

Tool-based Optimization of the Topology of an Electrical Distribution System (EDS)

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ABSTRACT

The topology of an EDS, defined by the routing paths and by the location of the distribution boxes and the inline connectors, has a strong impact on weight and required amount of material, especially of copper, as well as on the manufacturing- and assembly time. Although a good part of the routing and packaging is fixed due to technical reasons and carry-over situations, in general there are enough optional paths and locations to allow up to several thousand alternative topologies. For these reasons, an optimization is possible as well as important. For such an optimization, in this paper a method is presented to concurrently minimize predefined criteria, e.g. the required copper, length of the wires, and the overall length of the wire bundles. It is based on designated algorithms for the variation of the topology, the routing, and the calculation of the optimization criteria as mentioned above. The paper describes the theory, the method, the implementation, and, for a midsize vehicle, initial optimization results.

CITATION: Brabetz, L., Ayeb, M., and Baumgarten, O., "Tool-based Optimization of the Topology of an Electrical Distribution System (EDS)," *SAE Int. J. Engines* 9(3):2016, doi:10.4271/2016-01-0103.

INTRODUCTION

Current electrical distribution systems (EDS) face multiple challenges in terms of cost, weight, volume, functionality, environmental requirements, and logistics. Unfortunately, these criteria must be optimized not only for a single EDS with specific feature content but for all its optional variants, of which the number can easily exceed several million. In addition, the electrical system description, which consists of the wiring diagram, communication architecture, configuration, and the spatial position of the electrical components, undergoes numerous changes during the development process and thus continually redefines the boundary conditions of the EDS layout. For these reasons, computer-aided tools and methods are mandatory in order to determine the optimum EDS design within a given time frame, e.g. [1][2][3].

Fig. 1 lists the major approaches for the improvement of the physical EDS if the electrical system description is fixed. As an example, their impact on the criteria "weight" is depicted. Even though the assessment is subjective, it shows that the layout of the topology, defined by the routing paths and by the location of the distribution boxes and the inline connectors, is fundamental to the optimization of the EDS. As described in fig. 2, it affects not only the weight and the costs for the material, manufacturing, and assembly, but also the electrical properties such as voltage drop, circuit impedances, EMC characteristics, and energy losses.

Although a good part of the routing is predefined due to given packaging, environmental constraints, and carry-over situations, in general there are enough optional paths and locations to allow up to several thousand alternative topologies. Furthermore, in the early development phase, this number might be even higher.

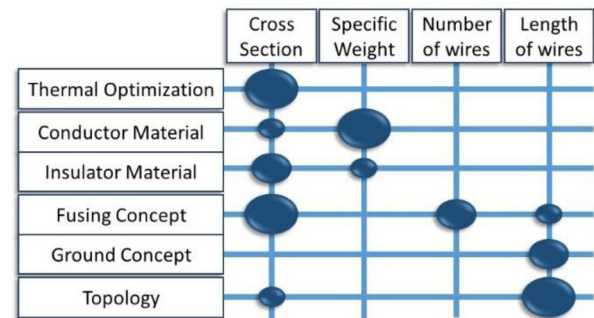


Figure 1. Impact of various EDS design approaches on the criteria "weight"

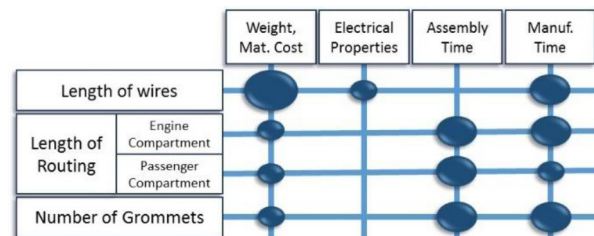


Figure 2. Relevance of the topology on EDS design criteria

The method presented in this paper uses a rule-based altering of topologies and the calculation of their respective optimization criteria as mentioned above. The approach applies KBL (harness description list) data to describe the electrical systems, components, and their locations, and specific algorithms for routing and splice setting and the creation of new alternative topologies. A simple user interface allows the addition of optional routing paths and distribution box positions, and also the definition of the parameters that should not be

altered. The paper describes the theory, the method, and the implementation. Finally, for a midsize vehicle, initial optimization results are presented and discussed.

