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Reliability-Constrained Design of a High-Gain Power Optimizer based on a Real Mission Profile

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Abstract—This article proposes a methodology for the design of a step-up solar optimizer based on the minimization of the cost-to-output energy ratio and constrained by reliability criteria. Real-world annual mission profiles are used in the optimization, allowing to a more accurate lifetime analysis and output energy estimation. The proposed approach is applied to the case study of an Input-Parallel-Output-Series power optimizer and exploits analytical and empirical loss and cost models for the converter components. The algorithm is implemented in Matlab and is based on the Particle Swarm Optimization (PSO) method, which discards the solutions not meeting the reliability requirements. The optimal solution found by the PSO is then compared with the exhaustive search in the variables space. A converter is designed based on the optimal solution, and its efficiency and accumulated damage are validated by LTSpice and Matlab simulations.

Keywords—Design optimization, Reliability, Power optimizer, Particle Swarm Optimization.

I. INTRODUCTION

Module-level power converters (MLPC), such as microinverters and power optimizers, are becoming widespread solutions to maximize the energy harvesting from small-scale distributed photovoltaic (PV) systems [1]–[3]. The shift from centralized or string configurations to MLPC, however, requires careful design considerations in terms of multiple conflicting objectives such as cost, power density, efficiency and reliability [4]. To assist the off-line design of power converters, deterministic or Artificial Intelligence (AI)-based optimization algorithms have been proposed [5].

Many works focus on the multi-objective optimization of MLPC in terms of weighted efficiency and power density [3], [6], volume [7] or cost [8], [9]. These works do not consider at all the converter reliability in the optimization: this may lead to a late re-design or costly replacements of faulty parts in the field.

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Other works take into account reliability requirements, expressed in terms of the Mean Time Between Failures (MTBF), within the objective function [10]–[12]. This approach, however, has two fundamental limitations: 1) it may result in noncompetitive design solutions from the cost point of view, and 2) it does not model the physical degradation of the converter components due to the repeated thermal stresses. The mission profile-based lifetime consumption (LC) of the power modules was considered in the objective function only in the large-scale PV systems design in [13], however it did not consider the cost implications of a reliability-oriented optimal solution. The inclusion of the mission profile in the optimization approach allows for a more accurate estimation of the converter working points, thermal stresses and expected harvested energy [14].

To overcome the above-mentioned limitations, this article proposes a new design optimization methodology based on the minimization of a modified definition of Levelized Cost of Energy (LCOE) including a mission-profile based lifetime estimation of the converter switches as a constraint. The methodology is applied to the case study of an asymmetric Input-Parallel-Output-Series Power Optimizer (IPOS-PO) [15]. The proposed methodology can be generalized to different converter topologies upon characterization of the electrical stresses of the target converter.

The rest of the article is divided as follows: Section II introduces the converter topology considered as case study of the proposed optimization algorithm, defines the objective function, and describes the modelling and constraints of the methodology; Section III illustrates the Particle Swarm Optimization (PSO) method adopted as search algorithm, presents the impact of different mission profiles on the optimal solutions and the simulation results of a converter designed according to the optimal variable set; finally, conclusions and future work are drawn in Section IV.

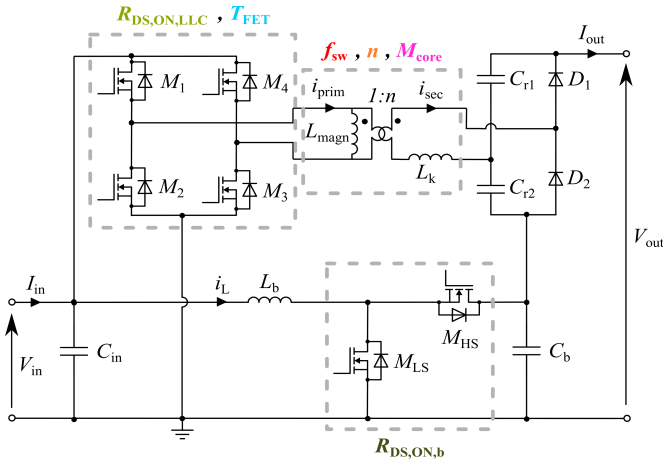


Fig. 1: Schematic of the IPOS-PO converter considered as case study for the optimization.

II. PROPOSED OPTIMIZATION METHODOLOGY

A. Case study

Before describing the details of the proposed optimization algorithm, the converter topology adopted as case study is introduced. IPOS converters are recently becoming attractive solutions for applications requiring high voltage gains with reduced electrical stresses [16]. In this work, the target converter is the asymmetric IPOS-PO shown in Fig. 1, consisting of a fixed-gain resonant LLC with Voltage Doubler Rectifier and a synchronous boost operating in Boundary Conduction Mode responsible for the Maximum Power Point Tracking (MPPT). In general, for improved performance, the two stages are designed so that the largest fraction of power is processed by the LLC. The detailed description of the converter operation and the derivation of the electrical stresses are out of the scope of this work and can be found in [15]. It is worth noticing that the proposed algorithm optimizes the design of both the conversion stages simultaneously.

