INNOVATIVE APPROACHES TO IDENTIFICATION AND REDUCTION OF DISTRIBUTION NETWORK LOSSES

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ABSTRACT

Electrical networks are subject to losses, both technical and non-technical, where a proportion of the energy entering a network is not delivered to customers. On distribution networks these losses can often account for a material proportion of the energy entering the system and there are significant consumer costs associated with this due to increased system generation requirements. The UK energy regulator Ofgem has put in place a number of mandatory and incentive based mechanisms to encourage Distribution Network Operators (DNOs) to better understand and manage the losses on their networks. The following study was delivered as part of the work that Scottish and Southern Energy Power Distribution (SSEPD) have carried out for the SSEPD's Losses Strategy.

INTRODUCTION

Every system encounters losses. In the electricity supply system, these losses are for the most part a result of heat and noise generated through operation of equipment. These are known as technical losses. There is also a small amount of energy that is unaccounted for in that it is not fully recorded or, in some instances, stolen. These are known as non-technical losses. On distribution networks these losses can often account for around 6% of the energy entering the system and there are significant costs associated with this. The paper is focused on the technical losses and how they can be identified and reduced based on measured data and power systems modelling in IPSA2 [1].

The purpose of the project [2] presented in this paper was to develop a methodology to identify the losses in the LV network with limited data available and propose interventions in order to improve the overall efficiency of the distribution of power across Scottish & Southern Electricity Networks (SSEN) and reduce the respective cost (6%) to the customers.

QUANTIFICATION OF LOSSES

A review of other studies and their findings regarding losses in the LV network was undertaken. The outcome of this exercise showed that the technical losses are primarily caused by: loss in the conductors (I^2R); load phase imbalance; and power factor. Other causes that account for rest of the losses are: high harmonic distortion, high/low terminal voltage (depending on the load mix). These aspects were explored further in this study methodology.

Data availability

From SSEN New Thames Vision Project, it was provided one year of 10 minute from the average current and voltage data for 316 LV substations clustered within a specific network are of their southern distribution licence area for the purpose of analysing the losses at LV. The data was available for particular points in the network as described in Figure 1. The LV feeders were fully monitored including all three phases along with the substation and the 11 kV side of the primary substation (33/11kV). Also, the number of customers and type was made available for the LV substations. As not all LV substations were monitored along a single HV feeder, it was not possible to calculate HV feeder losses based on current data.

SSEN provided LV network power system data including circuit and transformer specifications to enable production of a power system model in the software IPSA2. This model was used to support verification of losses, apply interventions and estimate the reduction in losses after these interventions and test its cost effectiveness.

Customer load profile

The data available contained the annual 10 minute demand per LV feeder and secondary substation and the number of customers connected to that feeder. In order to be able to analyse LV feeder losses, the total LV feeder demand and the total demand based on all connected customers can be compared at each measurement point. A representative customer load profile is required for this purpose. SSEN provided 'End Point Monitoring' data for 254 customers that allowed validation of generic customer load profiles such as that shown in Figure 2, based on Customer Led Network revolution (CLNR) innovation project [3].

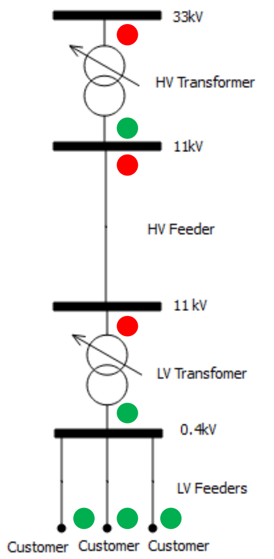

Figure 1 – Availability of Measurement Data for Loss Calculations

Loss calculation

To calculate the losses on the LV network i.e. along the LV feeder from the secondary substation to the customers, the following data was used:

- The secondary substation LV feeder monitoring data;
- The customer numbers; and
- Generic customer demand profiles described previously.

This was refined through use of approximated load profiles for customer type e.g. industrial, commercial and domestic.

Two methods were applied to calculate annual losses:

- Calculating the losses with annual real power energy consumption; and
- Calculating the losses with peak demand.

