Mission Profile Optimized Modularization of Hybrid Vehicle DC/DC Converter Systems

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***Abstract*—Vehicles based on electrical drive trains become more and more attractive due to rising oil prizes and environmental reasons. In these vehicles usually different and/or varying voltage levels for the drive and the energy storage elements are employed in order to fully utilise the components and increase the system efficiency. The DC-links with different voltage levels are interconnected by bidirectional DC-DC converters. Due to the high power levels the converters are often realised by interleaved smaller units for increasing part load efficiency and power density.**

In this paper an procedure for optimising the nominal power levels, operating points and distribution of silicon area of interleaved/parallel connected DC-DC converters is presented. There, the aim is to optimise the overall system efficiency for a given mission profile of the electric vehicle (e.g. NEDC/FTP-75) and to determine the optimal distribution of a fixed amount of silicon area between the parallel units for minimal losses.

For demonstrating the performance of the method a 48kW test system is optimised, where an improvement of more than 21% compared to equal parallel connected units is shown. There, the calculations are based on measurements on a 12kW bidirectional prototype DC-DC converter designed for electric vehicles.

***Index Terms*—DC-DC Converter, Hybrid Car, Optimisation, Mission Profile**

I. Introduction

Rising oil prizes, improved efficiency and reduced emission lead to a growing interest in vehicles, which are based on electrical drive trains [1]. A typical, simplified basic structure of a electrical drive train is shown in Fig. 1, where the electric energy is stored in batteries or super caps, which have a high output power and also can rapidly store energy from regeneration. This energy storage element is coupled via a bidirectional DC-DC converter to the DC link of the inverter(s) for the electric drive(s). There, the battery/super cap voltage usually varies in order to fully utilise the storage device and the DC link voltage is constant for optimally utilising the electric drive and for providing a constant voltage for the loads connected to the high voltage DC bus. The DC-link voltage is typically higher than the battery/super cap voltage, but could, depending on the design of the propulsion system and the individual components like the number of cells and characteristics of the storage device, also overlap with the nominal DC link voltage. For demonstrating the performance of the proposed efficiency optimisation a system with the specifications given in table I is assumed and numerical results are presented, but basically the method could be applied to any other system.

The interconnecting DC-DC converter has to meet the prevalent automotive requirements, i.e. a low cost design, high power density and a high efficiency also for output power levels below the nominal power, since this directly affects the overall drive train efficiency. A high power density could be achieved by increasing the switching frequency of the converter, what decreases the volume of the passive components to a certain degree. However, the efficiency usually decreases with increasing switching frequency and at higher power levels the maximal achievable switching frequency is limited by the available switching devices.

In order to alleviate this problem several converters can be interleaved [3] resulting in a smaller nominal power of the single converter and in higher possible switching frequencies. By phase shifting the interleaved converters also the output current ripple could be reduced enabling a smaller output filter size in some cases. Furthermore, at light load conditions the overall efficiency of a multi-phase/interleaved converter system is significantly improved by partial operation of the

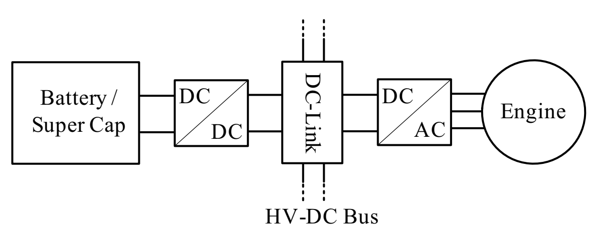


Fig. 1: Typical structure of a hybrid electrical/fuel cell vehicle.

individual converters, each in the optimum efficiency range [4]. This means that some of the interleaved converters are turned off at light load, since operating the single converter at light load results in a low efficiency due to the switching losses, which are to some extend independent of the output power, and the constant losses in the auxiliary circuitry/control circuit.

So far the interleaved converters have been designed so that they all have the same nominal power, i.e. at full load the power is equally provided by all converters. In case of a mission profile, where for example for relatively long times a low power compared to the full system power is required, a system design with interleaved converters which do not have the same nominal power could result in a better system efficiency

TABLE I: Specifications of the considered bidirectional DC-DC converter.