In this work, the reduced-order modelling approach [17] has been adopted to identify the minimum size of the solution space, in order to optimize the computational complexity and time. With this approach, the minimum set of variables significantly affecting the converter cost and output energy were identified and are highlighted in Fig. 1:

- for the low-voltage Field-Effect Transistors (FETs) M_{1-4} of the LLC, the conduction resistance $R_{DS,ON,LLC}$ and technology T_{FET} ;
- for the LLC transformer, the operating frequency f_{sw} , turns ratio n and core material M_{core} ;
- for the high-voltage boost MOSFETs, the conduction resistance $R_{DS,ON,b}$.

It is worth observing that the selected design variables exhibit multiple effects on the converter design: for instance, n determines, for a specific input voltage operation, the required voltage gains and the fraction of input power processed by each conversion stage, with significant impact on all the power

devices. $R_{DS,ON,LLC}$ not only has an impact on the cost, conduction and switching losses of the LLC FETs, but also on the magnetizing inductance requirement of the transformer, in turns affecting its size and cost. More detailed considerations on the modelling are provided in Section II-C.

B. Definition of the objective function

The LCOE is a widely adopted figure of merit to compare different technologies used in energy production in terms of the cost-to-benefit ratio over the system lifetime [18]. The complete definition of LCOE involves the computation of the Net Present Value (NPV) of the lifetime costs (including initial investment, operation and maintenance costs, and potential fuel costs) and the NPV of the total output energy produced during the lifetime [19]. In this work, it is of interest to optimize the design of the Parallel Power Optimizer (PPO) in Fig. 1, assuming that the topology, panel specifications and mission profile are design constraints.

The proposed design optimization is based on the search inside the N -dimensional solution space of the optimal variable set, i.e. the combination of design variables optimizing the objective function. As a consequence, all the cost contributions that are fixed independently of the converter design, such as the PV module or the installation costs, are not of interest in this discussion and are neglected from the objective function. Since one of the objectives of the proposed optimization is to ensure, through a reliability constraint, that the converter lifetime matches the PV module lifetime, no replacement costs are considered.

Thus, the system-level definition of LCOE is here reduced and simplified to take into account only the contributions of cost and power conversion losses related to the converter design. For this reason, the objective function is here explicitly called Converter Cost-Energy Ratio (CCER). Denoting by S the trial design solution and by M the mission profile, the definition of CCER becomes:

$$CCER = \frac{C_{tot}(S)}{E_{tot}(S, M)} = \frac{C_{tot}(S)}{\sum_{k=0}^{25 \text{ yrs}} (P_{MPP,k} - P_{loss,tot,k}) \Delta t_k}, \quad (1)$$

where $C_{tot}(S)$ is the cost of components of the design S , $E_{tot}(S, M)$ is the total harvested energy at the output of the converter in a 25-year operation (for this case study), P_{MPP} is the PV module power and $P_{loss,tot}$ is the total loss, dependent on both the specific design S and on the mission profile M . The minimization of the scalar objective function expressed in (1) is the goal of the proposed methodology.

The block diagram of the proposed optimization scheme is shown in Fig. 2. For any trial solution S^* inside the solution space, the corresponding $CCER^*$ is computed through cost models and loss models applied to the 25-year converter operation. For the converter transistors, the instantaneous losses and junction temperature profiles rely on electro-thermal models, considering the package-dependent thermal resistance $R_{th,j-amb}$ and the temperature-dependent $R_{DS,ON}(T_j)$. The trial solution S^* is discarded if the reliability criteria are not

TABLE I: List of the main cost and loss models adopted in the optimization algorithm.

