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Comparative Analysis of Optimization Techniques for Buck ZVS Quasi-Resonant DC-DC Converter Design

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ABSTRACT: A Buck Zero Voltage Switching (ZVS) Quasi-Resonant DC-DC Converter is the subject of this research, which attempts to evaluate and contrast the different optimisation methodologies that were used in the model-based design of the converter. Both the amount of time that is necessary for each optimisation procedure and the degree to which they guarantee the performance of the power electronic device are taken into consideration during the comparison. In order to construct quasi-resonant DC-DC converters in the most effective manner possible, the primary objective is to offer a variety of ways that make use of mathematical software. Because their creation is dependent on computational procedures, which sometimes need numerous iterations to finish, these topologies were selected as the best option. A target function reference curve was used in order to achieve optimal performance of the output voltage. Using this method, optimisation may be accomplished without the need for a comprehensive design of the device. Instead, the determination of starting values and parameter intervals is accomplished by relying on base ratios, design limitations, and previous experience gathered. The optimisation of the reference curve of the output is the primary emphasis of this technique, which provides a substantial benefit over other objective functions such as minimising losses or maximising efficiency.

KEYWORDS: Buck Zero Voltage Switching (ZVS), Quasi-Resonant DC-DC Converter, Optimization Strategies, Model-Based Design

1. INTRODUCTION

"Resonance is used by quasi-resonant direct current-direct current converters in order to improve efficiency and decrease losses during the process of transferring electrical energy from one direct current to another. As its fundamental concept, quasi-resonant direct current-direct current converters combine resonant and non-resonant characteristics [1,2]. The ratio between their switching frequency and the resonant frequency is tuned for a particular application, and their switching frequency is relatively close to each other. Additionally, as comparison to DC-DC converters, this power electronic device transforms energy in a more efficient manner and with less loss.

Quasi-resonant DC-DC converters are used in a variety of applications, including power electronics, industrial systems, medical equipment, and more. [3] It is possible to use it in a variety of converter topologies, including Boost, Buck, and LLC converters, and it may work with a wide range of settings and currents based on the need of the application.

However, before using them, it is necessary to take into consideration both the benefits and drawbacks of quasi-resonant DC-DC converters. In addition to the following advantages [1,3], quasi-resonant DC-DC converters have:

- The efficiency of quasi-resonant converters is improved when compared to that of DC-DC converters. When energy is converted, there is less energy lost.
- Because they reduce electromagnetic interference (EMI), they are an ideal choice for applications that are required to comply with stringent electromagnetic norms and regulations.
- The ability to convert high powers and voltages is a feature of quasi-resonant converters.
- Comparatively speaking, they are more compact and lighter than traditional DC-DC converters.

Quasi-Resonant DC-DC converter weaknesses are connected to [3] and include:

- Controlling quasi-resonant converters requires more complicated circuitry to monitor the zero crossing of the resonant current and/or voltage. This complicates the designer's control synthesis, which increases design, setup, and operating costs and controller and device complexity.
- Quasi-Resonant converters cost more than DC-DC converters owing to their design and control complexity.
- Compared to other converters, semiconductor switches have on-time or off-time constraints that limit their working frequencies and output voltage adjustment range.
- Quasi-Resonant converters have larger part-load losses, which must be considered while designing the device.

However, Quasi-Resonant DC-DC converters, much like the majority of power electronic devices, are examined by finding the primary relationships between state variables in a predetermined mode of operation. This is done after energy has been accumulated in the inductances and capacitors of the circuit. This results in the development of approximation design approaches that do not take into consideration dynamics and operating modes. Devices are unable to function properly in transient modes such as start-up, changes in input voltage, and variations in load current when they are created using established techniques."

