IMPACT ON NETWORK LOSSES OF SHORTER LOW-VOLTAGE FEEDERS AND HIGHER TRANSFORMER DENSITY

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ABSTRACT

This paper summarises results from a simulation based study of the impact of shorter Low-Voltage (LV) feeders and higher transformer density, on distribution network electrical losses and the economic justification for such an approach. This is a part of a loss-inclusive policy approach by Western Power Distribution (WPD) to network losses. The paper further shows how the latest loss-inclusive network design policies adopted by the GB DNOs have led to more efficient LV network designs.

INTRODUCTION

During the current electricity regulatory price control period (2015-2023) in Great Britain (GB), Distribution Network Operators (DNOs) and Independent Distribution Network Operators (iDNOs) are giving considerable attention to the management of electrical distribution network losses [1]. Much progress has already been made in the concept of "loss inclusive network design" [2]. A loss inclusive design for a proposed network accounts for consideration of energy efficiency in addition to the more frequently used technical factors such as reliability, safety, quality of supply.

With existing electrical network design and operation, the highest concentration of electrical loss is typically found in the secondary or LV networks, which comprise secondary HV/LV transformers, LV feeders, and service cables.

The study has taken into account practical issues arising from any policy change arising. DNO design engineers and project managers were involved to confirm that the results are technically, economically and practically feasible.

NETWORK DESIGNS AND MODELLING

The following three network designs were considered and investigated as part of this study: (1) the "Business as Usual" (BAU) design based on the existing policy that does not account for losses-inclusive aspect fully, (2) alternative positioning of the existing transformer, and (3) the deployment of additional secondary transformers. Designs (2) and (3) are referred here as "Investigated Designs" (InvDes).

Four LV BAU electrical networks (labelled Site 1 to 4) within WPD licensed areas were selected and studied in detail. These were selected to represent typical LV network schemes involving a mix of domestic and small commercial/industrial customers. The study made use of models developed in DIgSILENT PowerFactory network analysis software. The modelled electrical networks reflected WPD's latest design standards of minimum LV cable size of 185 mm^2 and transformer specification based on based on EU Eco-Design Directive (EDD) Tier 1. Each model was studied using a one year loading dataset derived from standard Elexon annual half-hour mean load profile values (i.e. 17,520 values per profile per year)[3]. Elexon Profile 1 was applied to domestic loads, and Profile 3 for non-domestic loads. These profiles were normalised and scaled to match each customer's annual demand values. The load power factors were assumed to be 0.99 lagging (import) for domestic loads and 0.92 lagging for non-domestic loads.

Time dependent load flow simulations were performed for each network and accrued annual total electrical losses and their breakdown by network equipment, i.e. feeders and transformers, were calculated. Sensitivity analyses were conducted to assess the impact of using lower-loss transformers and separately to assess the impact of significantly increased load demand which may arise if electricity displaces other energy sources. The impact of phase imbalance was also examined.

COST-BENEFIT ANALYSIS

The UK's Office of Gas and Electricity Markets (Ofgem) has developed a Cost-Benefit Analysis (CBA) Spreadsheet for the use by the DNOs during the 2015-2023 price control period [4]. This Spreadsheet generates a Net Present Value (NPV) for optional network project proposals, using a period of 45 years and 3.5% test discount rate for valuation of the losses avoided during the period for first 30 years and 3% for the remaining 15 years. Losses evaluation includes UK Department of Energy & Climate Change's (DECC) traded carbon values and takes into account the forecast reduction in electricity Greenhouse Gas (GHG) conversion factors over the assessment period. All fixed data remains as directed by Ofgem during the RIIO-ED1 Strategy Development and Business Plan Review processes. The studies undertaken were evaluated using this CBA Spreadsheet for the purpose of economic justification evaluation of the various network designs and approaches.

The loads, and consequently losses, in each network study were assumed to be fixed over the CBA study period (i.e. 45 years). Simple sensitivity analyses undertaken as mentioned above provided an indication of the impact of change in network loading, losses, and their related costs on the overall economics of each investigated network design.

Where an alternative network configuration results in a reduction in losses, corresponding NPV was compared against the base case. The NPV calculation have accounted for costs related to extension of the High-Voltage (HV) network in order to relocate the transformer, additional switchgear at the new substation and only a small reduction in LV feeder costs (this is because the LV feeders will still require to connect to all new services).

The cost of a generic HV extension and additional substation has been estimated at about £34,000 using typical UK labour and materials cost data. This includes 500 kVA ground-mounted transformer, HV switchgear, LV cabinet, Glass Reinforced Plastic (GRP) housing, earthing, plant delivery and two HV straight joints. This is considered to be a minimum scheme that would enable a reduction in LV feeder length by approximately 100 metres. The avoided cost of 100 m of LV 185 mm^2 cable installed in the footpath or roadway was assumed at £10,000. As a result the net societal cost of a reduction in LV feeder length approximates to a minimum of £24,000. These costs are expected to increase for many schemes where there will be a need for longer HV cable lengths due to physical constraints. With many schemes involving new domestic housing developments, the cost savings associated with any reduction in LV feeder lengths may improve due to the lower cost of installing LV feeders in unmade trenches, i.e. not involving top surface removal or reinstatement.

