General comments

- The contribution explains the application of the iso-efficiency map method for determining the efficiency of rotating electrical machines. The method uses measurements at several combinations of rotation speed and torque for efficiency determination, which goes beyond other methods from existing standards. Measurements are undertaken at a small scale test bench (SSTB) for different operating conditions and measurement setups. It is shown that the iso-efficiency method yields comparable results to standardized methods but provides more insight due to the larger number of load steps considered. Furthermore, an analysis of the MU contribution to the measurements reveals the large importance of operating point instability for efficiency determination. The paper also briefly mentions the application of the method at a 4MW wind turbine nacelle test bench.

- The paper is well structured and allows for fluent reading and good understanding of its contents. The topic and motivation are introduced in appropriate detail and the state of the art is given adequate space and explanation. The paper is written using very well understandable language and grammar.
- The scientific approach and the methods used in the paper are valid and sufficient information to understand the individual steps is given.
- The originality of the paper is good. While it is obvious that the iso-efficiency map method provides more insights compared to standardized procedures since it utilizes more load points, the detailed explanation of the topic, the analysis of the MU and its contributions and the assessment of the temperature influence on MU are a relevant addition to the existing literature on the research topic.

- Due to the focus on measurements from the SSTB, it appears as if the application and demonstration of the method at a wind turbine nacelle test bench is not the focus of the paper. Hence, it appears questionable why the application of the method at the NTB is presented in a dedicated section (section 6), which does not have any subsections and contains only 5 lines of text and a figure taken from another publication. While it is important to point out the relevance of the rather theoretical (scaled-down) study at the SSTB to be utilized in large-scale wind turbine applications, the current form of doing so seems unfavorable, since in the current form section 6 does not provide a significant added value to the overall paper. The authors might either extend section 6 in order to explain similarities and/or differences found at the large-scale application compared to the SSTB, of present the NTB application it in a less prominent form, i.e. not in a dedicated section with only 5 lines of text.

- Following text had been added:
  The previous sections of this paper concentrated on efficiency determination methods, particularly emphasizing the validation of the iso-efficiency measurement method on the SSTB. This section offers a concise overview of the validated iso-efficiency map method's application and demonstration within the context of a wind turbine nacelle test bench (NTB). The traceable efficiency determination of a nacelle on a test bench, as presented in (Song et al., 2023), is based on the fundamental concepts outlined in this paper. It is important to note that while traceable efficiency determination of a nacelle on a test bench is addressed, it is not the primary focus of this paper. Furthermore, this paper summarizes the outcomes of applying and demonstrating the iso-efficiency map method at a wind turbine nacelle test bench, building upon detailed discussions previously presented in (Song et al., 2023).

- Formatting of the paper is generally satisfactory, but leaves room for improvement:
  - Font size and style changes in figure captions when including a citation (e.g. Table 6, Figure 6).

- Font size and style has been made same (bold) in figures and table captions.
  - Formatting of the figures could be improved: some figures are printed too small, so that it is difficult or impossible to read properly if printed at A4. It is apparent that the figure and plot style changes during the different chapters (e.g. font type and size, boxes around plots, see e.g. Fig 1 vs. Fig 3 vs. Fig 7, or Fig 13 vs. Fig 14). This might be harmonized by the authors.
- Figure 3 is reformatted in high resolution picture. Now Fig 1, Fig 3 and Fig 7 are in similar style. Almost all figures are reformatted. Now there is harmonization of the figures.

  - The general formatting of figures and mathematical symbols is not ideal and could be improved: some symbols are depicted using underscores instead of subscripts (e.g. lines 298f)
- All the symbols with underscore has been removed

- **Terminology "efficiency":** The paper elaborates on a method to determine the efficiency of a rotating electrical machine with a possible application in wind energy engineering for drive train / power train efficiency determination. The paper lacks a comprehensive and scientific usage of the term "wind turbine efficiency", since there is no definition given. In modern wind turbines, the drive train or power train efficiency might be an important factor, but the aerodynamic efficiency, i.e. the ability of converting the wind to rotor torque, is by far the more relevant factor when it comes to "overall wind turbine efficiency" (overall wind turbine efficiency = P_el/P_in = electric power / kinematic power of the wind). By not distinguishing between "overall wind turbine efficiency" and "drive train or power train efficiency" (i.e. mechanical rotor power at the main shaft to electric power output), the importance of the proposed method for drive train efficiency determination might be considerably overvalued when reading the introduction. The authors should distinguish clearly between the different efficiencies considered and comment on the relative importance of drive train efficiency as one factor of overall efficiency.

- **Terminology "validation":** The title of the paper puts a focus on the validation of the iso-efficiency map method. However, the word "validation" or "validate" is scarcely used throughout the paper, especially in the **relevant chapter 5.4**. It should be pointed out with more emphasis that the comparison of efficiencies from the different methods leads to a validation of the iso-efficiency map method. It should further be elaborated whether this validation shows a rather high or rather low level of accordance and what this means for further applications.
- Following changes had been done:
Comparison / validation: standardised methods (IEC) vs. iso-efficiency map with static MU values
- Comparison / validation: standardised methods (IEC) vs. iso-efficiency map with static MU values
- Figure 18 illustrates the comparison/validation between the standardised efficiency determination methods outlined in the IEC standards and the newly developed iso-efficiency map method with static MU values. The comparison of efficiencies validates that the newly developed load profile for iso-efficiency map determination aligns with standardised efficiency determination methods. The load profile for iso efficiency map determination, derived from standardised methods, has proven to be accurate, efficient, and cost-effective for full-range testing of DUT on SSTB, encompassing converter performance. In addition, the MU values of both methods align with each other as depicted in Figure 18. This validates and suggests that the iso-

efficiency map method on the DUT on SSTB appears straightforward and accurate. It indicates that the iso-efficiency map method could be easily applied in NTBs as well.