Component	Primary variables	Derived variables	Cost model	Loss model
LLC FETs M_{1-4}	$R_{DS,ON,LLC}, T_{FET}, f_{sw}$	t_{OFF}, α_R	$b_1 e^{d_1 R_{DS,ON,LLC}} + b_2 e^{d_2 R_{DS,ON,LLC}}$	$R_{DS,ON,LLC} \alpha_R (T_j) I_{RMS}^2 + \frac{1}{2} t_{OFF} f_{sw} V_{OFF} I_{ON}$
Boost FETs M_{LS-HS}	$R_{DS,ON,b}$	t_{OFF}, α_R	$b_3 e^{d_3 R_{DS,ON,b}} + b_4 e^{d_4 R_{DS,ON,b}}$	$R_{DS,ON,b} \alpha_R (T_j) I_{RMS}^2 + \frac{1}{2} t_{OFF} f_{sw} V_{OFF} I_{ON}$
Input capacitor C_{in}	f_{sw}, n	$C_{in}, ESR(C_{in})$	$c_1 + c_2 \cdot C_{in}$	$ESR(C_{in}) I_{RMS}^2$
Boost capacitor C_b	n	$C_b, ESR(C_b)$	$c_3 + c_4 \cdot C_b$	$ESR(C_b) I_{RMS}^2$
Transformer core and bobbin	f_{sw}, n, M_{core}	$L_{magn}, AP, N_1, V_{eff}, \alpha_{SE}, \beta_{SE}, \rho_{SE}$	$g_1 + g_2 AP^{\frac{1}{2}}$	$\frac{\pi}{4} K_{core} V_{eff} (AP) \rho_{SE} f_{sw}^{\alpha_{SE}} \Delta B^{\beta_{SE}}$
Transformer windings	f_{sw}, n	$d_s, \omega_{Cu}, N_1, N_2, R_p, F_p, R_s, F_s$	$g_3 + \omega_{Cu} \cdot [g_4 + g_5 e^{g_6 d_s}]$	$R_p F_p I_{p,RMS}^2 + R_s F_s I_{s,RMS}^2$

TABLE II: Empirical parameters of the cost models in Table I.

Parameter	Value	Parameter	Value	Parameter	Value
b_1	23.84 €(Si) / 39.36 €(GaN)	d_3	-0.0393 mΩ ⁻¹ (Si)	g_1	0.704 €
b_2	3.236 €(Si) / 2.346 €(GaN)	d_4	-0.003 mΩ ⁻¹ (Si)	g_2	2.83 €/cm ²
b_3	7.62 €(Si)	c_1	2.128 €	g_3	0.5 €
b_4	2.791 €(Si)	c_2	0.328 €/μF	g_4	19.04 €/kg
d_1	-2.467 mΩ ⁻¹ (Si) / -0.821 mΩ ⁻¹ (GaN)	c_3	2.017 €	g_5	1323 €/kg
d_2	-0.091 mΩ ⁻¹ (Si) / -0.013 mΩ ⁻¹ (GaN)	c_4	0.194 €/μF	g_6	-886 cm ⁻¹

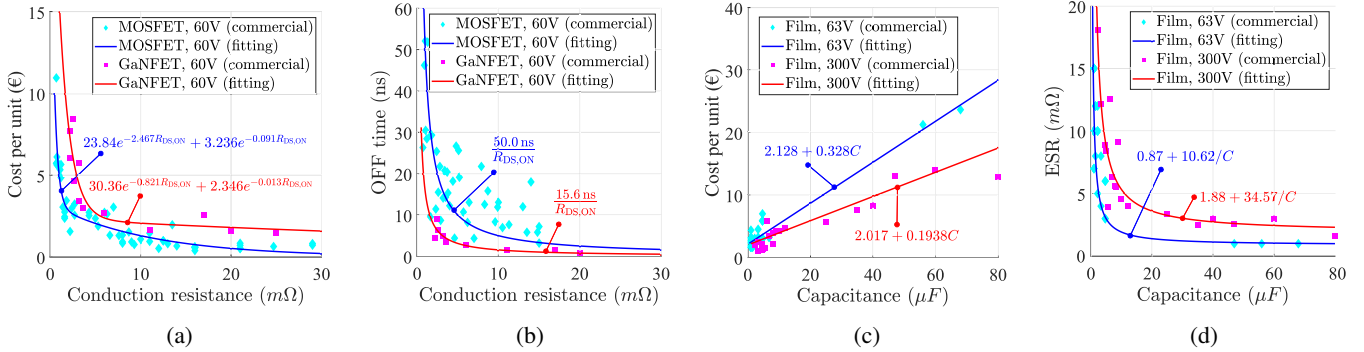


Fig. 3: Cost and key parameters of the loss models for some of the converter components, extracted from the analysis of commercial parts. (a) Cost per unit of 60 V Silicon MOSFETs and GaNFETs as function of $R_{DS,ON}$. (b) Turn-OFF time of 60 V Silicon MOSFETs and GaNFETs as a function of $R_{DS,ON}$. (c) Cost per unit of 63 V film capacitors (C_{in}) and 300 V capacitors (C_{boost}) as a function of the capacitance. (d) Equivalent Series Resistance (ESR) of 63 V and 300 V film capacitors as a function of the capacitance.