STUDY METHODOLOGY

Traditionally, networks have been designed to meet technical criteria of safety, current carrying capacity, volt drop, fault level and power quality (e.g. harmonics) together with practical issues relating to the physical site and local planning obligations. The addition of evaluated lifetime costs, including losses, in scheme appraisals may justify higher capital cost 'loss-inclusive' schemes. Accordingly, the study has considered four development sites (Sites 1 to 4), five case studies (as listed and detailed below) testing for sensitivity of the loss calculations, up to four network configurations, i.e. BAU, and three forms of Investigated Designs; these add to a total of 19 analyses with variables as detailed in Table 1 and Table 2.

1. Base Case: EDD Tier 1 transformer specification, BAU design loadings and no additional phase imbalance.
2. Lower loss transformers: EDD Tier 1 transformer specification, BAU design loadings and no phase imbalance.
3. Increased network load: EDD Tier 1 transformer specification; demand increased to 2 or 3 times normal load considered in Case 1, limited by selected transformer rating in Case 1; and no additional phase imbalance.
4. Increased network load: EDD Tier 2 transformer specification; demand increased to 2 or 3 times normal load considered in Case 1, limited by selected transformer rating in Case 1; and no additional phase imbalance.
5. Additional phase imbalance of about 30%.

The study used the CBA Spreadsheet mentioned earlier to compare the loss savings Net-Present Value (NPV) with any increase in network Capex and consequential increased losses on the HV network if it was required to be extended. Each NPV was calculated over an assumed lifetime of 45 years.

Table 1 – Considered Sensitivity Analyses Variables

Study #	Site #	Case #	EDD Tier #	Model. Load to BAU Load Ratio	Additional Imbalance?
1	1	1	1	1	No
2	2	1	1	1	No
3	3	1	1	1	No
4	4	1	1	1	No
5	1	2	2	1	No
6	2	2	2	1	No
7	3	2	2	1	No
8	4	2	2	1	No
9	1	3	1	2	No
10	2	3	1	3	No
11	3	3	1	3	No
12	4	3	1	2	No
13	1	4	2	2	No
14	2	4	2	3	No
15	3	4	2	3	No
16	4	4	2	2	No
17	1	5	1	1	Yes
18	2	5	1	1	Yes
19	3	5	1	1	Yes

Table 2 – Considered Transformer Sizes

Study #	Site #	Case #	Transformer Sizes [kVA]			
			Single Transformer		Two Transformers	
			BAU Design	InvDes 1	InvDes 2	InvDes 3
1	1	1	800	-	800 & 315	315 & 315
2	2	1	500	500	315 & 315	-
3	3	1	315	315	315 & 315	-
4	4	1	500	-	315 & 315	500 & 500
5	1	2	800	-	800 & 315	315 & 315
6	2	2	500	500	315 & 315	-
7	3	2	315	315	315 & 315	-
8	4	2	500	-	315 & 315	500 & 500
9	1	3	800	-	800 & 500	-
10	2	3	500	500	-	-
11	3	3	315	315	-	-
12	4	3	500	-	315 & 315	-
13	1	4	800	-	800 & 500	-
14	2	4	500	500	-	-
15	3	4	315	315	-	-
16	4	4	500	-	315 & 315	-
17	1	5	800	-	315 & 315	-
18	2	5	500	500	-	-
19	3	5	315	315	-	-

RESULTS AND DISCUSSION

Electrical Technical Losses

Annual losses for each study set, i.e. 1 to 19, are summarised in Table 3, highlighting the reduction (green) or increase (red) in losses compared with the BAU design.

It was observed in Case 1 that significant reduction in overall losses (mostly feeder losses) can be achieved when proposed transformer and its electrical connections can be relocated close to the centre of feeder load concentration (Investigated Design 1). However, in some studies, the reduction in feeder losses was outweighed by the increase in transformer losses.

Table 3 – Summary of Results

Study #	Site #	Case #	Annual Losses [MWh]			
			Single Transf.		Two Transformers	
			BAU Design	InvDes 1	InvDes 2	InvDes 3
1	1	1	20.2	-	22.2	21.3
2	2	1	7.6	5.5	-	7.5
3	3	1	6.0	3.8	0	6.9
4	4	1	16.6	14.5	-	15.9
5	1	2	18.2	-	19.6	18.5
6	2	2	7.0	4.9	-	6.8
7	3	2	5.6	3.4	-	6.2
8	4	2	15.2	13.1	-	14.5
9	1	3	63.4	-	54.2	-
10	*2*	*3*	32.9	13.8	-	-
11	*3*	*3*	28.9	9.2	-	-
12	*4*	*3*	52.8	39.1	-	-
13	1	4	57.2	-	48.8	-
14	*2*	*4*	31.1	11.9	-	-
15	*3*	*4*	27.4	7.7	-	-
16	*4*	*4*	48.7	35.3	-	-
17	1	5	20.2	-	-	21.4
18	2	5	8.0	5.6	-	-
19	3	5	6.3	3.9	-	-

As a general trend, it was observed that transformer no-load (or iron) losses make up a significant portion of site losses compared to transformer load losses and feeder losses. For this reason, increasing transformer density may not be a suitable solution to reduce overall LV network losses, especially when LV feeder load factors are low. However, where annual load factors are high, increasing transformer density may help reduce overall losses; higher load factors may be a consequence of continuing reliance on electricity to deliver low carbon energy to homes, electric vehicles and other consumers.

