Multi-objective optimal dimensioning of modular power converters

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(Dated: October 27, 2014)

Using optimization as a design approach has been used in many disciplines for a long time. Using optimization in the field of power electronics has not. This is a popular summary of the masters thesis *Multi-objective optimal dimensioning of modular power converters*. In this thesis, a methodology for optimization of power electronics has been developed.

Many modern power electronic converters today are based on a modular topologies where several sub-converters are associated in a series parallel combination. For a given functional specification the dimensioning of such complex structures becomes a difficult task. This is mainly due to the large number of possible combinations available, each one leading to several end results according to different goals and respecting the entire domain of constraints. In conventional dimensioning techniques the expertise of the design engineer in charge may have a large impact on the end result. Furthermore, one might never be sure if a given solution is the optimal one or if a better design would be possible. If the possibility of finding the optimal solution with a well formulated methodology would exists, the dimensioning of these systems can save a lot of energy and cost.

I. APPLIED OPTIMIZATION

Optimization is used in many disciplines such as physics, economics and engineering. It means to find the best, "optimal" solution to problems. What the optimal solution might be depends on the purpose of solving the problem. It can be for example to minimize or maximize different factors such as efficiency, volume, different kind of costs, sustainability, time, etc. The number of different ways to solve a problem to accomplish these goals grow large even for simple problems. It often becomes impossible to try all possible combinations by hand which calls for the use of computer based optimization. One software that can handle optimization problems are MATLAB which contains several different solvers for optimization.

A. Problem formulation

It is not easy and obvious how to formulate an optimization problem, but its important to do this correctly since this is the way of telling the computational software what the problem is. The four steps below describe how to formulate an optimization problem.

1. **Problem description.** To start with, a descriptive statement of the problem needs to be formulated. In this statement the scope of the problem is outlined. The overall objectives to be optimized and the limitations of the problem are described.

2. **Data and information collection.** In this step all the information needed to formulate the problem as a strictly mathematical problem should be collected. This information can for example be material properties, performance requirements, resource limits and cost of raw materials.

3. **Optimization criterion.** The objective to be optimized needs to be described as a function. This function is called the objective function, and is the function that should be either minimized or maximized, depending on the problem formulation. In some cases two or more objective functions may be identified, and the problem formulation can then be described as either a multi- or single-objective problem. Constraints make up the design space of the optimization problem with respect to physical boundaries, restrictions regarding performance and other possible criteria. They are, together with the objective function, needed as the mathematical description of the problem. There are several different types of constraints and the choice of these play an important role in the choosing of an optimization solver.

4. **Definition of design variables.** Design variables, or optimization variables, are the set of variables needed to mathematically describe the problem with constraints and objective functions. These variables are altered by the optimization algorithm in order to optimize the objective function. They are regarded free since they are able to assume any value possible within the bound of satisfying the constraints. The design variables should in the greatest extent possible be independent of each other in order to add flexibility to the problem. Once all the design variables are determined, these are given start points. Some solvers require

the start points to be located in the feasible design space.

II. MULTI-LEVEL BUCK CONVERTER

The methodology developed in this work attempts in providing a systematic and automatized tool to solve the problem of multi-objective dimensioning. The methodology is tried out on a multi-level topology which in this case consist of an multi-level buck converter. To be able to optimize the converter, shown in figure 1, a mathematical model of the converter needs to be established. The model needs to describe the dynamics as well as the physical properties and limitations of the converter.

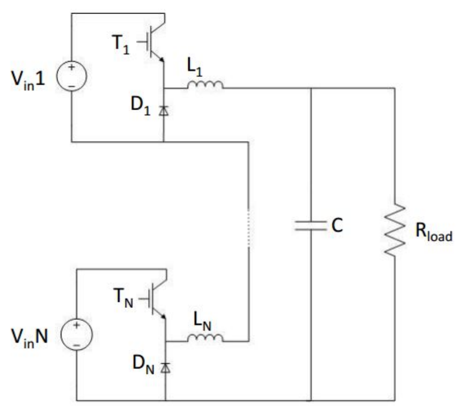

FIG. 1. Multi-level Buck converter

It is desirable to invest in an as cheap converter as possible. It is also desirable to invest in a converter that run as efficient as possible since it will save money in the long run. These two properties almost never coincide and the objective here is to find the optimal compromise resulting in the lowest total cost (equipment and installation cost and operational cost integrated over the lifetime of the components). The optimization problem is a minimization problem with the objective function as the total cost (see equation 1).

$$Cost_{total} = Cost_{capital} + Cost_{operational} \quad (1)$$

To find this compromise between capital cost and operational cost is called to find the Pareto optimality. A Pareto optimality is a state of allocation where it is impossible to make one function better without making at least one other worse. This situation is possible to show as a Pareto front, see figure 2.

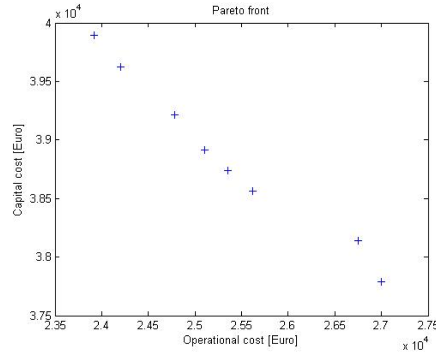

FIG. 2. Pareto front

By changing the relation between capital investment cost and operational cost it is possible to decide how strongly the optimization solver should focus on minimizing one part of the objective function and in what extent it can neglect another. It is also possible to change the goal of the optimization by adjusting the weighting factors in the objective function. These changes and weightings will affect the Pareto front.

III. CONCLUSIONS

The main feature with this methodology is that it is not limited to be used only with power electronics. The methodology can be used on nearly anything that can be expressed with a mathematical model and translated into objective functions and constraints. The complexity of figuring out the optimal design by hand points out the importance of this kind of methodology. An optimization is easily configured in the software using the presented methodology. It is describing the system that is the time consuming part but for an experienced engineer this can often be done easily. Many of the formulas needed to perform an optimization is also used in the conventional approach of designing. The extra work of putting them into the optimization software and using this methodology is small compared to the energy and money that can be saved if an optimal design can be proven found. We believe that the increasing importance of energy efficiency is forcing a paradigm change in the methodology of designing power electronics. This will make a methodology like the one presented in this work a necessary approach in the future.