2. LITERATURE REVIEW

A great number of publications provide data from examinations of known modes of operation with or without controllers. This is because the need for quasi-resonant DC-DC converters is growing increasingly. A Boost Quasi-Resonant DC-DC converter sample is analysed in depth in [4], which provides a step-by-step analysis, design technique, and experimental data. In control synthesis, the output voltage is extremely steady against disturbances since it is generated by a specialist integrated circuit. "The authors also achieved a power circuit efficiency of 93.5% while the circuit was operating at full load. Buck's quasi-resonant DC-DC converter research is presented in [5]. This circumstance is one of a kind due to the fact that switching loss is eliminated when the transistor is turned on simultaneously during ZVS and ZCS. For the purpose of ensuring gentle commutations, analytical calculations demonstrated that the parameters of the resonant circuit and the switching-on time of the transistor were connected. Using the calculations, a prototype of a 3 kW sample that had an efficiency of 98.7% was generated. This reference [6] presents an analysis and design of a quasi-resonant Buck ZVS DC-DC converter with two half periods. Using analytical equations, the converter is developed and prototyped once it has been built. Both the analysis and the design are validated by the outcomes of the tests. On account of the peculiarities of control, another significant problem is the synthesis and tuning of quasi-resonant DC-DC converter controllers. In reference number 7, a comparison is made between the current-mode and linear feedback Buck quasi-resonant DC-DC converter control concepts. As a result of the filter inductance, linear feedback control monitors the median current. To provide support for the theoretical conclusions and inferences, this part includes analytical connections as well as prototype testing data. Increasing efficiency is a benefit of synchronous topologies [8]. There is a suggestion made for a unique synchronous Buck ZVS DC-DC converter that has mild commutations throughout loading changes. A Buck synchronous DC-DC converter that has resonant components is used in the Buck Quasi-Resonant DC-DC converter configuration that has been developed. The functioning and effectiveness of this circuit have been validated by laboratory testing. The modelling of quasi-resonant direct current to direct current converters is helpful in achieving quality characteristics for both the power and the controller. The three transformer less DC-DC converters that are most often used are shown in [9] as Buck, Boost, and Buck–Boost versions. Additionally, a voltage–age–mode control synthesis was carried out. The transmission functions were computed by using state-space averaging analytical equations. A variety of open and closed system stability tests, including the DC-DC converter, were carried out on the models that were implemented. Using electromagnetic processes in a quasi-resonant DC-DC converter, [10] presents yet another modelling technique that may be used. The differential equations for state variables and the logic equations for ZVS mode switching conditions are both implemented in MATLAB/Simulink. Simulink makes it possible for those who are not specialists in computational mathematics to simply apply the model, which makes it valuable for designers as well as students. As a result, the model describes the behaviour of the device in both quasi-steady and dynamic modes. The examination of the sources that were provided demonstrates that in order to design and prototype quasi-resonant converters, ingenious approaches are required owing to the peculiarities of operating modes. This is because traditional methods are unable to completely guarantee the needs and quality indicators of current power electronic devices. Model-based optimisation is a unique approach that may be developed for the purpose of analysing this category of systems. Power electronics might potentially go in the direction of using optimisation strategies for the development of power electronic devices and systems. [11] examines the optimisation techniques that are used in the manufacturing of power electrical devices for a variety of applications. A taxonomy of optimisation methodologies targeting power electronics is shown here." This article presents and summarises the finest mobile device design for a variety of applications and uses. An optimal design technique was provided by the preliminary design of power electronics, which was applied [12]. When attempting to solve the optimisation issue on a virtual prototype, it is assumed that all of the state variables are continuous. This is done in order to simplify things. The approach that was presented is shown by a virtual design of an interleaved buck DC-DC converter. In addition, the authors said that the technique might be used for quick design and prototype in order to evaluate several modes of operation, verify prototyping technologies, and negotiate conversion requirements with the sponsors of the project. Power electrical device design is optimised with the use of a continuous variable in [13]. An objective function was used in order to achieve the goal of reducing the prices of the device's components. The advantages of this technique are shown by a Boost DC-DC converter with an input filter on the supply network side. This converter is used for power factor adjustment and to reduce electromagnetic interference. Through the use of optimisation strategies, it has been discovered that the values of the building elements may be optimised to decrease their total cost while still satisfying the structural restrictions and design work requirements.

Improved optimal design may be achieved by multi-objective optimisation [14]. Within the scope of this investigation, polynomial functions are used to simulate power electronic converters for the purpose of Mult objective optimisation. The convertor Within the context of a convex optimisation issue, multi-objective optimisation may be stated as a geometric program. The use of quick and sophisticated computer tools is made possible as a result of this, which guarantees the optimality of a global solution, also known as a non-local option. There is a demonstration of the concept using optimised low-power multistage flying capacitor step-down converters. According to the data presented, geometric programming has the potential to create globally Pareto-optimal circuit parameter values in a span of twenty-five seconds on a laptop computer that falls in between the middle-range and high-end categories. In comparison to earlier optimisation approaches, this methodology has a significant benefit in that it can discover optimal designs for three force resistance topologies for a large number of design spaces in only a few hours. [15] is a reference that was used to improve DC-DC converters for high-power, low-voltage applications. These applications include decentralised electric power producing systems (photovoltaic arrays and fuel cell stacks). Power electronic converter development in renewable energy systems has a significant challenge in the form of high efficiency. This research investigates “the differences and similarities of the Isolated Flyback Boost DC-DC Converter, the regular Boost DC-DC Converter, and the Interleaved Boost DC-DC Converter in terms of their efficiency and losses. Selecting the appropriate semiconductor switch technology, whether it be Si-MOSFET or Gan-HEMT, is an essential part of the optimisation process involved here. The article [16] proposes an enhanced full-bridge (ZVS) DC-DC converter that supports a wide range of input voltage and output current. In order to achieve maximum effectiveness, an optimal design is guided by a goal function. A 1.2-kW/105-kHz prototype was used to analyse the process, and it demonstrated an efficiency that was more than 95% while operating at full load. According to [17–19], the LLC topology was considered to be the most effective DC-DC converter design. These power electronic devices are distinguished from one another by the myriads of operating modes and the intricate theoretical explanation of the electromagnetic processes that occur inside the resonant circuit. The satisfaction or non-fulfilment of specified conditions for employment under various regimes is the basis for the intricate design approaches and recusal procedures that they have in place. Reference [17] provides a one-of-a-kind architecture for the control of energy flow in a DC microgrid that stores energy. We provide an approach for optimising circuit elements in order to preserve soft commutations while also reducing the amount of device AC circuit resonant current oscillations. In laboratory prototype tests, it was shown that reducing the losses of semiconductor switches might significantly improve efficiency. Within the realm of solid-state transformers (SSTs), [18] offers the most effective bidirectional LLC resonant DC-DC converter design. The introduction of the bidirectional LLC converter was a result of the possibility of achieving higher efficiency, a wider range of zero-voltage switching (ZVS), zero-current switching (ZCS), and a control approach that was more straightforward. Through the use of an objective function, optimising the design of a device may minimise the power losses of circuit elements, hence enhancing efficiency. Reference [19] presents an optimal half-bridge LLC resonant DC-DC converter design for zero voltage (ZVS) and zero current (ZCS) switching. This architecture serves to switch between zero voltage and zero current. Utilising a fundamental harmonic approximation (FHA) model, the properties of the resonant LLC circuit were improved. The results of the experiments indicate that the optimisation strategy that was presented is an effective component of the design toolkit. The authors of references [20,21] develop resonant DC-DCs that are optimised for the charging of electric vehicles. Analysing complicated power circuit topologies using the Fundamental Harmonic Approximation (FHA) approach and subsequent optimisation methods to guarantee soft commutation and reference efficiency is done with the goal of achieving high efficiency with a broad range of load fluctuation, which is a feature of electric car batteries. By incorporating artificial intelligence into engineering research, the design of power electrical devices may be optimised. The references [22–24] provide a comprehensive review of artificial intelligence methodologies for the implementation of electronic converters with guaranteed performance under a wide variety of output conditions and application mandates. The design, prototype, and operation of power electronic devices and systems are both discussed in length, along with the many optimisation methodologies that are used. [25,26] There have been presentations and empirical demonstrations of machine learning-based methodologies for the optimal design of electrical converters.” Gathering sufficient data that is representative of the population for training purposes is the most difficult difficulty in machine learning. In most cases, mathematical models are used in order to gather this data. Data normalisation and selecting an acceptable structure to train with a suitable data set are the key challenges that face the implementation of these novel technologies.