METHOD AND THEORY

Figure 3 shows the major steps of the method as a simplified flow chart. In principle, it is a straightforward approach which consists of (a) the transfer of the spatial information into the form of a graph description, (b) the alteration of the topology, (c) the calculation of all distances, and (d) the optimization of the splice locations. These steps are described in more detail in the following paragraphs. For each found topology, the aforementioned criteria are calculated.

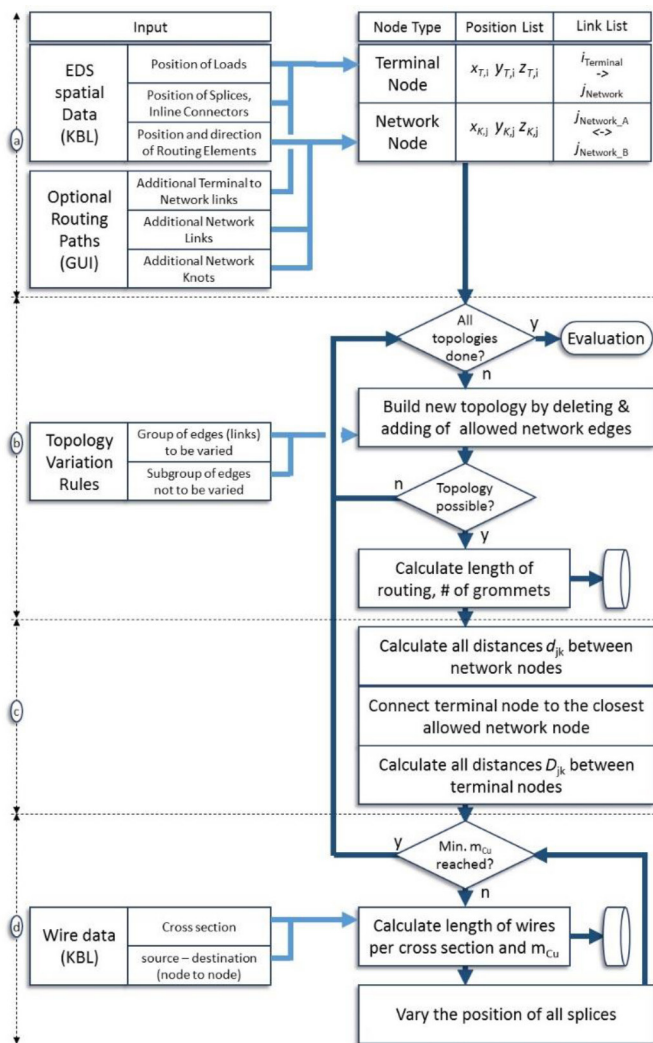


Figure 3. Simplified flow chart of the applied method

Graph Description (a)

Normally, the required spatial information is generated by using specific 3D CAD tools. Thus they are available but must be converted into the form of a graph description due to the requirements of the following algorithm. Two types of nodes and edges are used:

- Terminal nodes are connectors, splices, in-line connectors, and ground connectors, whereby their edges are defined as links to the network nodes, and

- Network nodes are points describing the routing of the EDS, whereby their edges are defined as links between network nodes.

For the alteration of the topologies additional network nodes and edges as well as optional edges between terminal and network nodes can be entered in order to describe alternative routing paths.

Table 1. Required quantities and parameters

Quantity or parameter		Terminal	Network	Comment
Nodes	Index	v	μ	integer
	Position	x_v, y_v, z_v	x_μ, y_μ, z_μ	vehicle coordinates
	Type	m_v	-	connector, splice,...
	Option	-	on_μ	alternative node y/n
Edges	Index	i	j	integer
	Node-node	$v_i - \mu_i$	$\mu_{a,j} - \mu_{b,j}$	linked nodes
	Location	le_i	le_j	Engine-, passenger compartment, with/w/o grommets
	Option	oe_i	oe_j	alternative edge y/n
	Var. group	-	ve_j	integer
	Subgroup	-	se_j	integer

Table 1 lists the required quantities. The parameters “option” and “location” indicate whether the node or edge belongs to an alternative routing path and where an edge is located. The parameters “var. group” and “subgroup” are explained in the next paragraph. Finally, figure 4 shows the 3D- (from KBL data) and the derived graph representations.

