# A HYBRID METHOD FOR DESIGNING POWER ELECTRONIC DEVICES BASED ON THEIR LIFE CYCLE

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**Abstract:** The work presents a hybrid approach to the design of power electronic devices, which combines various techniques with the aim of achieving optimal coverage of certain indicators under set restrictions and requirements. Thus, by jointly using state-of-the-art means of applied mathematics, computer modeling, artificial intelligence techniques and information and communication technologies, a new method for the optimal design of power electronic devices, oriented to their life cycle, considering the specifics is described for different applications.

**Key words:** hybrid method, life cycle, optimal design, power electronic devices.

## 1. INTRODUCTION

Power electronics is focused on the conversion and control of electrical energy through electronic devices, in most cases based on semiconductor elements operating in key mode. It is an interdisciplinary field that covers various components and systems such as rectifiers, inverters, regulators, etc. Designing power electronic devices is a complex process that requires balancing multiple factors and constraints.

The main stages related to the design of power electronic devices are as follows [1-3]:

1. Requirements analysis. First of all, the requirements for the device must be determined: power, voltage, current, frequency, depth of adjustment of certain values, etc.
2. Topology selection. Depending on the application, it is necessary to choose an appropriate topology for the designed device, such as half-bridge, full-bridge, flyback, boost or buck converters. Also, following a technical-economic analysis, justify the use of a modular structure with an optimal number of modules.
3. Selection of components. Selection of suitable power semiconductor elements (such as IGBTs, MOSFETs, diodes) and other passive building components (such as inductances, transformers, capacitors and resistors).
4. Thermal design. Ensuring sufficient cooling for the power components, through radiators, fans, liquid cooling.

5. Schematic design. Prepare the circuit part of the device by selecting/designing all the building blocks.

6. Simulation. Using specialized software such as LTSpice, MATLAB/Simulink, Python or others to simulate different operating modes of the device to verify that it will perform as expected.

7. Design the printed circuit board, taking into account the location of the components, traces, power supply and grounding.

8. Prototyping. Assembling a physical prototype of the device for testing in a relevant environment.

9. Testing and Validation. Conducting various tests to verify that the device meets the requirements and works reliably in real-world conditions.

10. Optimization. Based on the test results, make the necessary adjustments and optimizations to the design.

11. Documentation. Create detailed documentation for the designed device, including schematics, component lists, installation and operating instructions.

In this sense, the successful development and application of power electronic devices requires specialized knowledge and experience from diverse fields of technology. In addition to the technical aspects of design, it is also important to consider issues related to the safety, reliability and value of the device, and more recently, its environmental impact. In the present work, given the complexity of the design process of power electronic devices, the part related to circuit design will be considered mainly.

## 2. LITERATURE REVIEW

The circular economy is an economic model that aims to minimize waste and maximize the use of resources. This is achieved by: designing for sustainability, where products are designed to be longer lasting, easily repairable and recyclable; extending the life cycle of products, through effective maintenance, repair, reuse and recycling; closing the resource loop by using renewable resources and recycling materials to reduce the need for extraction and use of new raw materials and waste prevention by minimizing waste with efficient planning and production. Power electronics can support the development of the circular economy in several ways:

1. Extending the life of electronic devices by developing components and systems that are more efficient and long-lasting, thereby reducing the need for frequent equipment replacement.

2. Power electronics play a key role in increasing the energy efficiency of systems, which leads to a reduction in energy consumption and resources needed for its production.

3. By using power electronic devices, renewable energy sources are more efficiently integrated into the electrical grid, ensuring sustainable energy production.

4. Recycling and reuse of electronic components. The design of electronic devices should also be carried out with a view to their easy disassembly and recycling to reduce waste and facilitate the reuse of components.

The circular economy and power electronics are interconnected fields that can work together to achieve sustainable development. The integration of energy efficient technologies and waste minimization approaches in the production and consumption of electronic devices is a key step towards a more sustainable future.

A power electronic device should be considered as composed of two power sources, one at the input and one at the output, interconnected by a matrix of switches that operate in a specific timing pattern and passive L and C elements, as shown in Figure 1. A system of power electronic devices is built by cascading two or more of these basic cells [4-6].

The input power sources are either of the voltage source or current source type. In this sense, the circuit synthesis process begins with placing a voltage/current source at the input and finding different switch configurations that are acceptable to achieve the output power source parameters. The passive LC circuit participates in the energy conversion process, depending on the topology and operating mode, it works around or far away from its resonance frequency [7]. In this way, it is possible to describe or generate a different topology by specifying the type of switch from the matrix: unidirectional or bidirectional blocking, unidirectional or bidirectional conduction, and also the sequence of their switching.