3. ASSESSMENT OF THE BUCK ZVS QUASI-RESONANT DC-DC CONVERTER

The Buck ZVS Quasi-Resonant DC-DC Converter schematic is depicted in Figure 1. Basic elements—transistor, diode, filter inductor, and filter capacitor—form the traditional Buck DC-DC converter. Resonant elements—resonant inductance and resonant capacitor—enable soft commutations (ZVS) under particular situations. Designations include: U_d—input voltage; L_r—resonant inductance; C_r—resonant capacitance; L_f—filter inductance; C_f—filter capacity; Rload—load resistance; $T = 1/f$—transistor switching frequency; and pulse generator—Duty cycle D control pulse generator.

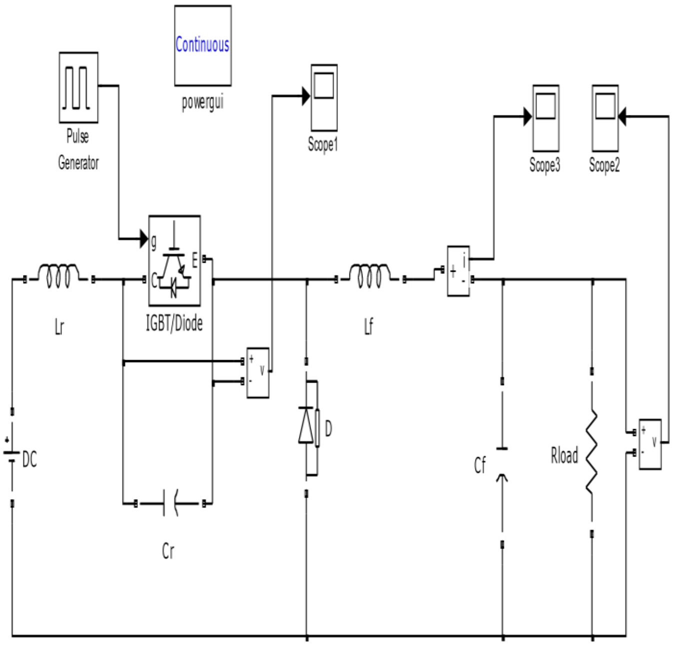

Figure 1. DC-DC Converter with Buck ZVS Quasi-Resonance

"In general, the power circuit functions in four phases: the buildup of energy in the resonant inductance, the conducting of the transistor with the diode turned off, the charging of the resonant capacitor, and a resonance process in the consecutive resonance circuit of the resonance components [2]. Following the completion of the transient processes in the power circuit, the DC-DC converter is evaluated in a mode that has been developed in order to provide separate transfer functions for one or two half-period modes of operation.

Because of the construction and operating modes of the power circuit, the diode is required to conduct both forward and reverse currents, which also need to be reflected. The circuit shown in Figure 1 is being replaced with the circuit shown in Figure 2, which corresponds to it.

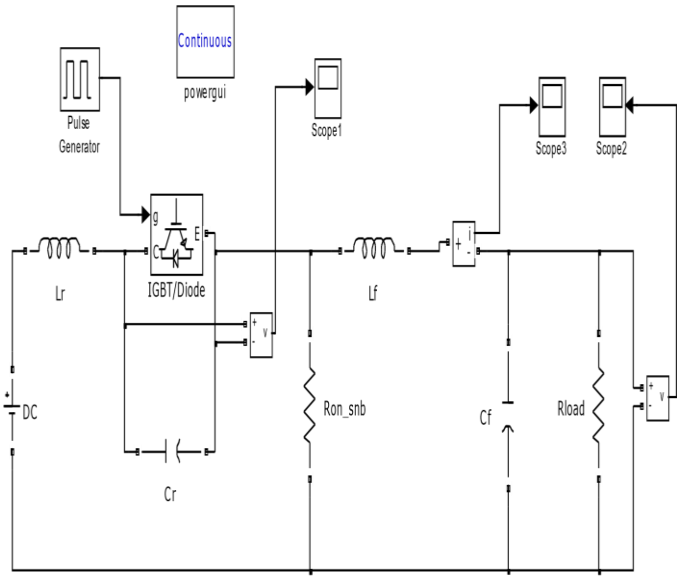

Figure 2. Equal circuit for Buck ZVS quasi-resonant DC-DC converter.