material-related parameters of the transformer core, such as the area product AP , the number of primary turns N_1 , the effective volume V_{eff} or the Steinmetz Equation coefficients $\alpha_{SE}, \beta_{SE}, \rho_{SE}$ [22]. The cost model was derived from commercial EE and ETD cores, for their widespread adoption in power electronics applications and their availability in different sizes and materials. For the transformer windings, the cost model for Litz wire coils is based on the overall windings weight ω_{Cu} and diameter d_s of the copper strands [23]. The

loss model takes into account the increase of the winding resistance due to the proximity effect through the coefficients F_p and F_s [24]. To limit the impact of the AC losses in the windings, the strand diameter is selected to be 1/3 of the skin depth. For a specific variable set S^* , the most impactful degrees of freedom on the transformer losses and cost are AP and N_1 , from which many derived variables follow. At each iteration of the PSO algorithm, thus, the transformer design subroutine is responsible for identifying the domain of all

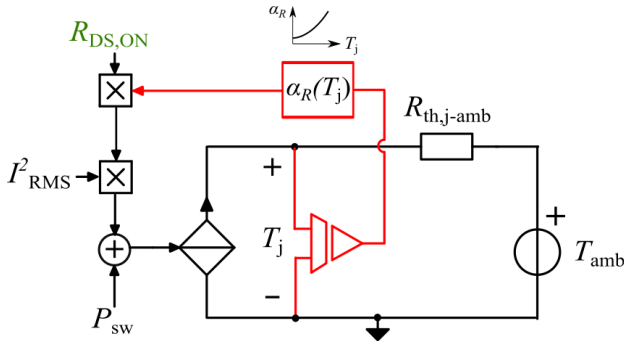


Fig. 4: Steady-state electro-thermal circuit considered in the optimization algorithm for the computation of the temperature-dependent losses of the converter switches.

the potential solutions $\{AP^*, N_1^*\}$, intersecting the following constraints:

- for a specific AP^* , N_1 must be sufficiently large to keep the flux density ΔB across the magnetic cross-section A_e lower than the maximum desired value (in this case, the ΔB_{\max} associated to 100 mWcm^{-1} loss density [25]):

$$N_1 > \frac{V_{\text{in,max}}}{2f_{\text{sw}}\Delta B_{\max}A_e(AP^*)} \quad (3)$$

- for a specific AP^* , the primary and secondary coils, with conductor cross section A_{cond} must fit in the available window area A_w [26]:

$$N_1 < \frac{K_w A_w(AP^*)}{2A_{\text{cond}}} \quad (4)$$

- the operation of the LLC switches in Zero-Voltage Switching (ZVS) requires a certain magnetizing inductance L_{magn} , resulting in a triangular magnetizing current superimposed to the resonant sinusoidal current [15], [27]. For a specific AP^* and inductance factor A_L , N_1 should be large enough to obtain the required L_{magn} :

$$N_1 > \sqrt{\frac{L_{\text{magn}}}{A_L(AP^*)}}. \quad (5)$$

The intersection of (3), (4) and (5) defines the domain of all the potential solutions $\{AP^*, N_1^*\}$. The subroutine is responsible for searching the optimal solution $\{AP_{\text{opt}}, N_{1,\text{opt}}\}$ that minimizes the *ad hoc* cost-output power ratio CPR_T objective function:

$$CPR_T(AP, N_1) = \frac{C_{\text{core}} + C_{\text{bobbin}} + C_{\text{coils}}}{P_{\text{rated}} - P_{\text{core}} - P_{\text{windings}}}, \quad (6)$$

where the numerator consists of the sum of the core, bobbin and coils costs, whereas the denominator is obtained by subtracting the total transformer losses from the rated input power.

Additional constraints are added in the transformer design subroutine: the transformer temperature should never exceed $T_{\max} = 100^\circ\text{C}$, and the maximum flux density should be kept below the saturation B_{sat} .

D. Constraints

In order to limit the 6-dimensional solution space, the range of the design variables are constrained: $f_{\text{sw}} \in [50 \text{ kHz}, 500 \text{ kHz}]$, $n \in [3.2, 4.0]$, $R_{\text{DS,ON,LLC}} \in [1 \text{ m}\Omega, 20 \text{ m}\Omega]$, $R_{\text{DS,ON,b}} \in [10 \text{ m}\Omega, 150 \text{ m}\Omega]$, $T_{\text{FET}} \in \{\text{Si}, \text{GaN}\}$, $M_{\text{core}} \in \{\text{N27}, \text{N87}, \text{N97}\}$.

Contrarily to other works [9], in which the converter topology is a degree of freedom, here the IPOS topology in Fig. 1 is given as constraint, as well as the PV module [28].