Output power	48kW
DC link voltage	450V
Battery voltage	150V-300V
Power density	29kW/ltr.
Efficiency	$\geq 95\%$ for $P_{Out,S} \geq 0.1 \cdot P_{Nom,S}$

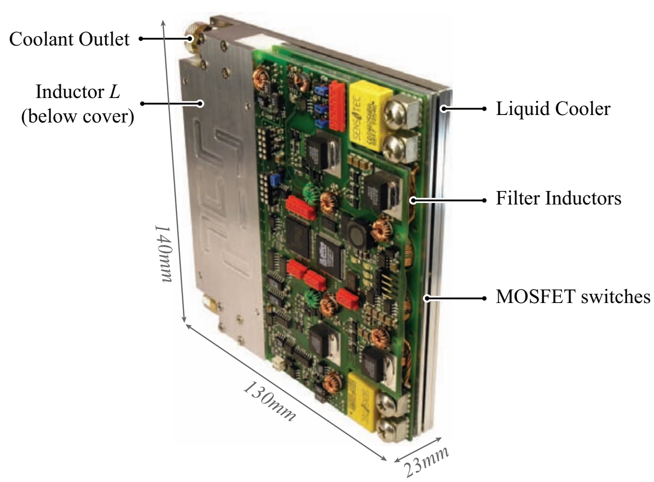


Fig. 2: Photo of the reference DC-DC converter with an output power of 12kW.

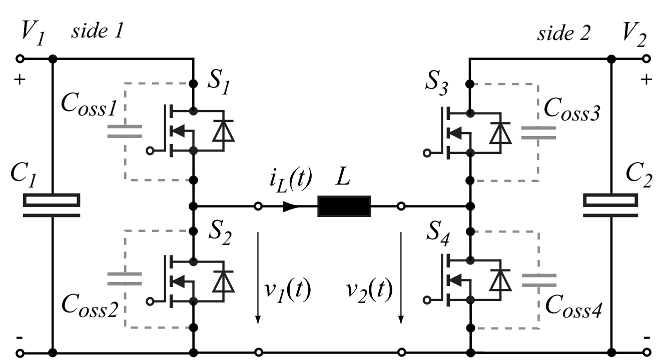


Fig. 3: Schematic of the bidirectional DC-DC converter shown in Fig. 2.

compared to a design with equal converter units as will be shown in this paper. There, the total energy, which is lost / converted to heat, is the criteria for comparison, since it is important not only to consider the efficiency but also the time interval, where this system efficiency must be considered. Based on this approach an optimisation method, which optimises the nominal power levels and the operating points of parallel connected DC-DC converters is presented in **section** II. Besides the operating points and power levels also the distribution of the silicon area between the parallel connected converters is optimised, so that minimal losses result.

Thereafter, a model of a bidirectional DC-DC converter for automotive applications for calculating the converter efficiency in dependency of the in-/output voltages, the operating point and the silicon area is presented in **section** III. This model is based on the prototype system shown in Fig. 2. Finally, results for an optimised system based on the reference converter system shown in Fig. 2 are presented in **section** IV.

II. Minimisation of Loss Energy

Basically, the efficiency of a converter is defined by

$$\eta_\nu = \frac{P_{Out,\nu}}{P_{In,\nu}}, \tag{1}$$

where $P_{Out,\nu}$ is the output power and $P_{In,\nu}$ the input power of the considered converter. There, the efficiency is a function of the ratio output power to nominal power

$$\delta_\nu = \frac{P_{Out,\nu}}{P_{Nom,\nu}}, \tag{2}$$

where $P_{Nom,\nu}$ is the nominal power. With the efficiency the losses of the converter can be calculated by

$$P_{L,\nu} = P_{In,\nu} - P_{Out,\nu} = \frac{1-\eta_\nu}{\eta_\nu} P_{Out,\nu}. \tag{3}$$

These losses depend on the efficiency and therewith on the current output power of the converter. In a mission profile for cars as for example the New European Drive Cycle (NEDC – cf. Fig. 4a) or the Federal Test Procedure (FTP-75) [5] the velocity is given as function of time. With the characteristics of the electric drive train and the car, the velocity profile could be converted to an electric drive power profile and with the efficiency of the inverter/drive directly to a power profile for the considered DC-DC converter (cf. Fig. 4b and c). Based on the frequency of the respective power level the levels can be summarised to a few values as for example given in table II. There, 4 values are used but basically any number of power levels is possible. However, with a higher number of power levels the calculation effort during the optimisation increases significantly, while the gain in accuracy is limited.