A resistance R_{on_snb} replaces diode D and adjusts its value based on the current ratio. Thus, these circumstances determine this resistance:

$$R_{on\_snb} = \begin{cases} 500, & for\ i_{Lr} - i_{Lf} \geq 0 \\ 0.01, & for\ i_{Lr} - i_{Lf} < 0 \end{cases},$$

Kirchhov's laws state that the diode's current equals the difference of the resonant and filter inductances' currents.

For modelling Figure 2's variable structure, K0 and K1 switching functions and Kirchhov's laws were utilised. This yielded the mathematical model of the power electronic device's operation:

$$\begin{aligned} &L_r \frac{di_r}{dt} + K_0.u_{Cr} + R_{on\_snb}(i_{Lr} - i_{Lf}) = U_d \\ &L_f \frac{di_{Lf}}{dt} = -u_{Cf} + R_{on\_snb}(i_{Lr} - i_{Lf}) \\ &C_r \frac{du_{Cr}}{dt} = K_0.i_{Lr} - K_1.\frac{u_{Cr}}{0.01} \\ &C_f \frac{du_{Cf}}{dt} + \frac{u_{Cf}}{R_l} = i_{Lf} \end{aligned}$$

Where

$$K_0 = \begin{cases} 0, & when\ applying\ a\ control\ signal\ to\ the\ transistor\ or\ u_{Cr} \leq 0 \\ 1, & for\ all\ other\ cases \end{cases}$$

$$K_1 = \begin{cases} 1, & for\ u_{Cr} < 0 \\ 0, & for\ all\ other\ cases \end{cases}$$

The mathematical model in Figure 3 is implemented in Simulink/MATLAB and validated using the system (2). Author's code is compiled to implement optimisation procedures using fminbnd and fgoalattain commands, resulting in optimal values based on selected criteria.

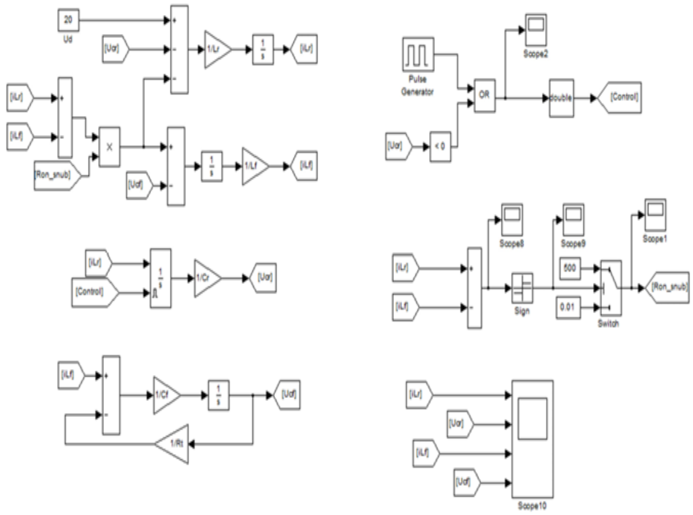

Figure 3. Mathematical model of the power circuit.

4. INITIAL SELECTION OF SCHEMATIC ELEMENTS

The Buck ZVS Quasi-Resonant DC-DC converter was designed using [1,3].

This approach yielded the following algorithm:

1. The DC-DC converter's initial DC transfer function, M_{vdc}, is set;

2. The resonant circuit's quality factor Q= M_{vdc}.
3. The converter's control frequency (f) selection;
4. Finding the load resistance's nominal value, R_{load};
5. Finding the frequency of resonant waves in each subsequent resonance circle (f0);

$$f_0 = \frac{3f_s(\pi+1)}{4\pi(1-M_{vdc})}$$

6. Duty cycle calculation for Quasi-Resonant DC-DC converter—D;

$$D = 1 - \frac{f_s(3\pi+2)}{4\pi\ f_0}$$

7. Calculating the resonant inductance (L_r);

$$L_r = \frac{R_l}{2\pi\ Q\ f_0}$$

8. Calculating the resonant capacitor's value (C_r);

$$C_r = \frac{Q}{2\pi\ R_l\ f_0}$$

Optimisation strategies are shown using a computational example with the following input parameters:
U_i = 20 V, U_0 = 10 V; f = 1 MHz; R_{load} = 10 Ω.
The following device parameters were calculated using the proposed method:
D = 54.0242%, L_r = 1.6097 µH, and C_r = 4.0242 nF.
Unfortunately, this design approach [1] did not provide a filter element calculation technique. We compute these components using Buck DC-DC converter filter element calculation [29,30].
After computing parameters this way, we get:
Minimum filter capacitor *Cf_min = 367.65 nF* and minimum filter *inductance Lf_min = 48.849 µH*.
With these two design methods, we may pick converter design parameters:

$$L_r = 1.6\ \mu H,\ C_r = 4\ nF,\ L_f = 0.5\ \mu H,\ and\ C_f = 37\ \mu F.$$

The Buck ZVS Quasi-Resonant DC-DC Converter was simulated using these parameters, and Figure 4 displays the results (from top to bottom: output voltage $U_0 = U_f$, transistor voltage, and resonant capacitor u_{Cr}—for the whole process and in enlarged view to illustrate ZVS mode). The results are shown in the figure. While the transient process is taking place, the output voltage and the voltage of the resonant capacitor are both greater than they were in the established mode."

