URBAN DISTRIBUTION NETWORKS – SOME GENERAL PLANNING OBSERVATIONS

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ABSTRACT

Efficiency and performance targets are nowadays being tangibly addressed by the regulation authorities. Customer demands on distribution networks, both qualitative and quantitative, are increasing. Whilst most urban distribution network development occurs in the context of existing and ageing developed networks, it is legitimate to highlight some general planning targets showing the cost implications of various medium voltage planning philosophies, such as voltage levels, the use of parallel conductors in congested and heavily loaded regions, and full or economically optimal backup connections and switch placement.

This paper uses a new automatic network routing algorithm to show the topographical impact of these considerations on a realistic network, serving to both demonstrate some aspects of the algorithm and highlight planning concerns going into the future. It is the authors' wish to illustrate the new algorithm, because it directly addresses a comprehensive range of actual planning requirements in real distribution networks, both urban and rural, although it is the former that forms the focus of this paper.

INTRODUCTION

A multitude of considerations confront the contemporary electricity network planner. This paper represents part of the ongoing attempt to automate as many of the mundane aspects of planning as possible, in order to free the planner from some of the more laborious tasks, such as the hit and miss building up of line routing.

Our attempt in this regard is both modest, in that it is limited to providing an efficient routing algorithm for a commercially available state-of-the-art network information system, and at the same time ambitious, in that we have taken the complicating issues head-on, such as directly dealing with outage – in the form of optimum or full backup and switching topography.

In addition to placing reserve connections and cross-ties, manual- and remote-operated disconnectors and network circuit breakers, the algorithm can cope with load-specific outage cost parameters, geographically-dependent fault frequencies, geographically-dependent installation costs and choose between 2 possible inter-nodal route choices, which gives the user the ability to see whether a more direct but more expensive per km choice is more or less cost effective than a longer but perhaps cheaper alternative. If the information required to implement the above-mentioned requirements is not available, then the algorithm reverts to default values, and point-to-point distances are scaled up by a line length adjustment factor.

The algorithm is comprehensive in terms of the above capabilities but at the present point of development it is capable of only static planning, that is, producing a horizon year network based on present load predictions, load growth, interest rates and so on. When the focus is on comparison of networks in different environments, dynamics is not a crucial issue and we can use the algorithm in its present form [1]. It is also felt that for developed networks where load growth is very small, and for fully building up new networks, where load growth is very fast over a short time, the algorithm as it stands is already very useful.

The admission of this limitation, however, should be qualified by noting that existing lines can be investigated by the algorithm and can be used, if beneficial, by assigning existing lines with a worth factor between 0 and 1 depending on their age. The focus on practicality and reasonable computation time render the algorithm suitable for future development into a dynamic planning tool.

Space does not allow a full literature review, but to acknowledge the work in this area by others, we list a few previous publications on the topic [2]-[4]. To give this paper a clear and digestible theme, we will demonstrate the algorithm in its Greenfield capacity, to show the topographical and cost impact of some different medium voltage planning paradigms. First, a necessarily brief overview of the algorithm is given.

ALGORITHM OVERVIEW

While at present the algorithm is operating as a stand-alone routine, it operates from input files that will in practice be created by the network information system (NIS), which obviously has fully-developed user-interface and data base capabilities. This information is converted into numerous vectors and matrices which the algorithm then processes. It is likely that this part of the algorithm, shown in Figure 1, will be somewhat modified when the interface details are fully worked out. The 'VOH' algorithm itself (where VOH is the Finnish acronym for the project in which it was developed) is presented, in skeletal form, in Figure 2.

An initial network is generated by an iterative procedure that uses an approximate power flow and a linear cost function. This is itself quite a sophisticated routine that is driven by a linear cost function, but passively considers the user-defined parameters by calculating the full cost of the network at each iteration using a full, non-linear line cost function and full outage consideration with backup and switching depending on the user's requirements.