By integrating the losses as given in (3) over the mission profile, the energy with is wasted, i.e. converted in heat, is obtained by

$$E_{Loss,\nu} = \int_0^{T_{cycle}} \frac{1-\eta_\nu}{\eta_\nu} P_{Out,\nu} \mathrm{dt}. \tag{4}$$

In the simplest case the efficiency curve of one converter is optimised, so that the wasted energy is minimal. There, the degrees of freedom could be for example shifting a limited silicon area between the different switches/diodes, adapting control modes/current shapes [6] or optimising passive components for special operation conditions.

Due to the high power levels required in electrical vehicles a parallel connection of several converter modules offers the advantage of higher possible switching frequencies, i.e. higher power densities, since faster devices are available in the lower power range, and of additional degrees of freedom for shaping the efficiency curve for a given mission profile. There, the distribution of the output power on the parallel connected converters and their operating points can be optimised.

These degrees of freedom have not been utilised so far, since with most interleaved converter systems, the output power has been equally shared between the parallel connected converters. Furthermore, the converters are operated at the same operating point, what could be used for reduction of the output current ripple [3]. Since a minimum capacitance at the output is required for transients and since the ripple current carrying capability of ceramic capacitors is relatively high, the current ripple does not significantly influence the size of the output capacitor.

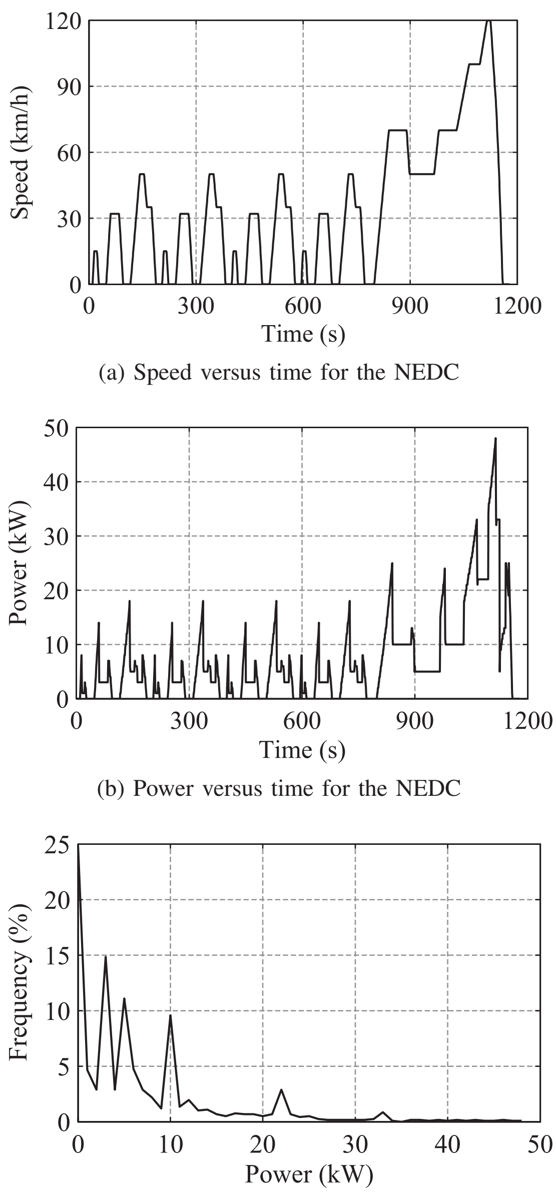
In a next step, besides the operating points also the nominal power levels $P_{Nom,\nu}$ of the single parallel connected converters can be optimised in order to minimise the losses for the drive system. For this optimisation the losses of the converter system are derived as function of the parallel connected units and the operating points in the following. There, the efficiency for converters with different nominal output power levels and for different operating points must be calculated. Consequently, the efficiency η_C must be given as function of the nominal converter power and also of the relative operating point. In order to simplify the calculations the function is normalised to the nominal system power $P_{Nom,S}$ and to the nominal converter power $P_{Nom,\nu}$, i.e.

$$\eta_C = \mathfrak{f}\left(\frac{P_{Out,\nu}}{P_{Nom,\nu}}, \frac{P_{Nom,\nu}}{P_{Nom,S}}\right). \tag{5}$$

In Fig. 5 the efficiency curve for the converter system considered in section IV is shown as example.