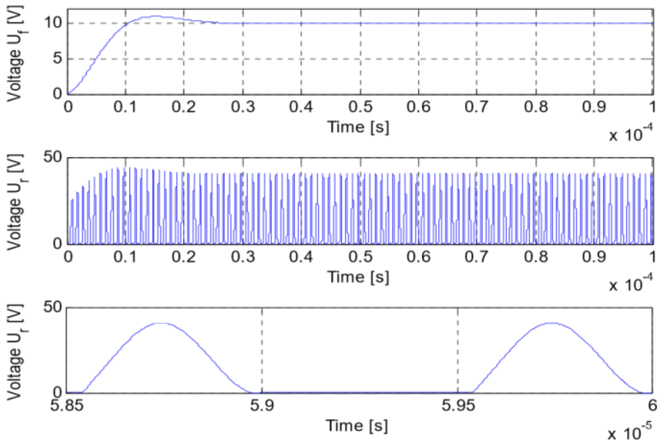

Figure 4. Timing diagrams from the Buck ZVS Quasi-Resonant DC-DC converter simulation research, from top to bottom: output voltage U_f, transistor voltage, and resonant capacitor u_{cr}, throughout the process and expanded.

Due to non-matching assumptions and the fact that the above two design processes include classical and quasi-resonant DC-DC converters, the findings are approximate. The authors will utilise the aforementioned values as starting estimates to launch numerical optimisation processes to better tune these parameters.

5. A TWO-CRITERIA OPTIMISATION PROBLEM WITH LIMITS FORMULATED

To get the best possible result while adhering to the constraints, we will use numerical optimisation. In order to evaluate the root mean square error between the reference and actual output voltage trajectory and the maximum voltage between the resonant capacitor and transistor, we will attempt to achieve specific dynamics. These dynamics will be evaluated using two criteria, which are denoted by the letters $J_1(x)$ and $J_2(x)$. It is planned to make use of equalities constraints, which include model equations (1–2) and the resonance condition constraint. It is also going to be stipulated that there will be limits on the types of inequalities, such as restricting the change of circuit elements and ensuring that there is continuous current through the filter inductance. It is the selection of the elements L_r, C_r, L_f, and C_f in the converter circuit that will decide the two criteria.
Calculating the first criterion $J_1(x)$ requires the use of the analytical equation of an appropriate reference trajectory, which is denoted by the symbol u_{Cf_ref} [31].

$$u_{C_{f,ref}} = 10(1 - e^{-t/T}),\ for\ t \in [0,\ 1\ \times 10^{-4}]\ and\ T =$$

The chosen trajectory will be utilised to find an appropriate value of L_r, C_r, L_f, and C_f to minimise functional difference between the reference shape u_{Cf_ref} and the simulated voltage u_{Cf}.

$$J_1 = \int_0^{t_{end}} \left(u_{C_f} - u_{C_{f,ref}}\right)^2 dt \underset{(C_r, C_f, L_r, L_f)}{\rightarrow} \min$$

Second, $J_2(x)$ uses the maximum resonant voltage u_{Cr}. The resonant voltage must not exceed two or three times the input voltage U_d., hence we will minimise:

$$J_2 = u_{Cr} \underset{(C_r, C_f, L_r, L_f)}{\rightarrow} \min$$

This creates a two-criteria optimisation problem that minimises a vector of goals.

$$J = [J_1, J_2] \underset{(C_r, C_f, L_r, L_f)}{\rightarrow} \min$$

This optimisation issue is addressed under these constraints:
Inequalities establishing schematic element boundaries:

$$C_{r,\min} \le C_r \le C_{r,\max}, \quad C_{f,\min} \le C_f \le C_{f,\max} L_{r,\min} \le L_r \le L$$

Providing continuous current mode via filter inductance inequality:

$$i_{Cf}(t) > 0.2, \text{for } t \in [\tau, t_{end}]$$

Equality—model equations (1–2);
Equality preserves the resonance frequency and operating mode chosen during design:

$$L_r C_r = \textbf{constant}$$

Two-criteria optimisation problems cannot be addressed using Simulink/MATLAB's 'Check Against Reference' optimisation process, as shown in [31]. Thus, this job needs the author's code.
We also have a vector optimisation issue with dependent $J(x)$ components, thus the Pareto frontier is the answer. A Pareto-optimal (non-improvable) approach improves one aim while deteriorating another. The Pareto frontier is difficult to find, and even if it is, an extra restriction will be needed to remove a single point from it. To design the converter, unique circuit element values must be chosen. We won't search for the complete Pareto frontier, but rather reduce the issue to many one-criteria problems, as illustrated in the following sections.

6. MINIMISATION TO A CONSTRAINT-BASED ONE-CRITERIA OPTIMISATION ISSUE

“Multicriteria optimisation often reduces two-criteria problems to one-criteria problems with restrictions. This technique uses one criterion as a constraint and the other as an objective function. The essential conversion stages are [32,33]:

- To begin, it is necessary to make a decision on which of the two criteria will serve as the main target function and which will be used as a constraint. This depends on the specifics and the importance of the assignment.
- The criteria for the constraints are being created. In the event where the second criterion is "minimum time," it is possible that a restriction such as "time must not exceed a certain value" would be assigned.
- Aim function optimisation: when one of the criteria is a constraint, the optimisation problem transforms into a single-criteria optimisation problem with the objective of either maximising or reducing the remaining criterion while adhering to the constraints.
- Analysing the solutions is necessary in order to guarantee that the requirements and anticipations are satisfied. The results might be improved by modifying the limitations or the objective functions.
- Depending on the objective function and the restrictions, several optimisation strategies, such as linear programming, nonlinear programming, metaheuristic methods, and others, may be used.”

