THE IMPACT OF DISTRIBUTED GENERATION UPON NETWORK LOSSES

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ABSTRACT

This paper presents work undertaken with funding by the DTI's Distributed Generation & Electricity Networks Programme. This project [1] undertakes a review of distribution network loss calculation methodologies. The work then goes on to develop a unique modelling and assessment tool which is used to investigate the impacts of distributed generation upon Distribution Network losses. The tool uses load profile information (established during the course of the project) and calculates the annual losses for three GSP (Grid Supply Point) networks with varying levels of distributed generation. This is done at all voltage levels from the 132kV network down to the consumers cut out. The tool is based within Microsoft Excel and uses the IPSA + loadflow engine to solve each of the 17,520 half-hourly load flows for an annual study.

INTRODUCTION

Losses occur in all systems for electricity transmission and distribution. These are usually divided into two categories; technical (related to the characteristics of the carrier equipment and supply and demand patterns) and commercial (energy nor accounted for, for example, theft, meter errors). Changes to the pattern of supply and network configuration due to the installation of Distributed Generation are expected to affect the levels of technical losses that occur within the distribution network.

This study was focused on the calculation of the technical losses to help provide an understanding of the constraints and likely impacts upon the distribution network from the deployment of distributed generation.

The losses calculated within this work take into account both the 'Fixed' losses within a Distribution Network (e.g. transformer iron core heat losses) and the more usual I^2R resistive losses from the various network components involved in the power delivery process.

The actual calculation of losses for a particular element is relatively simple. However, the complexity increases significantly when both the number of components and network size increases and the aspect of time is introduced.

The technical losses in a particular network at one point in time are likely to be very different over the course of the day due to the varying load and generation network profiles.

APPROACH USED

In order to tackle the challenges laid down within this project, a structured approach was developed in order to tackle the key areas. The key areas are now highlighted.

The GSP Network and its variants

With the guidance and support of the project steering group, a 'typical' GSP was established as the foundation for the modelling. This GSP laid down an overall base network topology. Network parameters (including demands) were established from real data and information/guidance from the project steering group. Rural and urban variations were then established which used the same basic topology.

Generation Scenarios

The DTI/OFGEM WS1 [2] distributed generation scenarios were used as a base for the analysis. Within these scenarios a low and high penetration level is provided. This data was reviewed and updated to reflect actual progress.

The data was further processed to map it to a single 'typical Distribution Network Operator', and then the single GSP. When the data and scenarios were then mapped to the modelled GSP, it was further checked and adjusted to ensure validity (e.g. a whole generator being connected to a busbar).

Development of the Tool

As a result of the literature survey, existing tools and processes were found to be lacking and not easily transferable to the rationale and approach established within this project. As such a customised tool was developed specifically for use within this project. More information on the tool is given later in this paper.

Assessment of the impact

With the tool, network and distributed generation scenarios established load and generation profiles were determined from data supplied by the steering group and data from EA Technology. These were then used to assess the distribution network losses. The analysis was carried out for all the modelled voltage levels (132kV, 33kV, 11kV and 0.4kV).

MODELLED GSP

It was clear that the modelling of every possible network type and scenario was impossible, and so the project steering group established a 'base' GSP network topology. In order to determine the 'typical structure' data from the steering group was obtained and the number of supply points and primaries were analysed. GSPs with only one supply point were not considered as these were deemed to be 'special'. The typical structure used for the modelling of the GSP was:

- Main voltage transformation levels are taken as 132kV, 33 kV, 11 kV and 0.4kV.
- 5 Bulk Supply Points per GSP
    - Some radial (132/33kV)
    - Some ring (132/33kV)
- 6 Primaries fed per bulk supply point
    - Some radial (33/11kV)
    - Some ring (33/11kV)
- No single phase transformers (other than 11/0.4kV) are assumed

The typical structure is illustrated in Figure 1.

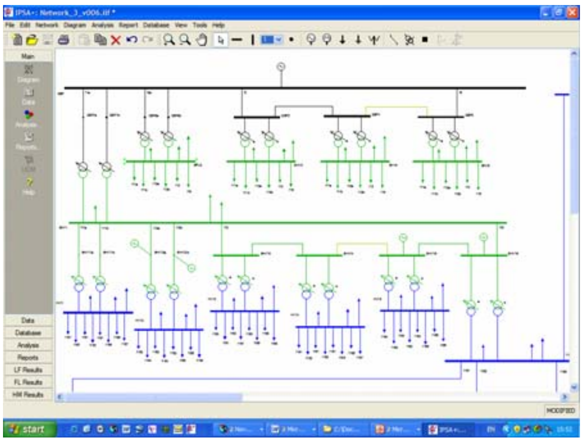

Figure 1. Typical GSP supply & primary supply point structure

For the LV (0.4kV) network three types of network were modeled, These were a 500kVA 11kV/LV group (urban), a 100kVA 11kV/LV group (rural) and a 50kVA 11kV/LV group (rural).