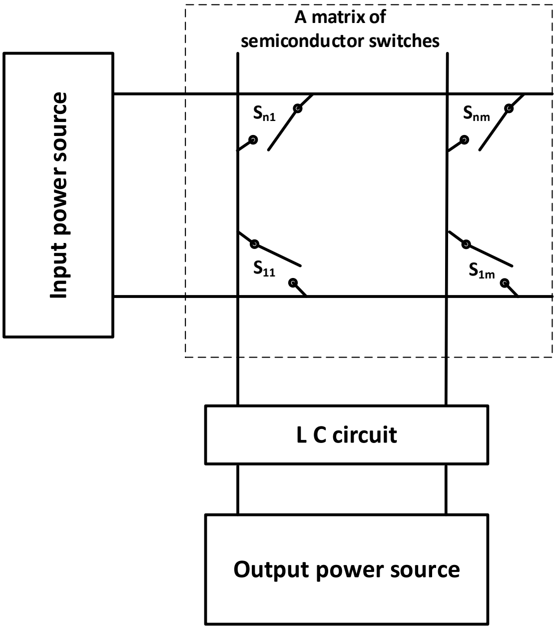

*Fig. 1. Basic presentation of a power electronic device*

The methods used for the design of power electronic devices at the moment are characterized by:

1. They are based on generally accepted average estimates of the state variables of quasi-static modes of operation, and evidence for the validity of these procedures under different design requirements is not always available.

2. As a result of the calculations, values of the schematic elements are obtained, which are impossible to materialize. As a consequence, as close as possible to the calculated values of the elements are selected. This necessitates repeated repetition of

the calculation procedure until the requirements of the assignment are satisfied or the initially imposed restrictions are relaxed.

3. In the design process, do not take into account the influence of the parasitic properties of the circuit elements such as: non-linearities; fluctuations of their nominal parameter values and strong dependence on operating modes and external disturbances (input supply voltage, operating temperature, aging, etc.).

4. If the relationship between the selection of parameters and the dynamics of power electronic devices, the amplitude values of the currents and the voltages on the building elements is taken into account, then the process of selecting elements is further extended and finding a solution to the task is not guaranteed.

5. There is a lack of rational methodologies for the design of power electronic devices and systems that approach from general positions regardless of specific topologies and thus enable the formalization and unification of determining the values of circuit elements.

6. On the basis of a study of the specialized literature, it was concluded that in the design phase of power electronic devices, AI techniques are at least applied, which makes it possible to carry out research in this area.

In this sense, there is a certain lag between the achievements in the production and technologies of building blocks for power electronics and the methods of proctoring power electronic devices, which relatively rarely apply the latest achievements of modeling, computational mathematics and software products.

## 3. PROPOSED ALGORITHM

Designing power electronic devices with a life cycle orientation requires a hybrid approach that integrates concepts from the circular economy and modern electronics design methods. The implementation of this approach should include the following main elements:

1. Conceptual design, which includes: assessment of needs and requirements to form an understanding of specific application requirements and user needs; choosing sustainable and environmentally friendly materials that are easy to recycle and have a low impact on the environment.

2. Detailed design based on: designing devices with modular components that can be easily replaced or upgraded and using components with high durability and reliability, and also selecting and designing circuits where there is a minimization of stress on them.

3. Manufacturing, by applying: efficient manufacturing processes that minimize waste and energy consumption and applying strict quality control to ensure the longevity and reliability of the devices.

4. Use and maintenance with the following features: designing devices that are easy to maintain and repair, including easy and serviceable access to key components and providing long-lasting software and hardware upgrade options, thereby extending the life cycle of the device.

5. End-of-life, by ensuring: designing devices that are easy to disassemble and recycle and using waste management strategies that minimize environmental impact.

This design approach is applied in combination with the following tools and methods: Life Cycle Analysis (LCA). Using LCA tools to assess the ecological footprint of the device throughout its life cycle; Design for Disassembly (DFD), by incorporating DFD principles to facilitate disassembly and recycling; Using simulation tools to optimize the design, energy efficiency and reliability of devices and collect user data to improve the design and functionality of future devices.

An example description of the full implementation of the hybrid algorithm for design is given in Figure 2. The idea of the presented algorithm is depending on the specific needs of the project, and according to the available resources to use completely or partially its individual modules.