6.1. Minimisation to a Weighted One Criteria Optimisation Issue

Linear combination or weighted sum is a common approach for reducing multi-criteria optimisation problems to single-criteria ones. This strategy combines numerous criteria into a single objective function by weighting them according to relevance. Some fundamental steps:

- Weights: Each criterion is weighted to represent its value. Weights are commonly selected to add up to 1.
- Before adding weights, normalise the criteria to make them comparable. This may be done by rescaling each criteria to 0–1.
- Formulation of the objective function: the standardised criterion values and weights are added to generate the objective function.
- Objective function optimisation: after the objective function is defined, the issue becomes a conventional optimisation problem to maximise or minimise it.

Analysis of the outcomes: after finding the ideal solution, analyse the results to verify they meet all requirements.
This strategy works best when it's feasible to prioritise criteria and create a balanced solution that addresses all key parts of the situation.
Therefore, (5) is substituted by:

$$J = w_1 J_1 + w_2 J_2 \underset{(C_r, C_f, L_r, L_f)}{\rightarrow} \min \qquad (9)$$

Where, w_1 and w_2 are reasonable weights.
Other task components (1–8) remain unchanged.
To tackle this problem, the author writes code using the fmincon command.

```
[x,Fval]=fmincon(@Opt,x0,[],[],[],[],xlb,xub,@Con,options)
```

The point 3 approach calculates initial x0 estimates.
The programme produced the following optimum circuit element values:

L_r = 1.6337 μH, L_f = 32.879 μH, C_r = 3.9175 nF, C_f = 82.684 nF.

Figure 5 shows the simulated outcome using the parameters collected in this way.

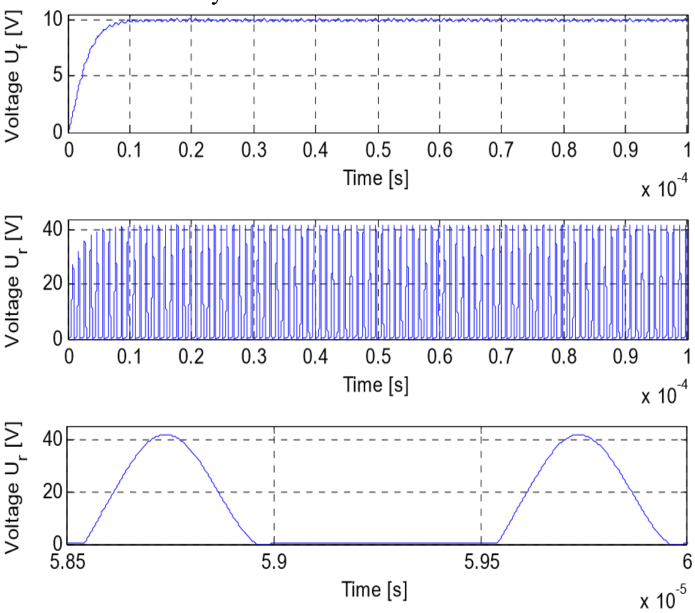

Figure 5 The point 6.1 technique calculates resonance voltage u_{Cr}. Optimisation from here takes 182 s..

6.2. Partial Elimination to a Constraint-Based Single-Criteria Optimisation Problem

The maximum voltage between the resonant capacitor and transistor u_{Cr} may be decreased to 41 V using the optimisation technique from point 5.1. The two-criterion optimisation issue is adjusted as follows:

Conditions are added to inequality constraints:

$$u_{Cr} < 2.1\ U_d \quad (1($$

Condition (5) is replaced by

$$J_1 \underset{(C_r,C_f,L_r,L_f)}{\rightarrow} \min$$

The remaining task components (1–8) stay unchanged. To tackle this problem, the author writes code using the fmincon command again.

```
[x,Fval]=fmincon(@Opt,x0,[],[],[],[],xlb,xub,@Con,options)
```

This code modifies the preceding one. In @Con, condition (10) is introduced, but in @Opt, condition (9) is replaced with (11).

The programme produced the following optimum circuit element values:

```
[x,Fval]=fmincon(@Opt,x0,[],[],[],[],xlb,xub,@Con,options)
```

Due to condition (10) being selected, these values are similar to point 5.1 (u_{Cr} < 2.1 U_d). This option matches point 5.1's optimal. If u_{Cr} < 2 U_d is used, studies indicate a considerable decrease in the best value of $J_1(x)$. Figure 6 shows the simulated outcomes from these parameters.