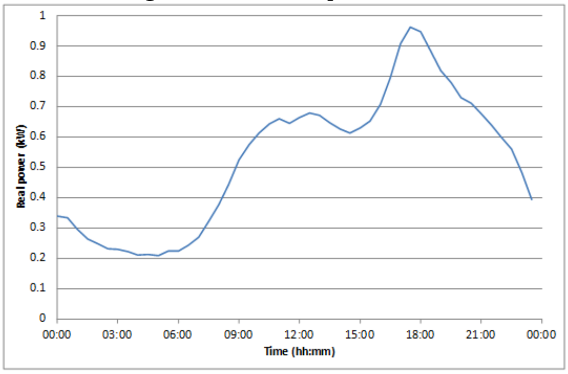

Figure 2 – Generic Domestic Customer Maximum Demand Profile from the CLNR Project

From these two methods it was found to be more reliable to use the peak demand calculation approach. The load profiles of Industrial & Commercial (I&C) customers are more bespoke and thus challenging to generalise. There was some variance in losses calculated including outliers that were considerably higher or lower than the rest, this is thought to be mainly due to the modelling of I&C customer load profiles (lack of visibility of specific load profile). Some margin of error has been considered for LV feeders where 50% of customers are I&C.

Site prioritisation

From the data analysed for the 316 secondary substations, the following aspects were explored in more detail:

- Customer type characterisation per LV feeder;
- LV substations with greatest data availability;
- LV feeders with high losses; and

These details were important to enable selection of an accurate and representative sample of LV substations on which to test interventions and to better understand uncertainties caused by prediction of I&C customers' load profile. This characterisation is based on the number of substations from 100% residential to mostly I&C customers (Figure 3). Selection of 73 representative substations for the purposes of exploring losses calculation, results interpretation and losses intervention is shown in Figure 4.

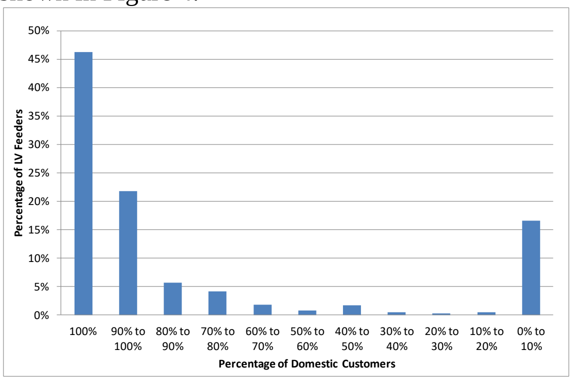

Figure 3 – LV Feeder Distribution According to Percentage of Domestic Customers

Correlation and identification of losses

The preliminary loss analysis carried out on all LV substations (316) showed a strong correlation between high current phase imbalance and losses. Further analysis carried out on the selected 73 LV substations examined in detail the impacts of phase imbalance on LV feeder losses.

The phase imbalance factor was based on highest phase current divided by the average phase current for the LV feeder. Figure 4 shows this relationship between the losses and the imbalance factor. This phase current imbalance index is calculated based on the phase currents of the LV substation by the following equation:

$$Imbalance = \frac{I_N}{I_A + I_B + I_C}$$

where I_A, I_B and I_C are the three-phase currents and I_N is the neutral phase current.

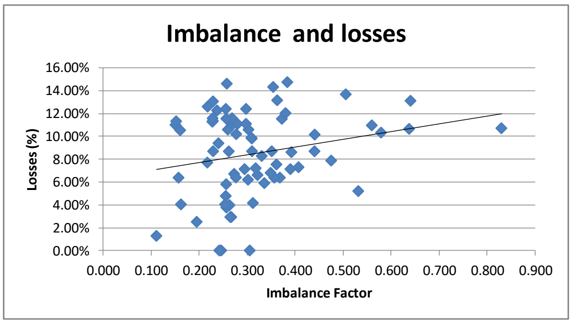

Figure 4 – Correlation between phase imbalance and losses

The median of the losses across the selected substations is approximately 5.9% which aligns to the high level figure of 6% reported by SSEN in the losses strategy document [4].