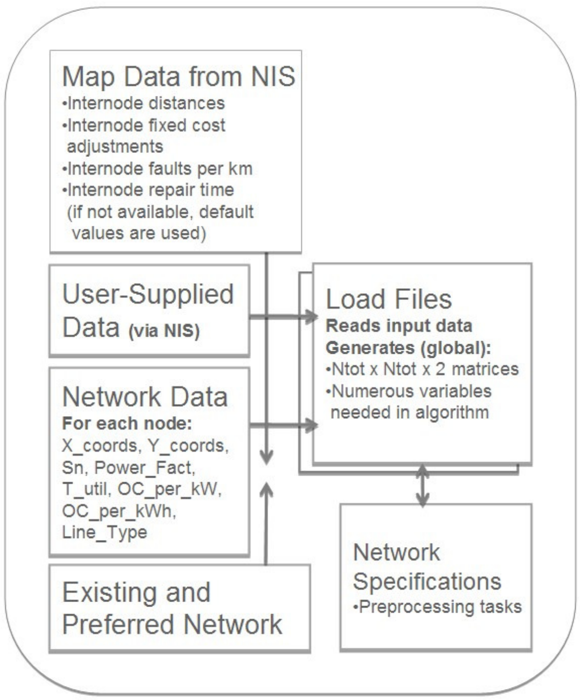

Figure 1 Generating network data for the algorithm

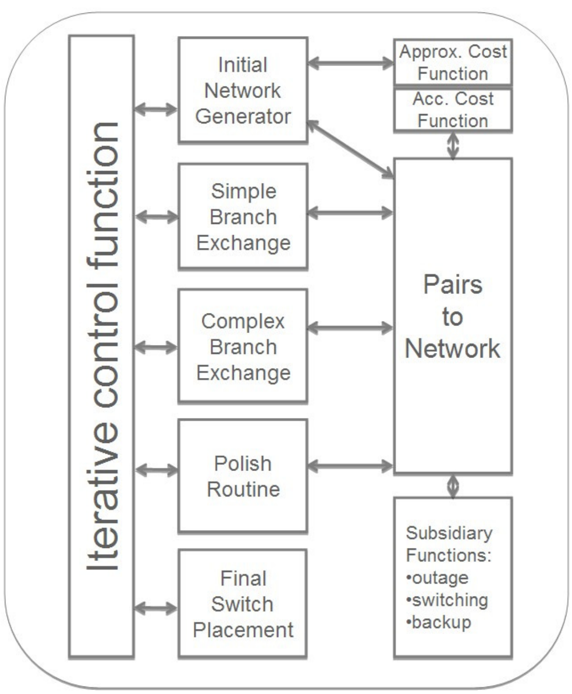

Figure 2 The 'VOH' algorithm

The network is represented by connected node pairs, and one of the central routines is 'Pairs to Network', which does what the name implies plus computing the full cost of the network including investment, loss and outage costs.

The algorithm is fully deterministic, sensible and comprehensive, but not fully exhaustive, in order to strike a balance between a very close to optimum result in reasonable computation times. A random optimisation procedure will also be provided for users that are interested in approaching the elusive theoretical optimum more closely, and do not have pressing time concerns!

We will now proceed to illustrate the algorithm in Greenfield form, to show the effects of voltage level, either 10 or 20 kV, the allowance of parallel cables in the same trench, and full or economically optimal backup connections and manual switch placement in the generated network, which connects a single primary substation (110/10 or 110 to 20kV, depending on the MV voltage level being investigated) with 107 realistic MV load nodes. A line length adjustment factor of 1.414 is used to approximate the street grid. Each group has been assigned appropriate outage cost parameters ranging from 0.36 €/kW/fault and 4.29 €/kWh for domestic buildings, to 3.00 €/kW/fault and 60 €/kWh for hospitals and the fault frequency is 1.0 fault per 100 km. The repair time for a cable fault is 10 hours.

SIMULATIONS

A series of simulations is presented, first using the voltage level of 10 kV, which is often the voltage for central city areas that were first electrified several decades ago. Initially, only a single 3-phase cable system per connection is allowed. A range of possible network topologies is shown, starting with a purely radial network with no outage consideration up to a fully looped and switched network. The voltage level is then raised to 20 kV in scenario 4 and parallel cable connections are allowed, with a suitable lowering of ampacity due to mutual heating but a significant lowering in the installation costs.

Fault rates are kept the same per km of line routing, as most cable faults are due to diggers and external influences, and are likely to affect both cables sharing the same trench. The grid width in all simulation figures is 100 m, meaning the network is about 1.3 km x 1.3 km. The network contains a variety of central city customer types, including commercial and public service premises, some industry and apartment blocks. Load growth is a very modest 0.12 %/year.

Scenario 1 : No outage consideration

It is revealing, although unrealistic, to begin with a network that makes no allowance for outages, but to compute the cost of outages according to the costs stipulated by the regulation authorities. This network is shown in Figure 3.