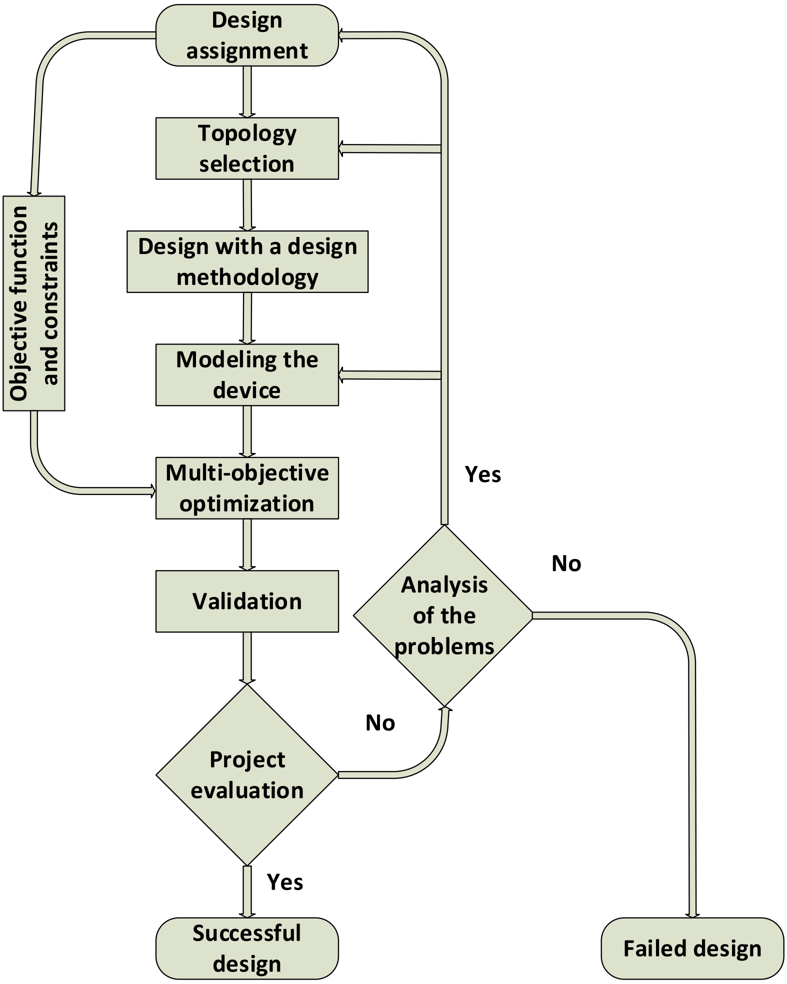

*Fig. 2. An example algorithm of hybrid life-cycle-oriented design of power electronic devices*

For example, multicriteria optimization can be replaced by a graphoanalytic method for enclosing a region of feasible solutions or repeated experiments and selection of results (as shown in the next section). Also, the design can be carried out partially and initial approximations based on experience from previous projects and limitations related to technological, economic or environmental requirements can be used. In this aspect, the proposed algorithm is maximally flexible and adaptable to the specific needs and specifics of the project. In the next section, the main points of application of the hybrid design method and evaluation of the obtained results based on a bridge-parallel resonant DC-AC converter (current source inverter) will be demonstrated.

## 4. SIMULATION

An example of the application of a hybrid design method is a resonant inverter with a parallel-loaded capacitor (parallel DC-AC converter). The schematic of the power electronic device under study is shown in Figure 3. It consists of an input DC source $V_{DC}$, with its rolling resistance $R_I$, an input filter capacitor $C_{IN}$, four semiconductor switches (thyristors T1 to T4), a load RL and a parallel load capacitor C.

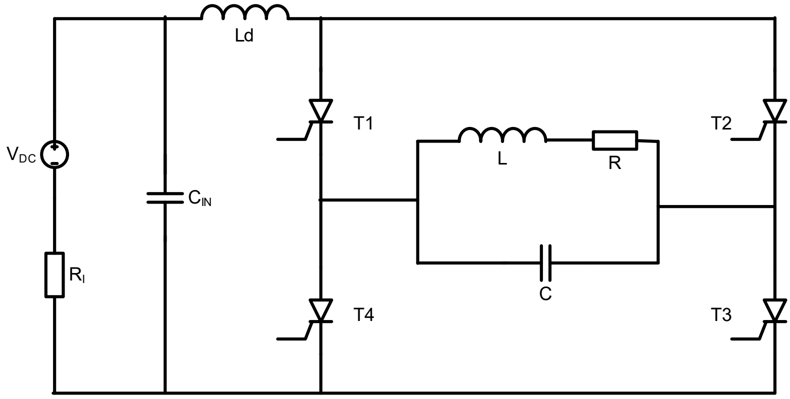

Fig. 3. Resonant inverter with parallel loaded capacitor (parallel resonant inverter)