TABLE II: Simplified power levels and durations for DC-DC converter based on the NEDC (cf. Fig. 4) and a peak system power of 48kW.

Duration t_j	Power Level P_j
52s	34kW
164s	17kW
408s	6.9kW
264s	2.5kW



(a) Speed versus time for the NEDC

(b) Power versus time for the NEDC

(c) Relative frequency for the different power levels

Fig. 4: (a) New European Drive Cycle and (b) simplified power levels as function of time as well as the the relative frequency of the different power levels in (c).

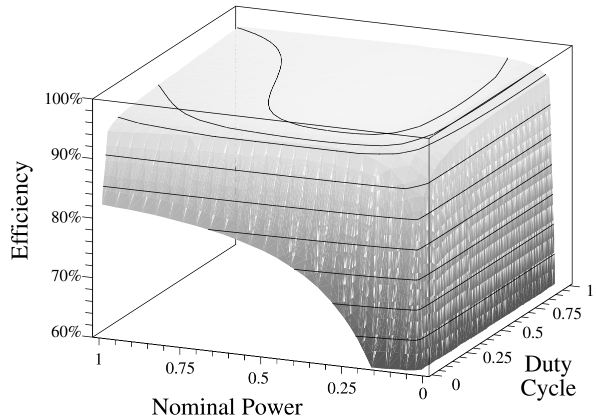


Fig. 5: 3D plot of the normalised efficiency function for the system considered in section section IV.

With the 3D efficiency function, the efficiency values for the N_{inter} interleaved converters and the $N_{Profile}$ different power levels of the mission profile are given by

$$\eta_{i,j} = \mathfrak{f}\left(\delta_{i,j}, fac_i\right) \tag{6}$$

with

$$\delta_{i,j} = \frac{P_{Out,\nu}}{P_{Nom,\nu}} \text{ and } fac_i = \frac{P_{Nom,\nu}}{P_{Nom,S}}.$$

In the next step the overall efficiency for each power level P_j of the mission profile is calculated by

$$\eta_{P,j} = \frac{P_{Out,j}}{P_{In,j}} \tag{7}$$

with

$$P_{Out,j} = \sum_{i=1}^{N_{inter}} \delta_{i,j} \frac{P_{Nom,S}}{fac_i}$$

$$P_{In,j} = \sum_{i=1}^{N_{inter}} \delta_{i,j} \frac{P_{Nom,S}}{fac_i \eta_{i,j}}.$$

With this efficiency the total energy, which is wasted/converted to heat is given by

$$E_{Loss} = \sum_{j=1}^{N_{profile}} t_j \frac{1-\eta_{P,j}}{\eta_{P,j}} P_j. \tag{8}$$

This is the quality criteria for the optimisation, i.e. this value must be minimised. There, also some constraints must be considered.

First, the sum of the nominal output powers $P_{Nom,\nu}$ of the parallel connected converters must be equal to the required nominal output power of the converter system, i.e.

$$P_{Nom,S} = \sum_{\nu=1}^{N_{inter}} P_{Nom,\nu} \tag{9}$$

Basically, it would be also possible that the sum of the nominal powers of the parallel converters exceeds the required nominal power, but this would lead to poor utilisation of the single converters and higher system costs.

Moreover, the operating points of the parallel converters must be chosen so, that the sum of the output powers (cf. (7)) is equal to the corresponding power level of the mission profile, i.e.

$$P_{Out,j} = P_j \;\; \forall \;\; j = 1 \ldots N_{profile}. \tag{10}$$

Besides these minimal requirements additional constraints could be used, as for example restrictions on the volume or the weight of the system. There, the applied models (cf. section III) must be extended, so that these also describe the dependency of for example the volume/weight on the nominal output power.