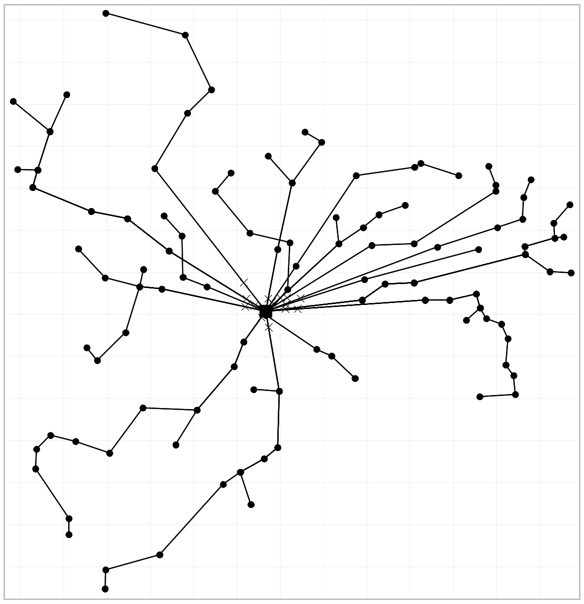

Figure 3 Radial network with no outage consideration

The network costs, which include investment costs and the cost of losses over the 40 year time period being considered, are €2.323 million for the network shown in Figure 3. The only switching available are the circuit breakers on each outgoing feeder from the substation, and this would give a hypothetical total outage cost of €2.337 million.

Optimally locating manual line switches enables restoration of supply to customers above the closest upstream switch from the fault. This slightly increases the network costs to €2.325 million, but the outage costs are reduced to €1.187 million. This situation is not illustrated in the figures. It should be noted that a discount of €3000 is given to all switch locations that do not have a manual line switch, as the ring main units used at the secondary substations are usually provided with manual line switches in urban cable networks.

Scenario 2: Optimal switching and backup

The economically optimum network topology is obtained with optimal placement of both switches and backup connections, and this is shown in Figure 4. It must be cautioned that the networks an optimising algorithm produces are very sensitive to the input parameters. It is quite surprising to the authors that only 49% of the MV load nodes have backup in the cost optimal network of what is a quite densely loaded downtown network. The algorithm is discriminatory in that it does tend to loop critical nodes, but not all less critical nodes are treated equally.

For the cost optimal network shown in Figure 4, the total network cost is €2.750 million, but the outage costs drop substantially, to €0.396 million, due to the increased sectionalising of the network possible during contingencies.

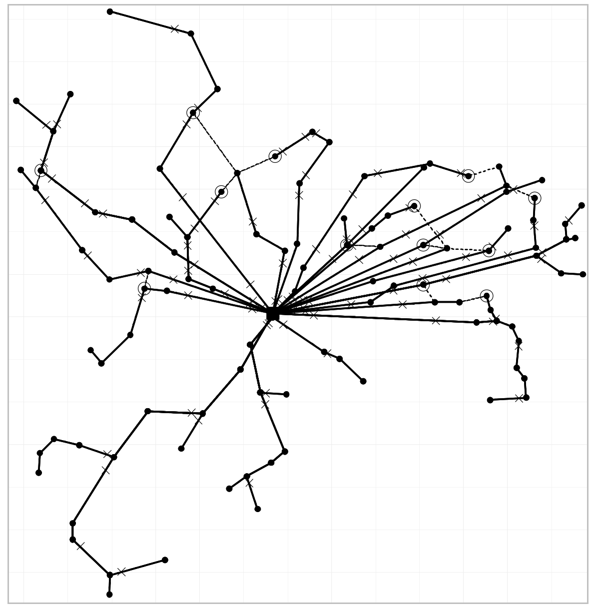

Figure 4 Optimal backup and switching

It is common practice to provide the same level of backup to the majority of customers in urban distribution networks, which means full switching and full backup for each secondary substation. This is illustrated in the next scenario.

Scenario 3: Full switching and backup

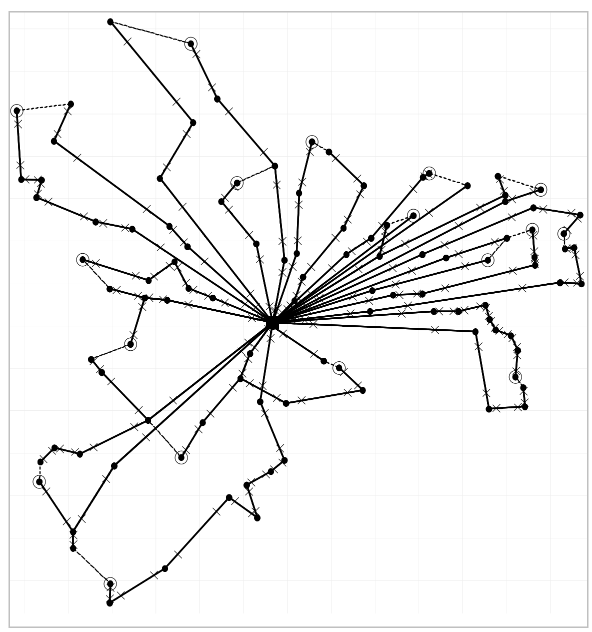

Figure 5 Full backup and switching

Following standard urban practice and providing full backup to MV load points carries quite a cost in the network shown in Figure 5.