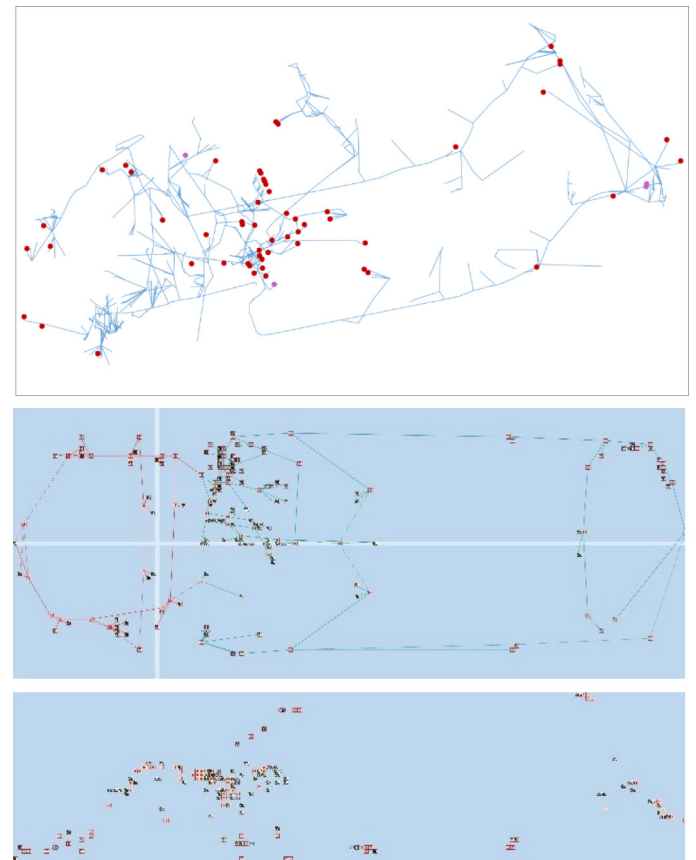


Figure 4. Above: 3D presentation based on CAD data, middle: xyand xz-diagrams of the derived graph

Alteration of Topology (b)

If n_T and n_N are the numbers of terminal and network edges, the count of possible combinations is $2^{(n_T + n_N)}$ (although just a small fraction of these are functional topologies). Thus several measures must be taken to minimize this count in order to allow a reasonable calculation time. The first approach is to alter only the network edges and then link the terminal nodes to the closest network nodes. Second, as only a limited number of network edges can be altered due to technical reasons, these edges are identified by a variation group number. In addition, it is possible to combine all edges that should not be altered independently by marking them with an identical subgroup number. Moreover, non-functional combinations are deleted. Finally, for each created topology variant, the length of routing paths $R(l_e)$, sorted by the location l_e , is calculated for the following evaluation.

As an example, figure 5 shows a topology investigation of the routing of the front of the engine compartment (which is the far left section of figure 4, middle). Four network edges are identified to be altered (bold lines in figure 5a). Supposing the variation group number of the front-end investigation is “2”, this number is assigned to all these edges. The two adjacent edges at the lower end are not independent. For this reason, they get an identical subgroup number, which reduces the number of potential combinations from 16 to 8. Two of these are technically not possible (figure 5b) as the terminal nodes cannot be connected. So finally, just 6 topologies (figure 5c) are found, but of course, more complex investigations (or combinations thereof) will result in much higher numbers.