The device design limitations are defined as:

- requirements regarding the harmonic composition of the output voltage - the condition must be met:

$$\frac{P_2+P_3}{P_1}\le\delta\ , \tag{1}$$

where $P_1$, $P_2$ and $P_3$ are respectively the powers corresponding to the first, second and third harmonic of the output voltage, and $\delta$ – set coefficient of the harmonics;

- maximum value of the output voltage (voltage on the load capacitor):

$$U_{C\max}\le U_l$$

- set dynamic indicators, such as the duration of the transition process being minimal or within certain limits;

It is assumed that with a positive signal of the control generator, a signal is given to unblock transistors T1 and T3. i.e. g1=+1, otherwise g1=-1.

The dynamics of the processes in the researched parallel inverter is described by the following system of differential and logic equations:

$$
\begin{aligned}
&L\frac{dI}{dt} = -R_L I - U_C + U_{CIN} g_2 \\
&C\frac{dU_c}{dt} = I - \frac{U_C}{R} \\
&C_{IN}\frac{dUC_{IN}}{dt} = \frac{V_{DC} - U_{CIN}}{R_I} - I \\
&g_2 = \begin{cases} +1 \ if\left(\left(g_1 > 0\right) and\ \left(I > 0\right)\right)\ or\left(\left(g_1 < 0\right) and\ \left(I > 0\right)\right) \\ -1 \ if\ \left(g_1 < 0\right) and\ \left(I < 0\right)\ \ or\ \left(\left(g_1 > 0\right) and\ \left(I < 0\right)\right) \end{cases}
\end{aligned} \qquad (2)
$$

the following designations are used: I – current in the AC circuit, Uc – output voltage of the inverter, UCIN – voltage on the input filter capacitor. Assuming the ideality of the input power source, system (2) is represented as follows:

$$
LC\frac{d^2U_c}{dt^2} + \left(R_L C + \frac{L}{R}\right)\frac{dU_c}{dt} + U_c = g_2 U_s \qquad (3)
$$

The following parameters are set for conducting the numerical experiments with the thus developed model:

$\underline{U}-$ minimum and $\overline{U}-$ maximum value of DC supply voltage;

$\underline{R}-$minimum and $\overline{R}-$maximum value of load resistance;

$\underline{C}-$ lower limit and $\overline{C}-$ upper limit of the interval in which the required value of the capacitor capacity should be;

$\underline{L}-$ lower limit and $\overline{L}-$ upper limit of the interval in which the desired value of the choke inductance should be;

$\underline{f}-$ lower limit and $\overline{f}-$upper limit of the frequency interval in which the desired value of the natural frequency of the RLC circuit should be.

With a set maximum quality factor of the parallel load circuit $Q = 8$, a lower limit of switching frequency 1800 Hz and an upper limit 3000 Hz in accordance with equation (3), the range of permissible values for L and C is obtained, which is presented in Figure 4. After the graphical interpretation of the equation (3) and the design restrictions introduced, the area of permissible values of L and C is obtained. It is located in the contour closed by the two red and cyan lines of Figure 4. In this way, the area of permissible values is determined of the building blocks of the inverter.

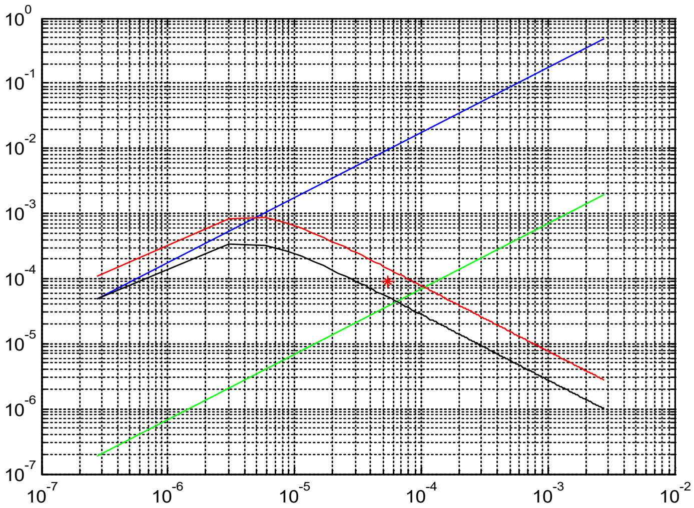

Fig. 4. Setting the operating area of a parallel resonant inverter to a parallel loaded capacitor resonant inverter (parallel resonant inverter)

## 5. RESULTS AND DISCUSSION

With the created inverter model, a planned two-level center-point experiment was conducted. The number of factors n = 4 was chosen. The factors subject to variation are: the input supply voltage; inductance in the resonant loop; capacitance of the capacitor in the resonant loop; switching frequency. For the purposes of the research, experiments will be conducted. i.e. 17 experiments. The variation of the parameters is 5% with respect to the center point. Processing of the results obtained by this algorithm.