An increase in network costs to €3.277 million is to be expected but, paradoxically, ensuring full security to all MV nodes increases the overall outage costs to €0.407 million – in other words the extra line length and exposure to faults offsets the benefits.

Scenario 4: Raising the voltage level from 10 to 20 kV and allowing parallel cable systems

Raising the voltage level has a dramatic effect on the network topology and, in addition, to provide a network of minimum bulk and cost to service the prescribed MV load nodes we allow parallel cables in the same trench. Current limits are reduced to allow for the mutual heating of cables sharing the same trench.

In Figure 6, full backup is maintained, but the fact that the dimensioning of the 10 kV cables is constrained by maximum current limits means the network becomes much less dense when the voltage level is raised. Of course 20 kV is the standard medium voltage nowadays, but it is a far from trivial matter to raise the voltage level of old urban networks. In this hypothetical simulation, network costs drop to €1.956 million and outage costs are € 0.485 million. Allowing parallel cables where they are cost beneficial for heavily loaded connections further also helps reduce the length of the network.

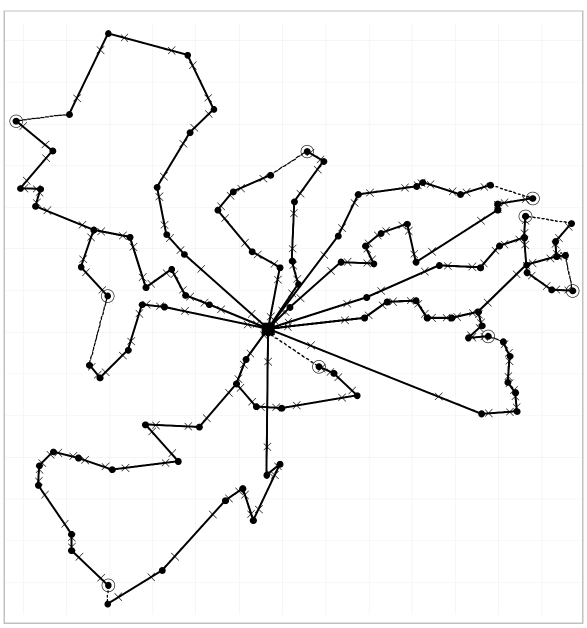

Figure 6 20 kV network with parallel cables allowed

SUMMARY AND CONCLUSIONS

The trend in the development of the networks from Scenarios 1 to 4, summarised in Table 1, is as would be expected, although the extent of the effect of outages, parallel cable connections and voltage level is revealing.

Table 1 Summary of simulation results

Scen-ario	Outage consid. ?	Manual switching ?	Backup conns. ?	Network costs (10^6 €)	Outage costs (10^6 €)	Full costs (10^6 €)
1	no	no	no	2.323	2.337	4.670
2	yes	opt	opt	2.750	0.396	3.146
3	yes	full	full	3.277	0.407	3.684
4	yes	full	full	1.956	0.485	2.441

The first scenario shows a purely radial network that is planned without any outage consideration. In Scenario 2, optimal sectionalising of the network during faults was provided by the optimal positioning of backup connections and manual line switches. The total cost of the network is increased when full looping and switching is stipulated, as can be seen by comparing the cost for Scenario 3 with the optimum in Scenario 2.

Full backup for MV load points is the norm for urban distribution network planning, however, and this philosophy was carried through to Scenario 4, which shows the line length reduction due to increasing the voltage and allowing parallel cables. The dramatic reduction in network length is because ampacity, i.e. thermal limits, are the driving parameter in densely loaded underground cable networks. The increase in outage costs is because the 20 kV cables, sometimes parallel, are serving higher loads so a fault has more impact.

The algorithm can cope with large networks and can handle multiple primary substations and cross-ties between adjacent substation areas. For clarity, this paper has focused on a single primary substation area but in reality, of course, considerable cross-connection exists between substation areas, even to the extent of providing full substation redundancy. Unacceptably long repair times for underground cables mean that full looping is mandatory in, for example, central business districts.

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