As mentioned in Section I, one of the novelties of this article is the inclusion of a mission profile-based reliability constraint on the converter switches. Electrolytic capacitors, which are among the most critical components in terms of reliability [29], are not adopted in this converter. The reliability constraint consists of a set of two conditions to be satisfied by each converter switch: the junction temperature must never exceed the maximum datasheet value $T_{j,\max}$, and the accumulated damage (AD) due to the repeated thermal stresses in one year must be low enough to ensure a 25-years lifetime. The lifetime computation follows the approach described in [30]. Firstly, the yearly junction temperature profiles are decomposed into elementary thermal cycles applying the rainflow counting method; then, the lifetime model expressed in (7) [31] is applied to derive the number of cycles to failure $N_{f,i}$ associated to each thermal stress; finally, all the damage contributions are summed up to compute the Accumulated Damage (AD), as expressed in (8):

$$N_{f,i} = A \cdot \Delta T_{j,i}^B \cdot \exp\left(\frac{C}{\bar{T}_{j,i} + 273}\right) \quad (7)$$

$$AD = \sum_i \frac{N_i}{N_{f,i}}, \quad (8)$$

where $A = 4.9283 \cdot 10^{13}$, $B = -5.2776$, $C = 812$ and N_i is the number of cycles counted for the specific thermal stress i [31]. The trial solution S^* is discarded in case at least one of the converter switches exceeds $T_{j,\max}$ or its $AD > \frac{1}{25}$, meaning that the converter is likely to fail before 25 years.

III. RESULTS

A. Impact of mission profile on optimal solution

A PSO search algorithm was chosen among other meta-heuristic approaches because of its low complexity and the limited number of user-defined parameters [5]. The algorithm was implemented in Matlab considering a population of 30 solutions moving in the 6-dimensional solution space: the algorithm stops when the objective function CCER converges to a stable value within $\pm 0.5\%$.

Table III reports the results of the optimization algorithm for three different mission profiles, i.e. Aalborg (Denmark), Arizona (USA), and Turin (Italy). Independently of the mission profile, the PSO always converges to $n = 4$: according to [15], this transformer ratio ensures that, at the rated PV panel voltage $V_{\text{in}} = 36.5 \text{ V}$, around 83% of the total input power is processed by the LLC stage, while only around 17% by the boost. A strongly unbalanced power splitting,

TABLE III: Results of the optimization algorithm for three different mission profiles: Aalborg (Denmark), Turin (Italy), Arizona (USA).

Mission profile	f_{sw}	n	M_{core}	T_{FET}	$R_{DS,ON,LLC}$	$R_{DS,ON,b}$	CCER
Aalborg	290 kHz	4	N97	Si	10 m Ω	130 m Ω	9.69 €/MWh
Arizona	240 kHz	4	N87	Si	10 m Ω	50 m Ω	3.43 €/MWh
Turin	250 kHz	4	N87	Si	13 m Ω	120 m Ω	6.19 €/MWh

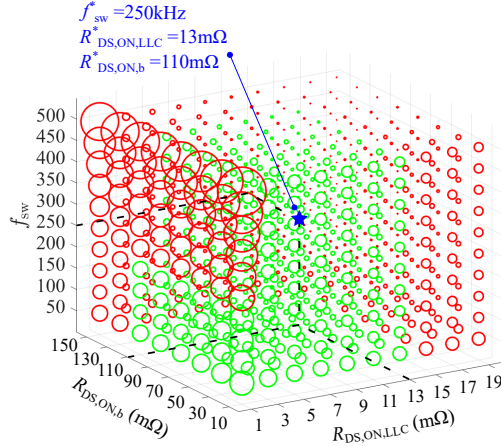


Fig. 5: Results of CCER with a constrained exhaustive search ($n = 4$, $T_{FET} = \text{Si}$, $M_{core} = \text{N97}$), for Turin mission profile. The markers size is proportional to the corresponding CCER. The optimal solution is highlighted with a blue star, while the red markers identify discarded solutions.

indeed, significantly reduces the current and voltage stresses on the boost switches, in terms improving their reliability, and helps reducing the size and cost of the filtering capacitors. In addition, the optimal variable sets always prefer Silicon MOSFETs over Gallium Nitride FETs: for the same $R_{DS,ON}$, the improved switching performances of the latter are not sufficient to justify the larger cost.

For the latter case, a constrained exhaustive search was performed by fixing transformer ratio $n = 4$, core material N87 and switch technology $T_{FET} = \text{Si}$, and sweeping the remaining design inputs. The results are graphically shown in Fig. 5, in which the size of the circular markers at each triplet of coordinates is directly proportional to the corresponding CCER. The green and red markers represent acceptable and non-acceptable solutions, respectively. It is relevant to observe that three different regions of the variable space do not satisfy the reliability constraints: 1 m Ω MOSFETs fail for $f_{sw} \geq 250$ kHz due to the high switching losses, whereas $R_{DS,ON,LLC} \geq 15$ m Ω and $R_{DS,ON,b} \geq 130$ m Ω are both unacceptable regions because of the high conduction losses. The minimum CCER solution is highlighted in blue and is consistent with the optimal solution found by the PSO (refer to Table III). Despite the larger conduction losses, the reduced cost of higher $R_{DS,ON}$ transistors is decisive to decrease the objective function. As a result, the minimum CCER is found in correspondence of the highest $R_{DS,ON,b}$ and $R_{DS,ON,LLC}$ still

TABLE IV: Selected components of the converter design for the Arizona case, used for the simulation results.