A. Optimised Silicon Area Distribution

In many DC DC converter applications, where efficiency plays an important role, the switching devices and the diodes are chosen so that a minimal required efficiency is achieved. Thus, more silicon area is used than thermal limitations like the maximal junction temperature would require in order to reduce the losses/improve the efficiency. This is an additional degree of freedom, which could be used for loss reduction.

Assuming for example a simple system with two converters with the same nominal power and the same silicon area. One is just operating a peak load and the other one is providing continuous output power. By subtracting some silicon area from the converter for peak load and add it to the converter for continuous load, the system/mission profile efficiency could be improved. For comparison it is important to keep the value of the silicon area constant, so that the total costs for the devices are approximately constant.

This degree of freedom could be also used for the general system described above, where the nominal power levels and the operating points of parallel connected converters are optimised for mission profile efficiency. There, also the losses of the converter providing the most energy to the output could be reduced by adding some silicon area, which has been subtracted from a converter providing less energy.

In order to consider the distribution of the silicon in the optimisation, the efficiency and/or the losses of the single converters must be given also as function of the silicon area A_{Si}.

$$\eta_{i,j} = \mathfrak{f}\left(\frac{P_{Out,\nu}}{P_{Nom,\nu}}, \frac{P_{Nom,\nu}}{P_{Nom,S}}, A_{Si}\right) \tag{11}$$

A value of 1 for A_{Si} is used for the original design, where the silicon area and/or the effective on-resistance of the MOSFET $R_{DS,on}$ is not altered compared to the reference data given in table III. For $A_{Si} > 1$ the silicon area is increased and for $A_{Si} < 1$ decreased. For keeping the silicon area constant the constraint

$$\sum_{i=1}^{N_{inter}} \frac{P_{Nom,\nu}}{P_{ref}} \left(A_{Si} - 1\right) = 0 \tag{12}$$

must be fulfilled during the optimisation.

III. Converter Model

An analytical, scalable converter model, that predicts the efficiency η_ν of a single converter in the converter system in dependence of the nominal output power $P_{Nom,\nu}$ and the operating point, is required for the optimisation.

The model for the optimisation is based on data of a bi-directional Buck+Boost converter system proposed in [6] consisting of four identical converter modules ($P_{Nom,\nu}$ = 11.7 kW) as shown in Fig. 2, each with the parametrisation listed in table III.

TABLE III: Components utilised in the reference DC-DC converter (cf. Fig. 2(b)).

Switch S_1 & S_3	each 4 × IXYS IXFB82N60P
Switch S_2 & S_4	each 3 × IXYS IXFB82N60P
Inductor	3 × EILP43
	L_{ref} = 5.7 μH / $\hat{I}_{L,ref}$ = 120A
Capacitor C_1 & C_2	X7R ceramic, 13.4 μF

Firstly, a scaling law for the passive converter components must be found. The required Buck+Boost inductance L_ν is primarily affected by the switching frequency and the modulation strategy and its value is given by

$$\frac{L_\nu}{L_{ref}} = \left(\frac{P_{Nom,v}}{P_{ref}}\right)^{-1} \cdot \left(\frac{f_{s,\nu}}{f_{s,ref}}\right)^{-1}. \tag{13}$$

With the low-loss modulation [6], the value of L_ν is proportional to $1/P_{Nom,\nu}$ since the energy $E = P_{Nom,\nu} \cdot T_p$ must be delivered to the converter output within the switching period $T_p = 1/f_s$.

Secondly, the relative inductor peak current and the relative RMS current

$$\frac{\hat{I}_{L,\nu}}{\hat{I}_{L,ref}} = \frac{I_{L,\nu}}{I_{L,ref}} = \frac{P_{Nom,v}}{\hat{P}_{ref}} \tag{14}$$

are proportional to $P_{Nom,\nu}$ as a result of (13). The relative inductor losses strongly depend on the inductor geometry which is scaled under the assumptions that

