

A Constructal Approach to Power Distribution Networks Design

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1. Introduction

By economic and political reasons, contemporary transmission networks are large and complex, spanning great distances and conveying power from many generators to many metropolitan areas located far away [1]-[2]. Superior, scalable grid topology that may provide for higher quality of service, survivorship capacity, and reconfiguration capability is a feature of modern grid architecture. The reported research is aimed at delivering a constructal solution that is based on a minimum-redundant, scalable, reconfigurable topology that helps increasing the grid immunity to faults. We assume that a tree network serves nodes of consumption that are evenly distributed throughout the territory. All nodes are equally important. The models and loads estimation is based on the load momentum method.

Key words: Power Network, Reconfigurable, Scalable architecture, Constructal optimization, Models and estimation of loads.

2. An Integral Method for the Evaluation of Electric Power Networks

We use an integral approach [3], [4] to evaluate the performance of a power distribution network design.

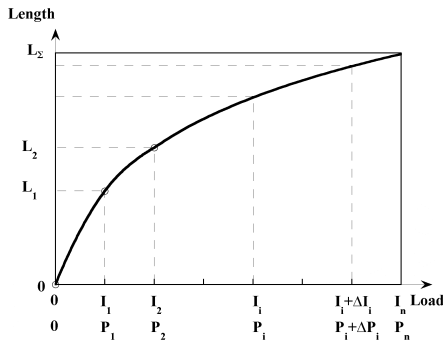


Fig. 1. Load length for currents and power.

This method accounts for the hierarchical, layered structure of tree shaped networks and for all the consumption nodes, links (lines) and loads carried by

each line. The *moment of the load* at the consumption node is defined as the load of that node times the direct distance (the minimum spanning tree) from the node (sink) to the source – Fig. 1. The load-length diagram may be used to size the network: it shows the total length of lines that have to carry a specific load, in a specific economic range. For instance, the group with a load in the range $I_i \dots I_i + \Delta I_i$ covers a range of lengths ΔL_i . Furthermore, the surface above the load-length curve is proportional to the total cost.

3. Constructal Design to Maximize Network Survivability under Destructive Events

The network model we propose comprises a source, located at the highest hierarchical level and a number of consumers, connected in a tree network. To increase the *capacity of survivorship* and *recovery* a second network functions in the same area. The two networks are comparable in size, regional coverage, power flow, and the nodes of consumption are evenly distributed.

Constructal theory [5], [6] is concerned with optimizing the access path from a volume (here, the territory where the nodes of consumption are located) to a point (here, the source), of given resources (the network), and subject to internal and external constraints (local restrictions, finite size area, ports of access to the territory).

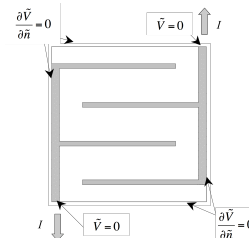


Fig. 2. The elemental cell of two concurrent tree networks.

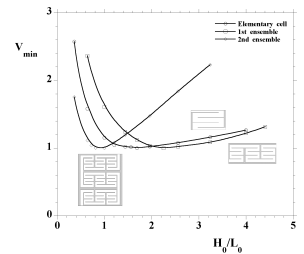
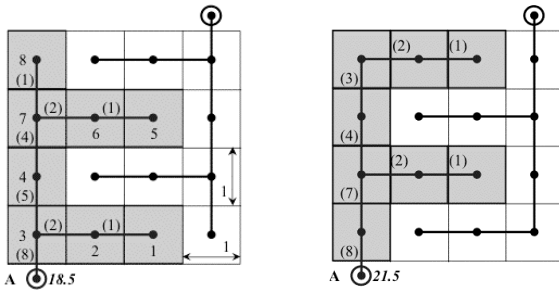


Fig. 3. Optimization sequence (non-dimensional).