Component	Part number
LLC switches M_{1-4}	IPB090N06N3
Transformer core	ETD 44/22/15, N97
Transf. primary coil	5 turns, 2400x44 μm
Transf. secondary coil	20 turns, 600x44 μm
Rectifier diodes D_{1-2}	STTH30R04
Boost switches M_{HS-LS}	IPB600N25N3
Boost inductor L_b	74437529203330
Boost capacitor C_b	R75MW51004030J
Input capacitor C_{in}	4x CB182D0475JBC

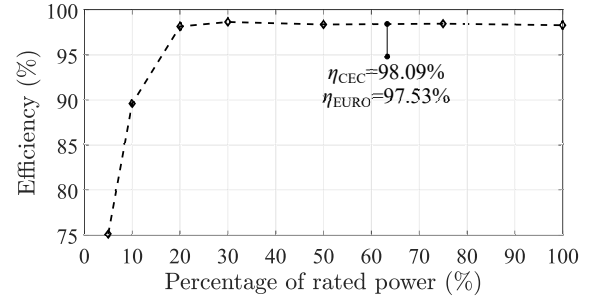


Fig. 6: Simulation results of converter efficiency as a function of operating power, at the rated voltage $V_{in} = 36.5$ V.

meeting the reliability constraints. In addition, independently of the mission profile, the PSO always converges to $n = 4$: according to [15], this transformer ratio ensures that, at the rated PV panel voltage $V_{in} = 36.5$ V, around 83% of the total input power is processed by the LLC stage, while only around 17% by the boost. A strongly unbalanced power splitting, indeed, significantly reduces the current and voltage stresses on the boost switches, in terms improving their reliability, and helps reducing the size and cost of the filtering capacitors.

B. Simulation results of optimal solution

From the worst-case solution of Table III, which corresponds to the harshest environment conditions (Arizona), a converter was designed with the components in Table IV and simulated in Matlab and LTspice. The transformer was designed according to the procedure illustrated in Section II.

Fig. 6 shows the simulated converter efficiency as a function of the output power at the rated input voltage condition, $V_{in} = 36.5$ V, and assuming 25 $^{\circ}\text{C}$ ambient temperature. The simulations were performed in LTspice with Spice models for both the active and passive devices. The calculated California Energy Commission (CEC) and European (EURO) efficiency are 98.09% and 97.53%, respectively.

Fig. 7 shows the annual junction temperature profiles for the selected converter transistors, referred to Aalborg (Fig. 7a), Arizona (Fig. 7b) and Turin (7c) mission profiles. The resulting annual AD is also reported for each temperature profile. The results were extracted in Matlab considering the electro-thermal circuit in Fig. 4. It is worth noticing that the selected MOSFET for the boost low-side switch does not meet

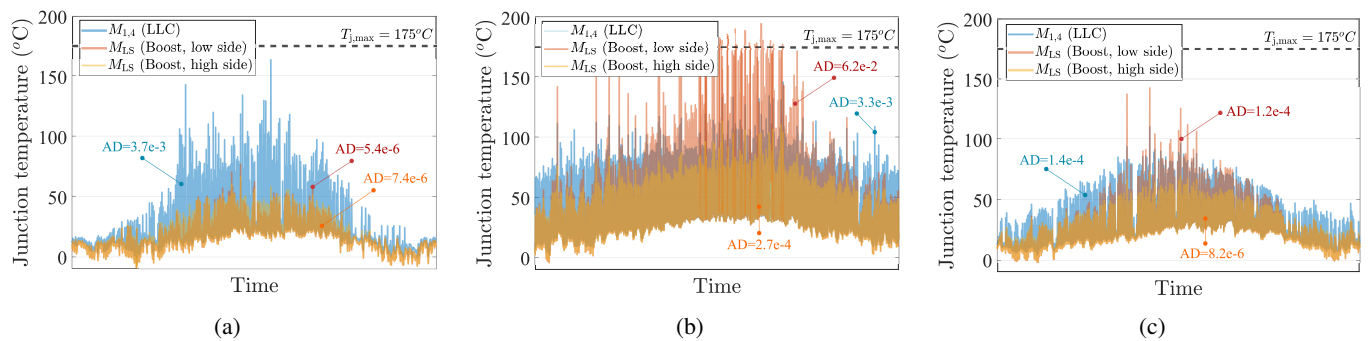


Fig. 7: Annual profile of the switches junction temperatures corresponding to three different mission profiles. (a) Aalborg (Denmark); (b) Arizona (USA); (c) Turin (Italy).

the reliability constraint in the Arizona mission profile: its worst-case junction-to-ambient thermal resistance is indeed higher than the one considered in the optimization (62 K/W against 40 K/W), and its $R_{DS,ON,b}$ is slightly larger than the recommended 50 m Ω . A more conservative components selection and a proper thermal design at a layout level would be essential to meet the reliability constraint with a sufficient safety margin. Notice that, in general, a higher ambient temperature in the mission profile (Turin or Arizona) shifts the MPP of a PV panel to lower voltages, thus increasing the gain requirement of the boost and the electrical stresses of its devices.

