NETWORK POWER-FLOW ANALYSIS FOR HIGH-PENETRATION DISTRIBUTED MICRO-GENERATION

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SUMMARY

The connection of large numbers of micro-generators to low-voltage distribution networks may undermine traditional network design techniques that rely on diversity factors and other simplifying assumptions. This paper describes on-going development of thorough and detailed modelling techniques applicable to complete distribution feeders: from primary substations, through medium and low-voltage networks to individual single-phase customer connection points. The modelling uses accurate unbalanced power-flow analysis (load-flow) and 1-minute time-series load data.

INTRODUCTION

Micro generators, with power outputs of a few kilowatts, include photovoltaic (PV) and domestic cogeneration systems (domestic combined heat and power – DCHP). Such generators are currently very few and far between and have little impact on power flows in large electrical distribution networks. As their numbers increase, however, due to technical advances and improved economics, their impact will become a concern for distribution network operators, particularly if large numbers are installed in close geographic proximity. One of the major concerns is that micro-generators alter the network power flows and this could lead to network voltages outside of statutory limits. In the UK this concern was recently reiterated by the Distributed Generation Co-ordinating Group [1].

Micro generators are often single-phase and are generally connected to low-voltage networks, (typically 400/230V in Europe). The design of such networks, in order to ensure that voltages are within statutory limits, is traditionally based on diversity factors and various simplifying assumptions. This approach, together with a wealth of experience gained over many years from similar networks with similar loads, is usually satisfactory. There is no such experience, however, of networks with high-penetrations of distributed micro-generation. In particular, diversity factors are likely to be altered.

Various studies [including 2] have been conducted that aim to assess the impact of high-penetrations of distributed micro-generation, and that aim to assess penetration limits that could be accepted within existing distribution networks. In general however, these studies tend to employ single-point-in-time deterministic analysis, usually of worst-case conditions. Load data is often based on half-hourly aggregated values, and therefore cannot represent the rapid fluctuations observed in real low-voltage networks. Furthermore, the effects of unbalanced power flows are often overlooked or grossly approximated. Lastly, the networks used in case studies are usually rather limited, having only a few nodes, and thus do not fully illustrate the operation of micro-generators in large distribution networks with thousands of connection points.

The above limitations are due in part to a lack of sufficiently detailed load and network data, and in part to limitations of existing network analysis software. The project supporting this paper seeks to address these issues: first through the development of load models to provide 1-minute time-series data for individual properties [3] and second, through the development of suitable power-flow analysis software, described below.

POWER-FLOW ANALYSIS SOFTWARE

A comprehensive unbalanced power-flow analysis software engine has been implemented in the Matlab programming environment. Matlab’s efficiency in manipulating complex numbers in large arrays has been fully exploited to provide a powerful and flexible package.

The underlying algorithm is the “forward/backward sweep”, also known as the “ladder-iterative technique” and described in detail by Kersting [4]. Its selection, in preference to Newton-Raphson was discussed previously [5].

The software now handles transformers efficiently, and including the 30-degree phase shift for delta-star windings. Thus, complete feeders and unbalanced low-voltage networks can be properly represented and analysed as a whole.

TEST NETWORK

The software has been tested on data describing a network in city-centre Leicester, Midlands, UK, shown in Figure 1. The network source is the 11-kV bus-bar of a primary substation (far right of the Figure). The transformers of the primary-substation include on-load tap changers, which are configured to provide a near constant bus-bar voltage (no line-drop compensation).
The 11-kV feeder comprises some 4 km of underground cables (shown bold in the Figure) and provides power to four distribution transformers. The associated low-voltage networks (400/230 V) are a further 23 km of underground cables, including “service” cables up to the customer connection points, most of which are single phase. There are over 1500 connected customers and the network has over 3700 nodes.

LOAD DATA

The load data is derived from models developed at De Montfort University [3]. Data is generated for each customer connection point and is provided as a time-series at 1-minute intervals. The models are designed to provide appropriate correlation and diversity across the data set, and, are configurable to include micro-generation. Active and reactive powers are provided separately, again with appropriate correlation. Initial testing of the power-flow analysis software engine has used data covering one day: 1440 time-steps.

PERFORMANCE

The load data is presented to the power-flow analysis software engine as a time-series and the output is the resulting time-series of voltages and currents throughout the network. The main performance consideration, at this stage, is the speed of execution, so that the package will provide an efficient mechanism for examining various scenarios of micro-generation uptake. With the 3700-node network described above, the simulation of one day at 1-minute intervals can be completed in less than 20 minutes using a laptop computer (Pentium M 745, 1.8GHz).
INITIAL RESULTS

Figure 2 shows the resulting data for just one of the 1500 customer connection points. Corresponding data is available for every other connection point. The upper graph shows the power consumption for this particular house modeled for this particular day; it happens to be the 1st of July. There appears to be a fridge and freezer cycling through the night, water heating between 5 and 6 AM, other general loads throughout the day and a kettle, which gives rise to the short duration spikes. It is spikes such as these that are totally overlooked when loads are represented by half-hourly data.

The lower graph shows the result of the power-flow analysis; in particular, the selected data is the voltage at the customer connection point of the same house. Again, this data is at 1-minute intervals, which captures the much of the detail associated with kettles and the like. Of course, the interval can readily be increased to permit simulation of longer periods of operation, for example, in consideration of the international standard EN 50160:1999, which states that, “during each period of one week 95% of the 10 min mean rms values of the supply voltage shall be within the range of +/- 10%.”

CONCLUSIONS

The initial results presented in this paper illustrate that the software is functioning and that it can provide a basis for the detailed study of large numbers of micro-generators. However, there remains much to do regarding the verification of the modelling. The power-flow calculations are believed to be accurate: special cases have been checked by hand and other results checked against a commercial (single-point-in-time) package. The network and load data are harder to verify, but the software can already be used to determine the sensitivity to errors in this data. This approach will guide the continuing work on the project.

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References