1) the switching frequency $f_{s,\nu}$ is constant,
2) the air gap length $l_{g,\nu}$, the core width $w_{c,\nu}$ and the core length $l_{c,\nu}$ are scaled by an identical geometry factor $r_{c,\nu}$,
3) the maximum core flux density $\hat{B}_c$ is equal to the reference converter
4) and the ratio of core losses $P_{c,\nu}$ to the winding losses $P_{wdg,\nu}$ is constant

in order to achieve comparable thermal conditions for the inductor loss calculation. The inductance of the gapped inductor is approximated by

$$L_\nu = \frac{\mu_0 N_\nu^2 A_{c,\nu}}{l_{g,\nu}} \tag{15}$$

and the maximum core flux density is calculated by

$$\hat{B}_c = \frac{L \cdot \hat{I}_{L,\nu}}{N_\nu A_{c,\nu}}. \tag{16}$$

Equations (15) and (16) are solved under consideration of assumptions 2) and 3) to determine the number of turns

$$N_\nu = \sqrt[3]{\frac{\hat{B}_c L_\nu l_{g,ref}^2}{\mu_0^2 A_{c,ref} \hat{I}_{L,\nu}}} \tag{17}$$

and the core width ratio $r_{c,\nu}$

$$r_{c,\nu} = \frac{w_{c,\nu}}{w_{c,ref}} = \frac{L_\nu l_{g,ref}}{\mu_0 N_\nu^2 A_{c,ref}} \tag{18}$$

of the inductor. The required number of turns is shown in Fig. 6. The winding dimensions (cross section and length) of the scaled inductor are given by

$$\frac{A_{wdg,\nu}}{A_{wdg,ref}} = \frac{h_{w,\nu}}{h_{w,ref}} \cdot \left(\frac{N_\nu}{N_{ref}}\right)^{-1} \cdot r_{c,\nu} \tag{19}$$

$$\frac{l_{wdg,\nu}}{l_{wdg,ref}} = \frac{N_\nu}{N_{ref}} \cdot r_{c,\nu} \tag{20}$$

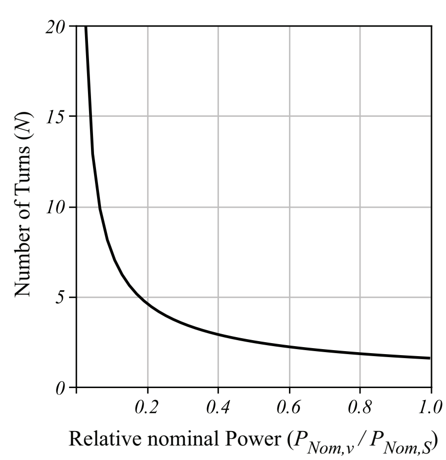


Fig. 6: Required Number of Turns N_ν

and the core volume is calculated by

$$V_{c,\nu} = (h_{c,ref} - h_{w,ref}) w_{c,ref} l_{c,ref} r_{c,\nu}^3 + \\ + (w_{c,ref} - 2w_{w,ref}) l_{c,ref} r_{c,\nu}^2 h_{w,\nu} \tag{21}$$

where $h_{c,ref}$, $w_{c,ref}$, $l_{c,ref}$ are the outer dimensions of the core and $h_{w,ref}$, $w_{w,ref}$ are the dimensions of the window cross section. Furthermore, the resistance of the winding and the worst-case copper losses are calculated by

$$\frac{R_{wdg,\nu}}{R_{wdg,ref}} = \frac{l_{wdg,\nu}}{l_{wdg,ref}} \cdot \left(\frac{A_{wdg,\nu}}{A_{wdg,ref}} \right)^{-1} \tag{22}$$

$$\frac{P_{wdg,\nu}}{P_{wdg,ref}} = \frac{R_{wdg,\nu}}{R_{wdg,ref}} \cdot \left(\frac{\hat{I}_{L,\nu}}{\hat{I}_{L,ref}} \right)^{2} \tag{23}$$

Finally, based on the new number of turns N_ν, on the core width ratio $r_{c,\nu}$, on a constant loss ratio

$$\frac{P_{wdg,\nu}}{P_{c,\nu}} = \frac{P_{wdg,ref}}{P_{c,ref}} = 4.4 \tag{24}$$

and on a constant copper fill factor of the inductor windings, the set of equations (19), (21), (23) is solved to calculate the actual inductor volume shown in Fig. 7 and the maximum core and winding losses shown in Fig. 8.