IV. CONCLUSIONS

This article proposes a new optimization methodology for the design of power converters that is based on the minimization of the cost-energy ratio and that includes a mission profile-based reliability constraint. The proposed methodology is suited for power converters designed for photovoltaic applications, where cost, efficiency and reliability are crucial tradeoffs. The approach is applied to the specific case study of an asymmetric IPOS power optimizer consisting of a LLC and a synchronous boost stage. At each step, the proposed algorithm exploits multiple analytical and empirical models to compute the cost and losses of the trial converter solution, and discards it if at least one of the converter switches does not meet the reliability constraints. The PSO method is used to search for the optimal solution inside a 6-dimensional solution space. The algorithm is run for three different mission profiles, highlighting that the optimal solutions privilege a strongly unbalanced power splitting between the two stages and Silicon devices over Gallium Nitride ones. From the worst case optimal solution, a converter is designed and simulated, showing a California Energy Commission efficiency above 98%. The future steps of this work include the design of a physical prototype and its experimental validation.

REFERENCES

[1] S. M. MacAlpine, R. W. Erickson and M. J. Brandemuehl, "Characterization of Power Optimizer Potential to Increase Energy Capture in Photovoltaic Systems Operating Under Nonuniform Conditions," in

IEEE Transactions on Power Electronics, vol. 28, no. 6, pp. 2936-2945, June 2013.

[2] K. Alluhaybi, I. Batarseh and H. Hu, "Comprehensive Review and Comparison of Single-Phase Grid-Tied Photovoltaic Microinverters," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 8, no. 2, pp. 1310-1329, June 2020.

[3] M. Kasper, D. Bortis and J. W. Kolar, "Classification and Comparative Evaluation of PV Panel-Integrated DC-DC Converter Concepts," in IEEE Transactions on Power Electronics, vol. 29, no. 5, pp. 2511-2526, May 2014.

[4] G. Spagnuolo, S. Kouro, and D. Vinnikov, "Photovoltaic Module and Submodule Level Power Electronics and Control," in IEEE Transactions on Industrial Electronics, vol. 66, no. 5, pp. 3856-3859, May 2019.

[5] S. Zhao, F. Blaabjerg and H. Wang, "An Overview of Artificial Intelligence Applications for Power Electronics," in IEEE Transactions on Power Electronics, vol. 36, no. 4, pp. 4633-4658, April 2021.

[6] M. D'Antonio, C. Shi, B. Wu and A. Khaligh, "Design and Optimization of a Solar Power Conversion System for Space Applications," in IEEE Transactions on Industry Applications, vol. 55, no. 3, pp. 2310-2319, May-June 2019.

[7] S. Vighetti, J. -P. Ferrieux and Y. Lembeke, "Optimization and Design of a Cascaded DC/DC Converter Devoted to Grid-Connected Photovoltaic Systems," in IEEE Transactions on Power Electronics, vol. 27, no. 4, pp. 2018-2027, April 2012.

[8] L. Schmitz et al., "Design optimization of a high step-Up DC-DC converter for photovoltaic microinverters," 2017 IEEE International Telecommunications Energy Conference (INTELEC), Broadbeach, QLD, Australia, 2017, pp. 432-437.

[9] E. O. Prado, P. C. Bolsi, L. Aleixo, H. C. Sartori and J. R. Pinheiro, "Optimized Design of Non-Isolated DC-DC Converters for PV System Applications," 2023 15th Seminar on Power Electronics and Control (SEPOC), Santa Maria, Brazil, 2023, pp. 1-6.

[10] G. Marsala and A. Ragusa, "Reliability and Efficiency Optimization Assisted by Genetic Algorithm to Design a Quadratic Boost DC/DC Converter," 2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Bangkok, Thailand, 2018, pp. 1687-1692.

[11] G. Adinolfi, G. Graditi, P. Siano and A. Piccolo, "Multiobjective Optimal Design of Photovoltaic Synchronous Boost Converters Assessing Efficiency, Reliability, and Cost Savings," in IEEE Transactions on Industrial Informatics, vol. 11, no. 5, pp. 1038-1048, Oct. 2015.

[12] M. Mirjafari, S. Harb and R. S. Balog, "Multiobjective Optimization and Topology Selection for a Module-Integrated Inverter," in IEEE Transactions on Power Electronics, vol. 30, no. 8, pp. 4219-4231, Aug. 2015.