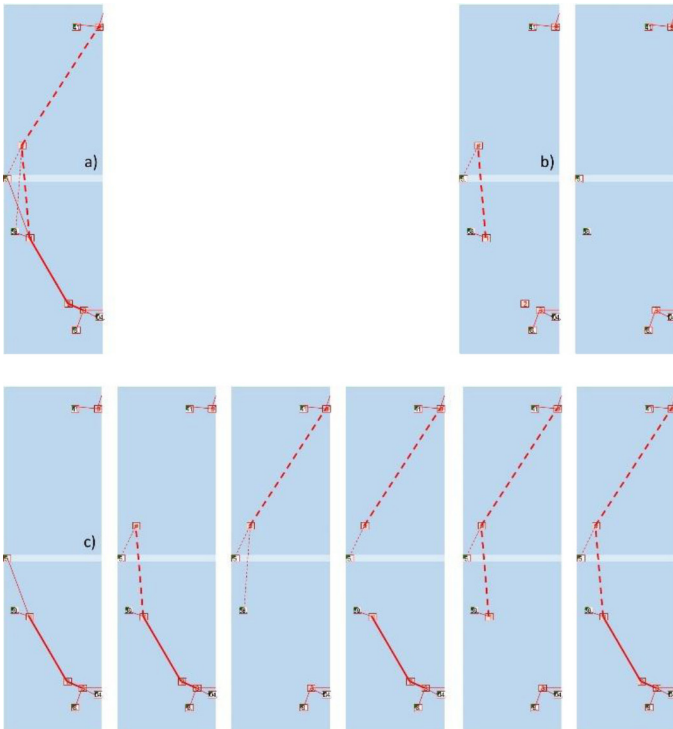


Figure 5. a) All possible edges are shown, bold lines indicate edges that are allowed to be altered, b) combinations technically not possible, c) potential topology variants

Calculation of Distances (c)

The length of the edges is approximately given by

$$\tilde{w}_{v_i, \mu_i} = \begin{cases} \sqrt{(x_{v_i} - x_{\mu_i})^2 + (y_{v_i} - y_{\mu_i})^2 + (z_{v_i} - z_{\mu_i})^2} & (v_i, \mu_i) \in \{(v_i, \mu_i) | 1 \leq i \leq n_T\} \\ \infty & \text{else} \end{cases}$$

$$w_{\mu_a, \mu_b} = \begin{cases} \sqrt{(x_{\mu_a} - x_{\mu_b})^2 + (y_{\mu_a} - y_{\mu_b})^2 + (z_{\mu_a} - z_{\mu_b})^2} & (\mu_a, \mu_b) \in \{(\mu_a, \mu_b) | 1 \leq j \leq n_N\} \\ \infty & \text{else} \end{cases} \quad (1)$$

where the distances between non-adjacent nodes are here defined to be infinite. Based on (1), the distance d_{μ_a, μ_b} between each network node can be calculated by using the Floyd algorithm [4] which is presented by the following pseudo code:

$$d_{\mu_a, \mu_b} \equiv w_{\mu_a, \mu_b}$$

$$\text{For } \mu_c = 1 \text{ to } n_N$$

$$\text{For } \mu_a = 1 \text{ to } n_N$$

$$\text{For } \mu_b = 1 \text{ to } n_N$$

$$d_{\mu_a, \mu_b} = \min(d_{\mu_a, \mu_b}, d_{\mu_a, \mu_c} + d_{\mu_c, \mu_b})$$

$$\text{Next } \mu_b, \mu_a, \mu_c \quad (2)$$

However, the actual quantity of interest is the distance between terminal nodes, because it determines the lengths of the wires.

$$D_{v_a, v_b} = \tilde{w}_{v_a, \mu_a} + d_{\mu_a, \mu_b} + \tilde{w}_{v_b, \mu_b}$$

with

$$\tilde{w}_{v_a, \mu_a} \in \{\tilde{w}_{v_i, \mu_i} | 1 \leq i \leq n_T\} \wedge \tilde{w}_{v_a, \mu_a} = \min(\tilde{w}_{v_a, \mu_i} | 1 \leq \mu_i \leq n_N)$$

$$\tilde{w}_{v_b, \mu_b} \in \{\tilde{w}_{v_i, \mu_i} | 1 \leq i \leq n_T\} \wedge \tilde{w}_{v_b, \mu_b} = \min(\tilde{w}_{v_b, \mu_i} | 1 \leq \mu_i \leq n_N) \quad (3)$$

Optimization of Splice Location and Wire Length Calculation (d)

The wiring diagrams provide for every wire k the information

$$\text{Terminal node numbers: } (v_{a,k}, v_{b,k})$$

$$\text{Cross section: } q_k \quad (4)$$

Thus the wire length per cross section q_i is given by

$$L(q_i) = \sum_{k=1}^{n_k} D_{v_{a,k}, v_{b,k}} g_{k,i}$$

$$g_{k,i} = \begin{cases} 1 & \text{if } q_k = q_i \\ 0 & \text{else} \end{cases} \quad (5)$$

and one obtains as the overall conductor volume V_{Cu} :

$$V_{Cu} = \sum_{i=1}^I L(q_i) q_i \quad (6)$$