With a set maximum voltage of the capacitor $Uc\max = 1000V$ and a minimum value of the load current $I_{R\min} = 1100A$, experiments No. 7 and No. 15 meet the set limits.

```
R=1.250e-001 f=2.280e+003 E=5.000e+002 Eta=93.01%  Uc OK  Tok R OK
R=1.250e-001 f=2.280e+003 E=5.000e+002 Eta=93.15%  Uc OK  Tok R OK
```

In the event that a more precise determination of the parameter values is required, a new search is performed, using the results of these experiments as initial values.

## 6. CONCLUSION

In this paper, the concept of hybrid design of power electronic devices was presented, where the multi-criteria optimization used in the design can be replaced by more pragmatic approaches, such as the proposed grapho-analytical one. A hybrid lifecycle-oriented design method for power electronic devices requires the integration of different approaches and tools. This method not only reduces the environmental footprint, but also increases the efficiency and longevity of the devices, resulting in more sustainable and cost-effective solutions. A comparison between classical power electronic device design methods and the life cycle-based hybrid method is made by looking at various aspects of the design process and its results. The main differences between these two design approaches are in terms of [8,9]:

1. Design goals and focus.

Classical Methods (KM): Main focus on productivity, cost and time to market. Usually short-term goals focused on product functionality and specifications.

A hybrid life-cycle approach (HLCA): Focus on long-term sustainability, recycling and waste reduction. Incorporating goals to minimize ecological footprint and maximize resource efficiency.

2. Design and selection of materials.

KM: Selection of materials and components based primarily on performance and cost. Less attention to sustainability and recycling.

HLCA: Selection of sustainable and easily recyclable materials. Inclusion of sustainability criteria in the material selection process.

3. Production processes.

KM: Processes optimized for speed and low costs. Less attention to energy efficiency and waste minimization.

HLCA: Optimization of production processes to minimize energy consumption and waste. Use of green technologies and processes.

4. Life cycle and maintenance.

KM: Performance oriented design with less attention to maintenance and life cycle extension. Repairs and maintenance are often more expensive and time-consuming.

HLCA: Designing for easy maintenance, repair and modernization. Life cycle extension through modularity and easily replaceable components.

5. End of life cycle and recycling.

KM: Lack of integrated strategies for disassembly and recycling, which often leads to a greater amount of e-waste.

HLCA: Incorporating strategies for easy disassembly and recycling. Waste minimization and resource conservation.

6. Environmental impact.

KM: They often result in a higher environmental footprint due to the lack of focus on sustainability. Energy inefficiency and use of materials that are difficult to recycle.

HLCA: Reduced ecological footprint through the use of sustainable materials and energy-efficient processes. Incorporating circular economy principles to minimize waste and optimize resources.

7. Innovations and technologies.

KM: Focus on established technologies and processes to minimize risk and costs. Less attention to the integration of new sustainable technologies.

HLCA: Incorporating innovative and sustainable technologies as part of the design process. Constant search for new ways to improve energy efficiency and sustainability.

Thus, classical power electronics design methods focus on short-term goals such as performance, cost, and speed of manufacture. They often result in a greater environmental impact due to the lack of attention to sustainability and recycling. On the other hand, the hybrid method based on the life cycle integrates the principles of the circular economy and sustainable development. This approach aims to minimize waste, use sustainable materials, energy efficiency and extend the life cycle of devices. It offers long-term environmental and economic benefits while meeting increasing demands for sustainability and resource conservation.

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**Nikolay Lyuboslavov Hinov** – Associated Professor in Department of Power Electronics, Technical University of Sofia, Bulgaria. Current research interests: development and design of power electronic converters with application in industrial technologies, electric vehicles, decentralized generation of electricity and energy storage.

## *Remark:*

Manuscript has been received in May 2024 to take part in the 38th International Conference on Information Technologies (InfoTech-2024), IEEE conference, Rec. # 63258, Section E: "Technologies for System Design". It has been accepted and revised based no double-blind reviewing and has not been published in full text elsewhere.