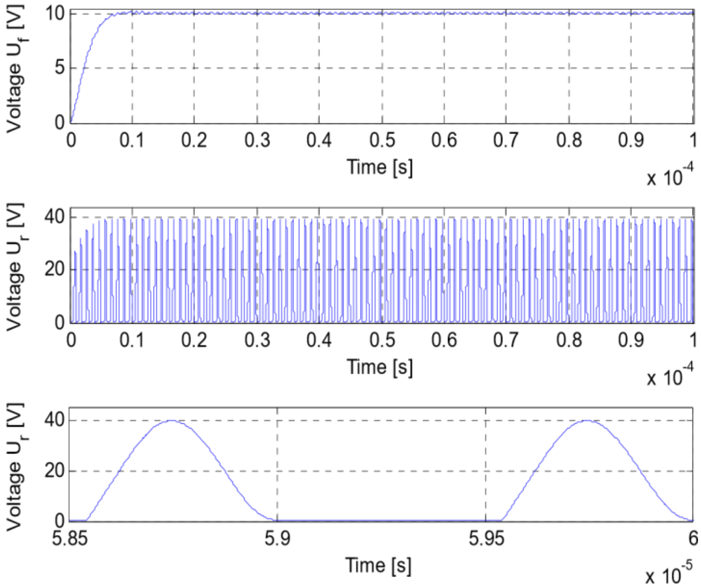

Figure 6. Point 6.2 calculation of resonance voltage u_{Cr}. The optimisation process now takes 30 s.

6.3. Goal attain-Based Reduction to a Single-Criteria Optimisation Issue

A goal-attain technique may reduce the two-criteria optimisation problem to a single-criteria one. Gembicki offered this approach [34]. It determines ideal design goals, $J^* = [J_1^*, J_2^*]$, and the relative degree of underachievement or overachievement, regulated by a vector of weighting factors, $w = [w_1, w_2]$.

Two-criteria optimisation becomes the optimisation issue with Condition (5) substituted by:

$$\gamma \underset{(C_r,C_f,L_r,L_f)}{\rightarrow} \min \quad (12)$$

The inequality type limitations are updated with (10):

$$J(C_1, C_2, L_3) - w\gamma \leq J* \quad (13)$$

The remaining task components (1–8) stay unchanged. The goal-attain command solves this new optimisation challenge.

```
goal = [0 0]
weight = [1 1]
[x,Fval,attainfactor] = fgo
-alattain(@Opt,x0,goal,weight,[],[],[],[],xlb,xub,@Con,options);
```

This job is solved using code similar to point 6.1. The @Opt function syntax is changed to suit criteria (12) and (13). The @Con function syntax matches point 6.1.

The programme produced the following optimum circuit element values:

L_r = 1.6097 μH, L_f = 10 μH, C_r = 4.0242 nF, C_f = 100nF.

Figure 7 was simulated using these settings.

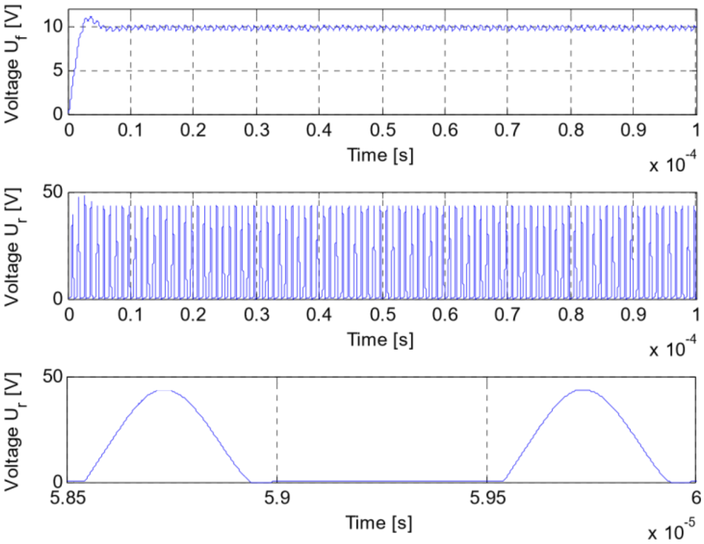

Figure 7. Point 6.3 calculation of resonant voltage uCr. The optimisation process continues for 120 s.

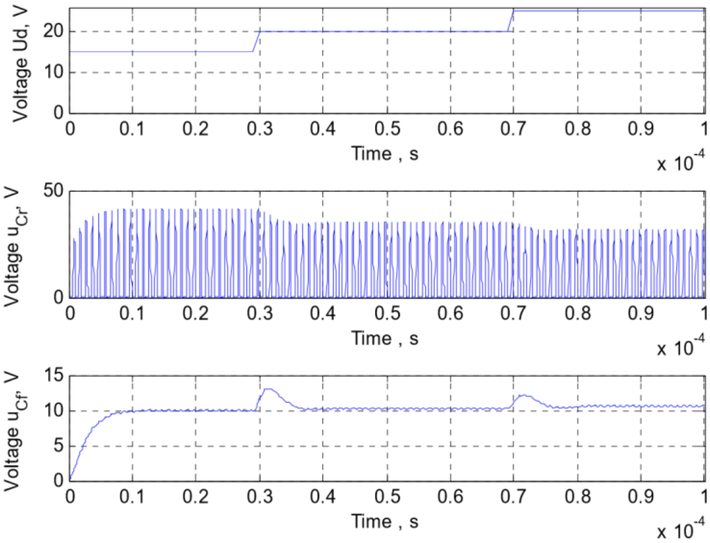

Figure 9. Input voltage U_d and the Buck ZVS quasi-resonant DC-DC converter's resonance and output voltage are both affected by this variation.

"Since Figure 3 was taken using non-optimal circuit components, its transient process time constant is $T = 0.5 \times 10^{-5}$. Since a quicker transition procedure (with time constant) was used for the reference curve $u_{Cf,\ ref}$, Figure 6 is clearly closer to the reference than Figure 3. In Figures 3 and 6, the u_{Cf} adjustments is almost identical. No correction occurs in Figures 4 and 5. Thus, optimisations in points 5.1 and 5.2 are better than 5.3.