Furthermore, (14) and the modulator model [6] are used to calculate the semiconductor conduction losses $P_{cond,\nu}(\delta_\nu)$ and the switching losses $P_{sw,\nu}(\delta_\nu)$ based on measured loss characteristics, whereas the $R_{DS,on}$, i.e. the die area is scaled with the switch RMS currents. The total losses for a individual converter module are a function of the ratio of output power to nominal power δ_ν and are given by

$$P_{L,\nu}(\delta_\nu) = \tag{25}$$
$$P_{wdg,\nu} \cdot \left(\frac{I_{L,\nu}(\delta_\nu)}{I_{L,\nu}(\delta_\nu = 1)} \right)^2 + P_{c,\nu} \cdot \frac{\hat{I}_{L,\nu}(\delta_\nu)}{\hat{I}_{L,\nu}(\delta_\nu = 1)}$$
$$P_{cond,\nu}(\delta_\nu) + P_{sw,\nu}(\delta_\nu)$$

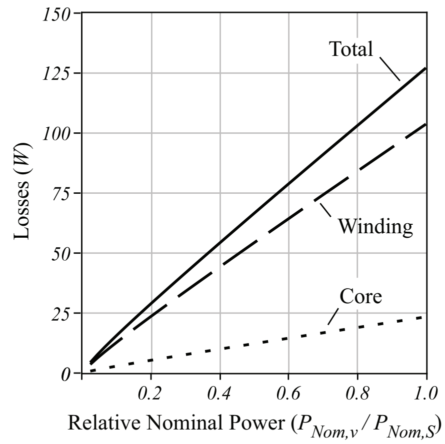


Fig. 8: Inductor losses versus relative nominal power

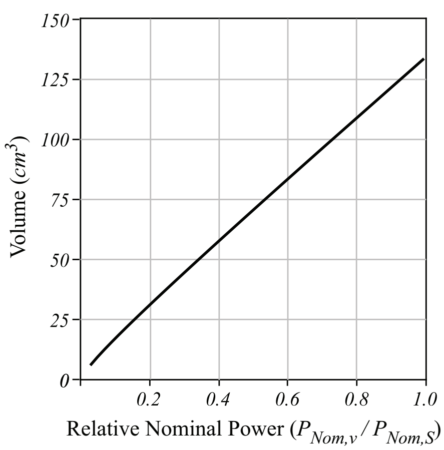


Fig. 7: Inductor volume $V_{c,\nu}$ versus relative nominal power

IV. Results for a 48kW Hybrid Car DC-DC

With the optimisation problem defined in section II and the model presented in section III a DC-DC converter system with the specifications in table I has been optimised for the mission profile in table II. The resulting operating points, nominal power levels and wasted energy are listed in table IV for a system consisting of two parallel connected converter. Results for more converters are summarised in table V and Fig. 9.

In case of two converters, the optimal nominal power levels are 17kW and 31kW, what results in 11.7% lower wasted energy compared to a system with two equal converters, which both have always the same operating point. Compared to a system consisting of only one 48kW DC-DC converter the wasted energy is reduced by 42%. The average efficiency for the whole mission profile is 97.4% for the optimised system, 97.1% for the system with two equal converter and 95.6% for a system based on a single converter (cf. table V).

In Fig. 9 the lost energy for systems with 1 to 4 parallel converters are shown. The losses of a single converter of 368kWs for the mission profile given in table II decrease rapidly by paralleling several converters. In case of two parallel converters with an equal operating point the losses are 240kWs. In the optimal case of 4 parallel converter with optimised nominal power levels, operating points and silicon areas the losses reduce by 53.4% compared to a single converter and by 21.5% compared to system with equal nominal power levels

TABLE IV: Operating points, nominal power levels and wasted energy for a system consisting of two parallel connected converters with optimised nominal power levels and with equal power levels.