Reduction in Losses with high number of customers

It was found across most of the LV substations that the losses as a percentage of peak load decreases when the peak loading increases although the magnitude of losses broadly increases (Figure 5). This is due to the main cause of losses at LV being phase imbalance from uneven numbers of customer connections across phases and dynamic variations in customer load profiles. The level of phase imbalance generally decreases with the number of customers and thus demand, as diversity increases.

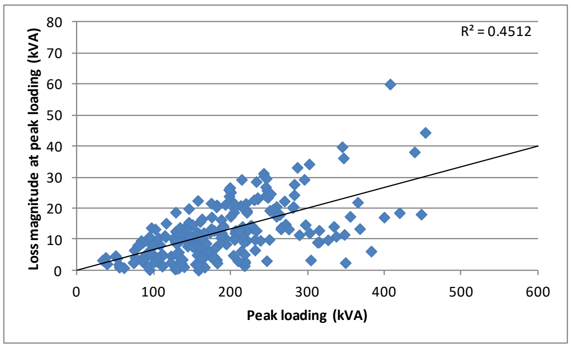

Figure 5 – Correlation of Losses at Peak Loading with Peak Loading

POWER SYSTEMS MODELLING

Based on the outcomes of the selected 73 substations and a horizon scanning exercise, the following interventions were selected as being most relevant for SSEN to consider:

1. Load Balancing
2. HV/LV Transformer Upgrading
3. LV Conductor Upgrading
4. Power Factor Correction through existing or innovative techniques.

These loss intervention methods have been studied in detail to assess their technical effectiveness through network modelling in power system software IPSA2. One LV network from the SSEN network area was modelled in detail with four LV feeders and included testing of the loss reduction interventions. This LV network is representative of suburban networks within the study area.

Network model build

A Python script was developed by TNEI to automatically convert the CYME network models provided by SSEN into unbalanced network models in IPSA2. This script was used to produce the IPSA2 network model with unbalance load flow capability of the selected sample network. The geographic diagram of this network model is shown in Figure 6.

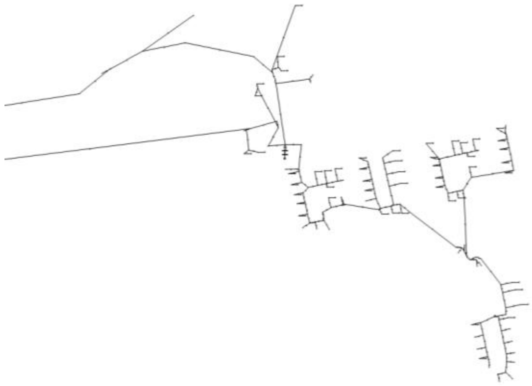

Figure 6– IPSA model of a particular feeder using its GIS capability

Interventions

Annual losses within the LV network have been assessed by simulation over one year using monitoring data provided for the LV feeders with and without interventions.

Table 1 Annual Losses with Loss Intervention Test Scenarios

Scenario No.	Scenario	Annual Losses (MWh)	Annual Losses Reduction (%)
1	Base Case (Power Factor = 0.97)	19.45	0.00%
2	Balancing loads	17.65	9.3%
3	Upgrading transformer	18.99	2.4%
4	Upgrading LV conductors	15.69	21.5%
5	Upgrading transformer and LV conductors (combination of 3 and 4)	15.29	23.5%
6	Power factor = 0.99	18.52	4.8%
7	Balancing phases, upgrading transformers and conductors, and correcting power factor (combination of 2, 3, 4 and 6)	12.53	35.6%

Recommendations for Network Interventions

From our analysis, the main causes for losses in the trial area were phase imbalance, with low power factor also prioritised after the horizon scanning of loss reduction techniques. Reactive power measured at the LV feeder showed significant variation suggesting measurement errors and/or data quality issues. This was further observed upon calculation of power factor values which were thus deemed unreliable. Total harmonic distortion for voltage was measured at the LV substation and analysed, it was found to be within G5/4 limits, harmonic distortion was not measured along LV feeders limiting the scope of the harmonic characterisation. Harmonic distortion was considered to be costly to improve as an individual issue at LV (based on TNEI internal knowledge of harmonic filter costs) and therefore not considered specifically. Phase current imbalance and power factor have a more material impact on losses.