Data was obtained from the steering group members and a baseline established for the asset impedances (per unit basis).

From this typical structure, the composition of the 11kV feeders was arranged such that the type of LV network it supplies (listed in the bullet points above) governs if it is a rural, urban or mixed 11kV feeder. Table 1 outlines the composition used for the 11kV/LV substations.

11kV feeder type	Composition of 11kV/LV substation		
	500kVA substation (GM)	100kVA substation (PM)	50kVA substation (PM)
Urban	8		
Rural		9	9
Mixed	3	6	6

Table 1 Composition of the 11kV/LV substations for different 11kV feeders

Using this approach, three networks were then developed (using the same overall topology established earlier). An urban, mixed and rural network was then established by the appropriate composition of 11kV feeders. These compositions were:

- Urban biased network: 80% urban, 15% Mixed (urban/rural) and 5% rural
- Urban/rural mixed network: 60% urban, 30% Mixed (urban/rural) and 10% rural
- Rural biased network: 40% urban, 40% Mixed (urban/rural) and 20% rural

Load Profiles

From information supplied by the project steering group and that available within EA Technology, a range of domestic, commercial and industrial annual load profiles were established.

A generic standard settlement profile for domestic unrestricted load (single) was used for the modelling of the domestic load customers. Load profiles for such properties are available in the WinDebut LV network design tool [3] and so the 'stylised' demand profile for the relevant customer type was used. The profile was split into average profiles for weekdays and weekends, for five seasons: spring, summer, high summer, autumn and winter. The plot below is an illustration of half hour (HH) profile for domestic properties with variations for the winter and summer periods shown.

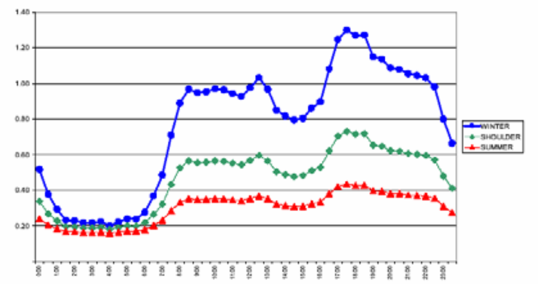

Figure 2. Seasonal half hour domestic load profile

This 'profile' was then used to synthesise one year's load data (17,520 half hours) based on representative days / months / seasons.
Various profiles for large and small commercial, and industrial loads were also synthesised based on profile

information provided by the steering group. As before, the profiles were apportioned into the particular seasons and days to ensure validity.

Generation Profiles

Real profiles for example windfarms were also obtained and two profiles were selected. One represents a windfarm with installed DFIG (Doubly Fed Induction Generator) machines, and the other is a windfarm with more traditional induction generator.

THE LOSSES TOOL

EA Technology and Power Analysis Ltd specifically developed a program to calculate network losses for explicit use in this project. This program solves a series of load flows on the network based on network loading and generation snapshots at half-hour intervals.

For every half-hour analysis period the losses are determined by subtracting the line flows calculated at the two ends of each branch. Total losses at a voltage level are calculated in the spreadsheet from the number of each asset type, and then aggregated with the branch flows to give the flow at the voltage level above. The losses program is designed to take a continuous run of load/generation curve data extending up to a year's worth of half hour values. The facility is provided to group branches into "loss zones" so that meaningful totals can be readily available for the particular voltage levels.

The annual network losses are then calculated based on the losses results of the groups for the different voltage levels.

In order to allow flexibility in the processing of the load flow results, the program has been written in VBA (Visual Basic for Applications) and runs within an Excel Workbook. The load flow calculation itself is performed by library routines provided by IPSA Power.

The principal functions of the tool are:

- **Load flow** capabilities (IPSA Load Flow engine is used – a 3 phase balanced network is assumed)
- **Manager code** to link network connectivity and load / generation scenarios together
- **Results presentation** to enable the extraction of network losses for the relevant network and voltage levels

The network to be studied is specified in the program from a set of worksheets, which tabulate the different categories of data. These worksheets are entitled Main Sheet, Generators, Busbars, Loads, Branches, Transformers, Half hourly profiles (Load and Generation)

The running of the losses program is controlled from the "Main" worksheet (illustrated in Figure 3 below). Data are input to the set of worksheets for network components of Generators, Busbars, Loads, Branches and Transformers. An illustration of the losses tool front worksheet is shown in Figure 3.