Power Level	Equal power & duty		Equal power / opt duty		Opt. power & duty		Opt. power & duty &SI-area	
	P_N=24kW	P_N=24kW	P_N=24kW	P_N=24kW	P_N=17kW	P_N=31kW	P_N=16.3kW	P_N=31.7kW
	$\delta_{1,\nu}$/ $E_{Loss,\nu}$	$\delta_{2,\nu}$ $E_{Loss,\nu}$	$\delta_{1,\nu}$ $E_{Loss,\nu}$	$\delta_{2,\nu}$ $E_{Loss,\nu}$	$\delta_{1,\nu}$ $E_{Loss,\nu}$	$\delta_{2,\nu}$ $E_{Loss,\nu}$	$\delta_{1,\nu}$ $E_{Loss,\nu}$	$\delta_{2,\nu}$ $E_{Loss,\nu}$
SI-area	1	1	1	1	1	1	1.5	0.74
2.5kW	0.03 14.4kWs	0.03 14.4kWs	0 0	0.1 22.7kWs	0.15 18.4kWs	0 0	0 0	0.08 21.3kWs
6.9kW	0.14 44.4kWs	0.14 44.4kWs	0 0	0.29 77.8kWs	0.41 66.7kWs	0 0	0.42 63.7kWs	0 0
17kW	0.35 37.7kWs	0.35 37.7kWs	0.71 74.8kWs	0 0	0.56 39.7kWs	0.23 38.6kWs	1 56.8kWs	0.02 3.1kWs
34kW	0.71 23.7kWs	0.71 23.7kWs	0.71 23.7kWs	0.71 23.7kWs	0.54 11.5kWs	0.8 37.2kWs	1 18kWs	0.56 31.1kWs
Losses	120kWs	120kWs	98.5kWs	124.3kWs	136.3kWs	75.8kWs	137.6kWs	55.5kWs
	240kWs		222.7kWs		212.2kWs		193.1kWs	

TABLE V: Dissipated energy, energy saving with respect to a system with equal nominal power levels and equal duty cycles and mission profile efficiency for 1 to 4 interleaved power supplies.

No Conv.	Equal power & duty	Equal power opt. duty	Opt power & duty	Opt. power, duty, SI area
1	368kWs 0 95.6%	368kWs 0 95.6%	368kWs 0 95.6%	368kWs 0 95.6%
2	240kWs 0 97.1%	223kWs 7.3% 97.3%	212kWs 11.7% 97.4%	193kWs 19.2% 97.6%
3	217kWs 0 97.4%	195kWs 10.3% 97.6%	194kWs 10.8% 97.7%	172kWs 20.9% 97.9%
4	218kWs 0 97.4%	192kWs 12.0% 97.7%	192kWs 12.1% 97.7%	171kWs 21.5% 97.9%

and operating points. The energy is saved mainly in the region of lower output powers, where in case of the optimised systems small converters are used, which operate in an operating point with higher efficiency.

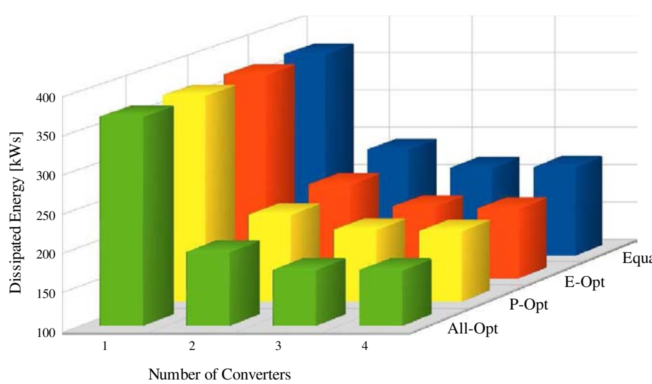


Fig. 9: Lost energy for 1-4 parallel connected converters with equal nominal power and operating point (*Equal*), with optimised operating point (*E-Opt*), with optimised nominal power and operating point (*P-Opt*) and with optimised nominal power, operating point as well as silicon area (*All-Opt*).

V. Conclusions

In this paper a method is presented for optimising the nominal power levels of parallel connected DC-DC converter, so that the energy, which is wasted by the converter system, is minimised for a given mission profile of the system output power. Besides the equations for the optimisation procedure also a model of a bidirectional DC-DC converter, with which the efficiency could be calculated as function of the nominal power, the output power, the input/output voltages and the utilised Silicon area is derived. There, a prototype system with 12kW nominal output power is used as reference.

Furthermore, optimisation results for a system with 2 to 4 parallel connected DC-DC converter and an output power of 48kW are presented. Compared to system with a single DC-DC converter the losses are reduced by almost 54% and compared to a system consisting of equal parallel connected DC-DC converter an improvement of more than 21% is possible.

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