The following recommendations are given for the future development/refurbishment of the network in order to reduce losses, which is also in line with SSEN's losses strategy:

- Installation of low loss transformers
- Setting a minimum transformer size
- Setting a minimum conductor installation capped for LV and 11 kV
- Replacement of transformers for low loss transformers where cost-effective
- Load balancing equipment (increase number of link boxes)
- Load monitoring to enable improvement of power factor (e.g. via capacitors)
- Customer re-jointing to mitigate phase imbalance

These options can be considered further through cost-benefit analysis. Preliminary exploration of cost-benefit suggests that phase balancing with power electronics were proven to be too costly compared to the current economics of loss reduction.

Part of the outcome of this project is the list of high losses substations that can be used as trial for the deployment of corrective actions. This is aided by the monitoring equipment already in the trial area.

LOSSES IDENTIFICATION STRATEGY

From the trial area and the data provided by SSEN for this project, measurement and connectivity were explored that have to be taken into account when identifying substations with high losses. The main causes for losses are phase imbalance and power factor. Monitoring the entire LV network is costly and should be considered in the context of future rollout of customer smart meters.

Efficient identification of LV substations across the entire SSEN licence area that are most likely to suffer from high losses, in order to implement monitoring and/or modelling to investigate further, has been assessed. It is key to be able to utilise what SSEN already monitors to identify high loss substations for monitoring and modelling and minimise the risk of extensive monitoring for limited benefit.

Maximum demand is currently measured at LV substations on a six monthly basis and is a key metric to support the identification of LV substations with high losses. Other asset and network data such as LV substation customer numbers and transformer rating can also be utilised.

Metrics were analysed based on available data and measurements for all SSEN LV substations in the Bracknell area to develop a suitable filtering process. This is shown in Figure 7.

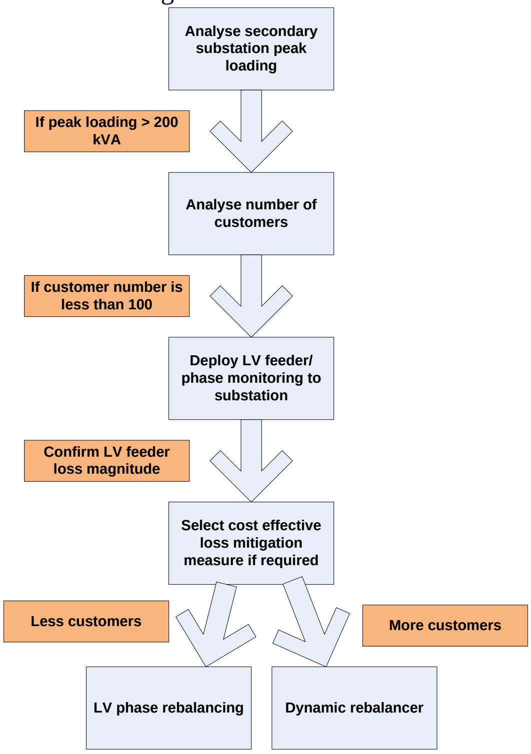

Figure 7 – Losses methodology Flowchart

Trigger criteria may be refined to adapt the percentage of lossy substations identified for further action i.e. monitoring and/or modelling.

CONCLUSIONS

Peak demand calculation approach was found to be the most reliable losses calculation approach. Uncertainties caused by prediction of I&C customers' load profile to an extent.

The level of phase imbalance generally decreases with the number of customers and thus demand, as diversity increases. As phase imbalance is correlated to losses, higher diversity reduces losses.

Part of the outcome of this project is the list of high losses substations that can be used as trial for the deployment of corrective actions. This is aided by the monitoring equipment already in the trial area.

Preliminary exploration of cost-benefit suggests that phase balancing with power electronics may be most feasible. However, at the moment the equipment required has proven to be too costly compared to the current economics of loss reduction.

A losses methodology was developed and tested that can be deployed to help identify secondary substations with high losses based on limited existing available data.

After the results found on this project, policy updates are recommended (within suitable equipment specifications). SSEN is considering it in its further work area to explore cost effective interventions for the benefit of its customers.

Acknowledgments

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