[13] T. Dragičević, P. Wheeler and F. Blaabjerg, "Artificial Intelligence Aided Automated Design for Reliability of Power Electronic Systems," in IEEE Transactions on Power Electronics, vol. 34, no. 8, pp. 7161-7171, Aug. 2019.

[14] M. Sandelic, A. Sangwongwanich, S. Peyghami and F. Blaabjerg, "Reliability Modelling of Power Electronics with Mission Profile Forecasting for Long-Term Planning," 2022 IEEE 13th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Kiel, Germany, 2022, pp. 1-6.

- [15] S. Cerutti, M. Pavone, F. Gennaro, N. Aiello, F. Musolino, and P. Crovetto, "Design of a Multi-Mode Input-Parallel-Output-Series Power Optimizer for Wide-Voltage Range Photovoltaic Applications," *2024 IEEE Energy Conversion Congress & Exposition (ECCE)*, pp. 444-451, 2024.
- [16] J. Zhang, Z. He, R. Han and Y. Liu, "Hybrid Structure for an Input-Parallel Output-Serial DC-DC Combined Converter with High Efficiency and High Power Density," *2021 IEEE 12th Energy Conversion Congress & Exposition - Asia (ECCE-Asia)*, pp. 432-437, 2021.
- [17] M. Mirjafari and R. S. Balog, "Multi-objective optimization of the energy capture and boost inductor mass in a module-integrated converter (MIC) photovoltaic energy system," *2012 27th Annual IEEE Applied Power Electronics Conference and Exposition (APEC)*, Orlando, FL, USA, 2012, pp. 2002-2007.
- [18] Y. Son, S. Mukherjee, R. Mallik, B. Majmunovi'c, S. Dutta, B. Johnson, D. Maksimović, and G.-Su Seo, "Levelized Cost of Energy-Oriented Modular String Inverter Design Optimization for PV Generation System Using Geometric Programming," in *IEEE Access*, vol. 10, pp. 27561-27578, 2022.
- [19] J. S. Saranyaa and P. F. A, "A Comprehensive Survey on the Current Trends in Improvising the Renewable Energy Incorporated Global Power System Market," in *IEEE Access*, vol. 11, pp. 24016-24038, 2023.
- [20] Digikey electronic parts distributor. [Online.] Available: <https://www.digikey.it/en>.
- [21] F. Iannuzzo, *Modern Power Electronic Devices: Physics, applications, and reliability*. Institution of Engineering and Technology Engineering Series Vol. 152, 2020.
- [22] H. E. Tacca, "Core Loss Prediction in Power Electronic Converters Based on Steinmetz Parameters," *2020 IEEE Congreso Bienal de Argentina (ARGENCON)*, Resistencia, Argentina, 2020, pp. 1-8
- [23] R. M. Burkart, (2016). *Advanced Modeling and Multi-Objective Optimization of Power Electronic Converter Systems* [Doctoral dissertation, ETH Zurich].
- [24] W. .-J. Gu and R. Liu, "A study of volume and weight vs. frequency for high-frequency transformers," *1993 IEEE Power Electronics Specialist Conference (PESC)*, Seattle, WA, USA, 1993, pp. 1123-1129.
- [25] "Section 4 – Power Transformer Design". Texas Instruments. <https://www.ti.com/lit/ml/slup126/slup126.pdf> (accessed October 15, 2024).
- [26] C. W. T. McLyman, *Transformer and Inductor Design Handbook – Third Edition*, CRC Press, Boca Raton, 2004.
- [27] U. Kundu, K. Yenduri and P. Sensarma, "Accurate ZVS Analysis for Magnetic Design and Efficiency Improvement of Full-Bridge LLC Resonant Converter," in *IEEE Transactions on Power Electronics*, vol. 32, no. 3, pp. 1703-1706, March 2017.
- [28] 3SUN-M40 module datasheet. [Online.] Available: https://www.3sun.com/content/dam/threesun/documents/technical/3SUN_M40_file.pdf.
- [29] S. Peyghami, Z. Wang and F. Blaabjerg, "A Guideline for Reliability Prediction in Power Electronic Converters," in *IEEE Transactions on Power Electronics*, vol. 35, no. 10, pp. 10958-10968, Oct. 2020
- [30] H. Huang and P. A. Mawby, "A Lifetime Estimation Technique for Voltage Source Inverters," in *IEEE Transactions on Power Electronics*, vol. 28, no. 8, pp. 4113-4119, Aug. 2013
- [31] S. Dusmez, H. Duran and B. Akin, "Remaining Useful Lifetime Estimation for Thermally Stressed Power MOSFETs Based on on-State Resistance Variation," in *IEEE Transactions on Industry Applications*, vol. 52, no. 3, pp. 2554-2563, May-June 2016.