From Case 2, when EDD Tier 2 transformers are modelled, there is an overall annual loss saving between 4% and 10% (with average around 8%). The loss savings are similar (between 2% and 10%, and with average around 6%) when feeder load is increased twofold or threefold and the Tier 2 transformer specification is used.

From Case 3 and Case 4, where an increase in demand of 2 or 3 times is modelled, there are significant feeder loss savings. This result confirms the sensitivity of loss saving potential to future LV load growth.

If future domestic electricity demands increase by between two and three times, the studies show that specifying shorter feeders will better accommodate the increase in demand with the opportunity for a reduction in LV losses as a percentage of total energy supplied, compared with BAU. The networks studies indicate that feeder length reduction may result in a positive business case when annual demand increases about threefold compared with existing demand estimates.

From Case 5, phase imbalance increased annual losses as shown in Table 3. These results were found to be highly variable, reflecting the diversity of network conditions built into the BAU designs.

Cost-Benefit Analysis Studies

To assess the viability of a change of policy, it is proposed that there should be two “hurdle rates” to be met, where the lifetime value of avoided loss with a “loss inclusive option” exceeds the additional costs of shortening the feeders. Based on an estimated costs of £34,000 for a second transformer (Investigated Designs nos. 2 or 3) and £10,000 for an optional single transformer installation at an alternative location (Investigated Design no. 1), it is estimated to require an estimated annual loss saving “hurdle-rate” of 23.4 MWh and 6.9 MWh respectively.

Table 3 also shows (highlighted using blue font and indented text in Columns 2 and 3) sites (2, 3, and 4) and cases (3 and 4) with annual losses exceeding the considered hurdle rate. It is important to note that, although none of the Investigated Designs 2 or 3 meet the hurdle-rate, it is expected that there will be sites at which the hurdle-rate would be exceeded with load multipliers as high as 3 times. This is an opinion based on experience, rather than specific analysis.

Policy Implications

WPD’s earlier loss-reduction policy includes standardising on larger cross-sectional area LV feeders. For this reason, the loss savings that may be expected from shorter LV feeders and increased transformer density do not generally outweigh the costs involved.

The deployment of transformers that comply with EDD Tier 2 limits will not make a significant change to the benefits available through reducing feeder length. Any reduction in maximum LV feeder lengths will deliver a small loss-saving benefit. As a consequence, a policy of encouraging the optimisation of transformer location, so far as is practicable, may be justified. A loss-inclusive network design policy will also highlight the need for additional transformers earlier than would be required under more traditional approaches to network design.

Domestic electric vehicle charging and the migration to electricity for decarbonisation of energy consumption may cause significant increases in future demands [5]. This study has indicated that under increased loading conditions there is potential to develop a more energy efficient LV network by optimising substation locations or installing an additional transformer. A loss-inclusive network design policy will highlight the need for additional transformers earlier than would occur under more traditional approaches to network design, i.e. reinforcement where network loadings exceed ratings or voltages are outside acceptable limits.

LV network load forecasting will always involve external factors, or errors. Examples of these errors include the single-phase connection/imbalance and unknown changes in the range of domestic appliances in use. The difference between 'as planned' and 'as built' network performance may be important to consider further and may assist with any loss-saving policy.

CONCLUSIONS AND RECOMMENDATIONS

The study concluded that a policy of reducing losses by shortening feeders alone may not be a compelling proposition; this is in part due to earlier changes to WPD's LV design policy including standardising on 185mm^2 LV cables instead of 95mm^2.

There is some evidence that with a two- to three-fold increase in network load, a more optimal positioning of existing secondary substation transformer, and in some cases even introducing an additional transformer, would be more energy efficient and economically justifiable over a design lifetime of 45 years. Principal recommendations drawn from the study are listed as following:

- As loss estimates are critically dependent on assumed profiles and annual consumption, the subject is likely to justify greater attention to be given to understanding present and future customers' demands.
- There will be occasions when options on alternative network configurations with shorter feeders should be explored to achieve a loss-inclusive network design. A change programme may be required and a four-point strategy for delivery was recommended.
- The appropriate remedial actions and design assumptions made when considering phase imbalance should be included in any review of LV network planning tools.
- The data, systems and processes supporting the loss-inclusive LV network design function should be defined and developed within the overall Distribution Business' approach to "Smart Grid" management of the network.

REFERENCES

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