We consider a related electrokinetic boundary value problem (Figs. 2, 3): an area that sinks current uniformly and which has a low electrical conductivity ($\sigma_0 \ll \sigma_p$) is fed through two high conductivity tree networks (σ_p).

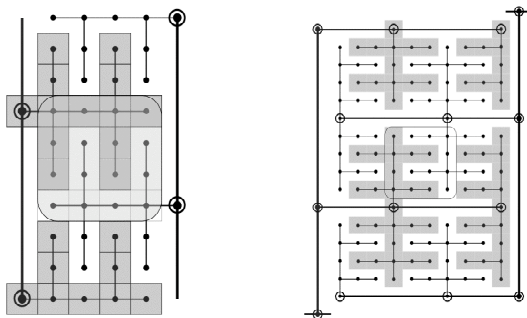
The amount of high conductivity material, the area of the cell (i.e., the current demand) and the structure of the trees are given. The optimization problem (minimize the highest voltage drop) regards the cell aspect ratio, H/L .

Figure 4 shows two elemental cell designs. The non-dimensional load for each segment is noted in parentheses (actual values are divided by I_0 , or P_0). Load moment at node (A) is shown too. Design 1 has a smaller total load momentum (18.5 vs. 21.5).



a. Design 1.
b. Design 2.
Fig. 4. The total momentum optimization.

Constructal growth follows a time arrow from the elemental cell to higher order ensembles. Each ensemble is made of ensembles of immediate lower level – Fig. 5. The topological scalability of this structure is noticeable.



a. First order ensemble: two elemental cells.
b. Second order ensemble: three first order ensembles.
Fig. 5. Concurrent flow networks.

As an example, the black network in Fig. 6 is supposed under fault such that part of it is islandized and must be disconnected. In the recovery scenario, node A connects the island without exceeding the load that the lowest level lines may withstand. Length-load curve analysis is then used to evaluate the proposed scenario.

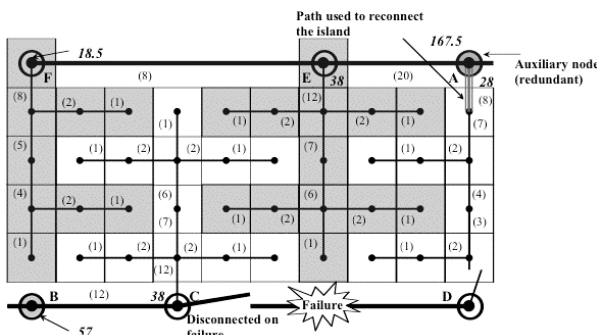


Fig. 6. An islandized subnet taken over by the second network.

4. Conclusions

The first phase of a roadmap to the new generation grid is the architecture: backbone, regional interconnections and local distribution. The *fundamental problem* is how to connect a collection of consumption nodes in a robust, reliable net that provides recovery capacity, flexibility in reconfiguration, with minimum redundancy, hence, costs.

A boundary value problem shows that only two tree networks may be combined in an interweaved, planar, non-intersecting scalable structure. The length-load integral method gives a concise picture of the electrical (moment) load (current or power) that a network supports, and the quantitative recovery means to quantify it. By using it, post-failure recovery scenarios may be evaluated, for complex networks.

Applications may be distribution networks in residential areas, camps, compounds, indoor networking with a certain degree of spatial regularity, power consumption request, multi-phase powered distribution areas may take advantage of the two-trees topology. The proposed design may have potential in structuring networks with distributed generation, for developing DC networks.

Concluding, the outcome of this study are: a *concept*: the planar constructal topology made of two concurrent, interdigitated networks that is scalable, minimum redundant and robust that we propose; and a *method* to quantify the electrical load of a specific network configuration.

Acknowledgements

A. Morega gratefully acknowledges the support provided through the research grants CEEX 05-D11-25/05.10.05, CNCSIS 358/2007. J.C. Ordonez acknowledges with gratitude the support from the Office of Naval Research through the ESRDC program and the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, under Award no. DE-FG02-05CH11292.

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