The circuit will be tested for the optimum values of L_r, C_r, L_f, and C_f determined in point 5.1 (near to 5.2 and better than 5.3) while adjusting the input voltage U_d and load resistance R_{load}. Simulation results are displayed in Figures 8 and 9.

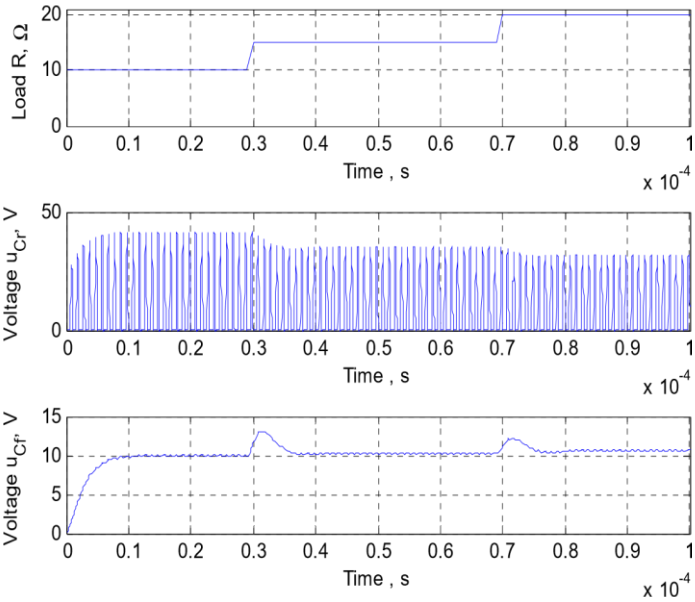

Figure 8. Changes in the load resistance R affect the output voltage and resonance voltage of the Buck ZVS quasi-resonant DC-DC converter.

7. DISCUSSION

On the basis of the data, it seems that reducing the second optimisation criterion to a constraint offers the best possible balance between the quality of the parameters and the time of the optimisation process. In this way, a good ratio between the projected and actual outcomes and the amount of time is achieved. The first method takes 182 seconds to optimise, whereas the second method takes 30 seconds, and the third method takes 120 seconds. As a result, a useful optimisation method may reduce the amount of time spent computing by approximately five times! The conclusion made here contributes to the optimisation of power electronic systems that include numerous power electronic devices as well as mechatronic systems that contain electronic, electro-mechanical, and mechanical components. Nevertheless, tests that introduce disturbances on input voltage and output current reveal that the best designed power electronic device is both long-lasting and low-sensitive to the most common DC-DC converter disturbances, even when it is not equipped with a controller.

There are power topologies in which switching between states during operation is not only determined by external influence, but also by the ratio of different parameters and operating mode. The optimal design of the Buck ZVS Quasi-Resonant DC-DC converter demonstrates that classical design methods and one-criteria optimisation with constraints are suitable for power topologies. Therefore, an optimal solution is quickly generated that fulfils the specified criteria to a high degree without demanding a significant amount of software and hardware resources or substantial mathematical skill from users. Such a solution is provided in a timely manner."

8. CONCLUSIONS

Different types of optimisation issues, such as single-criteria and multi-criteria, demand the selection of an optimal solution from a set of alternatives depending on a number of criteria. occupations in engineering, economics, management, and other fields are comparable to one another. A few advantages and disadvantages of single- and multi-criteria optimisation issues are as follows:

1. The benefits of optimising for a single criterion are:
   - Single-criteria issues are easy to solve since they have one optimisation criterion.
   - More defined objectives: optimising one criteria frequently produces clear aims and results.
   - Solutions to single-criteria issues are frequently less computationally demanding.
2. Limitations of optimisation problems with a single criterion:
   - Failure to account for real-world complexity: optimising one criteria might ignore key components in real-world circumstances.
   - Single-criteria techniques may struggle to discover a solution when goals are incompatible.
3. The benefits of optimising for multiple criteria:
   - Multi-criteria tasks may better reflect the complexity of actual life, where assessments must be balanced between a number of different elements. This may be the case since multi-criteria tasks were designed to better depict true circumstances.
   - Make room for adaptable solutions: When dealing with situations that require multitasking, it is essential to have many criteria that allow for the discovery of solutions that satisfy a variety of criteria or objectives.
4. Challenges with optimising for Multi criteria:
   - Multi-criteria issues are harder to solve because they require balancing and negotiating many goals.
   - Finding optimum solutions to multicriteria situations frequently demands more computing resources.

Each job has a position based on the problem's needs. Multicriteria approaches are used to provide adaptable and realistic solutions in complicated settings with various goals. Multi-objective optimisation of power electronic systems demands a lot of computer effort, particularly when several operating modes are addressed. Thus, several procedures are done to simplify the optimum design work and reduce the design area. Before optimising a device, the multi-criteria optimisation job is modified. This multi-criteria optimisation reduction method saves time and money but may provide inferior designs. The offered ways for reducing the optimisation job help achieve a maximum favourable relationship between running time and design optimality.

The suggested rational optimisation technique automates power electronic device design with complicated topologies and simplifies computational operations by combining single and multi-criteria optimisations. Due to the increasing requirements for electronic transformer indicators, conventional design solutions cannot meet them. One research effort is using machine learning to optimise the Buck ZVS Quasi-Resonant DC-DC converter.

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