement being required. The empirical approach simply selects an appropriate formula based on the reinforcement cost, utilisation and growth rate to match the desired behaviour. An alternative adopted here is to apply a financial approach based on Net Present Value.

Let the growth rate of the demand, D kVA, be denoted by r per annum. Then, if C kVA is the capacity at which reinforcement is required, the demand at time t years prior to the capacity being reached is given by:

$$D(t) = C \exp(-r\,t) \text{ kVA}$$

The Present Value, PV, of reinforcing the asset, cost £A, at an annual discount rate of i is:

$$PV = £\, A \exp(-i\,t)$$

The effect of a small change in D at time t is given by:

$$\mathrm{d}(PV)/\mathrm{d}D = A\, \mathrm{d}(\exp(-i\,t))/\mathrm{d}D = A\, \mathrm{d}((D/C)^{i/r})/\mathrm{d}D = i\,(A/C)\,(D/C)^{i/r-1}/r \text{ £/kVA}$$

This is the analytical form[1] of the standard formula for the LRIC marginal cost of individual asset reinforcements. It can be expressed in terms of time rather than demand:

$$\mathrm{d}(PV)/\mathrm{d}D = i\,(A/C) \exp(-i\,t) \exp(r\,t)/r \text{ £/kVA}$$

Note that the units are £/kVA and in order to determine an annual rate an additional factor needs to be introduced. Applying an annuity factor based on the lifetime of the asset is incorrect, since such a value is based on the rental rate or mortgage rate assuming that constant payments can be collected over the lifetime of the asset. Here the payments are not constant and will only be paid over the cost recovery period from the time when the previous reinforcement was carried out until the time of the next reinforcement. The factor therefore needs to be based on the cost recovery period, not on the asset lifetime. Moreover, in keeping with the concept of NPV, it is more appropriate to use repayments which contribute equal amounts to the final total rather than equal instalments. Thus, denoting the cost recovery period by T years, the annuity factor is chosen to be:

$$\exp(-it)/T$$

Denoting the initial demand by D_0:

$$\begin{aligned} \textit{charge rate} &= i\,(A/C) \exp(-2i\,t) \exp(r\,t)/rT \\ &= i\,(A/C)\,(D/C)^{2i/r-1}/\mathrm{Log}(C/D_0) \quad \text{£/kVA p.a.} \end{aligned}$$

If the additional reinforcement is assumed to double the capacity then the initial demand can be taken to be half the capacity and the numerical value of the denominator gives a multiplying factor of 1.44.

[1] EDF investigate the effect of using increments of 1 MVA and 1 kVA. Here the increment is infinitesimal. Using large increments and time steps of one year causes some differences in the actual values but doesn't change the overall behaviour of the results.