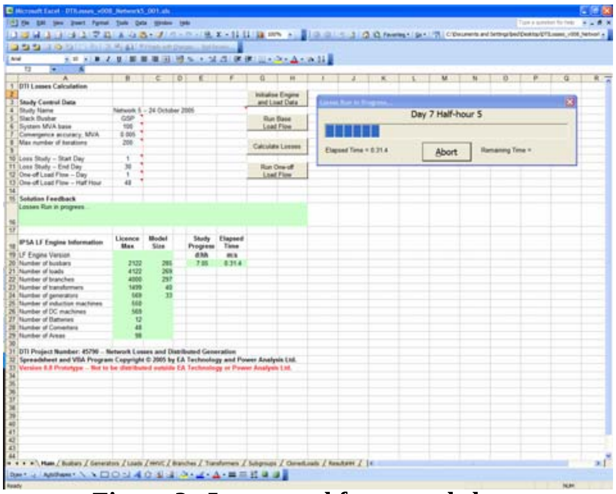

Figure 3. Losses tool front worksheet

Cloning

Rather than model every feeder for a complete GSP in detail a cloning process is applied to parts of the network to cut down the processing required. For a particular "replicated" feeder, the flow into this feeder is assigned the same value as the actual flow in the feeder modelled in detail. The same methodology is applied to sub-network so that the effect of a sub-network can be accurately duplicated without having to model it in detail more than once. The replication process ensures that the correct total loads are imposed on a higher voltage network from the lower one, even though the lower network is only partially modelled in detail. Without this approach it would be prohibitive to model down the LV in the manner that this project has uniquely carried out.

Results output

Results can be presented in various forms from the program outputs. An annual total can be established for the network, or daily totals can be established for assessment and more detailed investigation as to the interaction in load and generation profiles. In the results presentation the percentage losses relates to the percentage of the losses to the 'total energy intake' for the group.

Both fixed and variable losses are calculated and the plot below shows the annual loss profile for the GSP for one of the Distributed Generation scenarios.

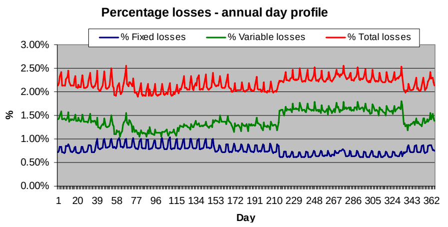

Figure 4. Annual loss profile for the GSP for Distributed Generation scenario 3

The fixed losses vary in this representation. This is because the losses are expressed in relation to the total demand which varies in relation to the load profile of the network.

DISTRIBUTED GENERATION SCENARIOS

As outlined earlier, the DTI/OFGEM WS1 distributed generation scenarios were used. Three distributed generation scenarios (DG 1, 2 and 3) each with increasing penetrations were applied to each of the three modelled GSP networks (rural, mixed and urban). The particular DG scenario was adjusted accordingly depending upon the GSP modelled (e.g. rural GSP would have more rural generation than an urban modelled GSP).

RESULTS AND OBSERVATIONS

The overall calculated losses for the modelled GSPs is of the order of some 4 to 5%. Given that no account is made for non technical losses, and published figures of the order of 7% [4], results from the tool are considered to be broadly in line with that experienced within the UK industry.

The overall results for the three DG scenarios for each of the three GSPs modelled are similar in term of the overall trend. The plot below outlines the results for the mixed urban/rural GSP for the three DG scenarios.

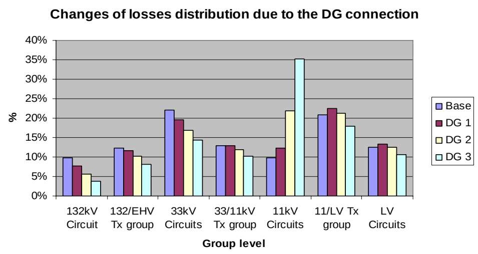

Figure 5. Loss distribution by voltage level for the mixed GSP and applied DG scenarios

From the results and analysis carried out in this work, the following conclusions and observations are made.

- Urban and mixed urban/rural network, overall network losses are reduced for distributed generation scenarios.
- Rural network, overall network losses are reduced for distributed generation scenarios 1 and 2 but losses are increased for the higher distributed generation penetration scenario.
- Distributed generation connection at lower voltage appears to reduce the losses for the higher voltage 132kV circuit groups, 132kV transformer groups and 33kV circuits groups.
- Distributed generation connection causes circuit losses to increase at 11kV. The increase is proportional to DG penetration within the voltage level.
- Analysis of the results suggests loss reduction at some voltage levels are cancelled out by the loss increases in other levels (particularly 11kV level in the modelling studies in this project).
- Losses in the 11kV circuit group, distribution transformer group and LV circuit group are **increased** for all distributed generation scenarios on the urban network. The **reduction** at higher voltage levels more or less balances out the increase at lower voltages, ending up with a **marginal** reduction in overall **GSP** network losses.

CONCLUSIONS

The conclusions from the study are that the view of Distributed Generation always reducing network losses is **not always** valid.

For urban and mixed networks it was found that the overall losses are reduced with Distributed Generation presence. For rural networks however, losses again were reduced but increase for higher Distributed Generation penetrations.

The unique and powerful tool developed within this project enables the user to analyse in detail the actual relationships and interactions since the overall result is both complex and dependent upon the network, voltage level and DG penetration

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