- The validation approach of the iso-efficiency map method appears to be simple, so that validation should be obtained in almost any case, since the new and the standardized methods take into account the very same load steps for efficiency determination. If the additional load steps of the iso-efficiency map method are not taken into account for validation of the method, how would there be any other differences in the determined efficiency than the ones coming from measurement uncertainties? This is not a general problem of the work, but the simplicity of this validation approach and its implications (e.g. it is very likely to achieve validation) should be elaborated on in this paper.
  - Figure 18 illustrates the comparison/validation between the standardised efficiency determination methods outlined in the IEC standards and the newly developed iso-efficiency map method with static MU values. The comparison of efficiencies validates that the newly developed load profile for iso-efficiency map determination aligns with standardised efficiency determination methods. The load profile for iso efficiency map determination, derived from standardised methods, has proven to be accurate, efficient, and cost-effective for full-range testing of DUT on SSTB, encompassing converter performance. In addition, the MU values of both methods align with each other as depicted in Figure 18. This validates and suggests that the iso-efficiency map method on the DUT on SSTB appears straightforward and accurate. It indicates that the iso-efficiency map method could be easily applied in NTBs as well.
- A critical error has been made in equation (4) (see specific comments). This error has the potential to propagate throughout the paper since it might be used in (all) later calculations for the different MU terms. It was not possible for the reviewer to check the actual calculations with numbers, so the authors are strongly asked to check for errors originating from equation (4) in their calculations.
  - In the previous version of the paper, the sensitivity coefficients were intended for motor mode operation but were mistakenly labeled with subscript_G for all terms. Equation 4 has now been corrected for generator mode operation, and the sensitivity coefficients have been adjusted accordingly. Additionally, the authors have rechecked the measurement uncertainty (MU) calculations for generator mode operation.
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Specific comments

Introduction

- As stated in the general comments, the usage of the term "**wind turbine efficiency**" should be more precise. Coming from the importance of high energy conversion efficiency it should be stated that drive train / power train efficiency is only part of this. In general, the function and importance of the wind turbine drive train / power train should be included in the introduction in some more words.
- Page 1, line 28f: it is unclear, how methods traceable to national standards could ensure highest possible efficiency. Efficiency determination methods have no direct effect on the efficiency itself, so they do not lead to higher efficiency.
  - These methods must also be characterized by high accuracy and traceability to national standards. This ensures precise efficiency measurements with minimal measurement uncertainty (MU)

Section 2

- Page 4, line 76: the Guide to the Expression of Uncertainty in Measurement GUM should be referenced.
  - GUM reference has been updated.

- Page 4, line 88: the factor k has not been introduced to this point, which makes it difficult to understand here.
  - (k = 2) is removed in the line 88 because it is described in line 96.
- Equation 4 is wrong, at least if using the given equation 2 as an input. It should be: d eta / d P_elec = 1 / P_mech
  - d eta / d P_mech = - P_elec/P_mech^2
  - (all terms with subscript _G)
-
  - ->In the previous version, sensitivity coefficients were for motor mode operation.
  - -> Now for Generator mode operation, sensitivity coefficients have been corrected.
  - -> Authors have already once again checked the MU calculations in this paper.

Section 3

- Page 5, line 111: "This approach was chosen because ..." – it is not clear to the reviewer what this means and why this is a logical consequence.
  - In an iso-efficiency map, the efficiency is a function of rotational speed n and torque T, with rotational speed plotted on the abscissa and torque on the ordinate, as also adopted in (Song et al., 2023).
  - . This approach to efficiency determination across the entire operating range was chosen because power loss segregation and efficiency determination are not feasible and easily accomplished in nacelle test benches (NTBs) due to their dimensions and complexity

- Page 5, line 121f: "torque is applied in descending order", but Figure 3 shows ascending torque steps. Maybe something is wrong here?
  - In accordance with well-known standards such as IEC 60034-2-1, torque is consistently applied in descending order, from the largest to the smallest torque, as stipulated in the standard. However, in the iso-efficiency map, torque can be applied in ascending or descending order. Similarly, rotational speed can also be applied in either ascending or descending order. For these measurements, it was progressively increased over time.

Section 4

- Page 8, line 185: as stated in general comments, the type and purpose of the "validation" is unclear and not precisely defined. What is validation at all, why do the authors want to validate the method? What is the purpose of the validation, what is an acceptance criterion for the validation to be carried out? There should be more explanation and definition.
  - The best way of efficiency determination traceable to national standards is still to measure the input and output powers directly with state-of-the-art measurement equipment – the so-called 'direct method'. In this study, we explore experimental setups for efficiency determination, particularly focusing on validating the newly developed iso-efficiency map method in comparison to the standardized efficiency determination method. As outlined in section 2 and 3, both methods utilize the direct efficiency determination approach, which involves directly measuring input and output powers. To ensure the robustness and reliability of the iso-efficiency map method, we conducted validation experiments on a four-pole rotating electrical machine using a 200 kW SSTB. Additionally, we extended iso-efficiency map method investigation to a 4 MW NTB, where

the method will be employed for assessing the efficiency of wind turbine drive trains in future applications.

- Table 2: the last column is offset:
  - Has been corrected

- Table 5: it is unclear what the purpose and unit of the given values is. Is this Nm? Or some relative value (unitless)?
  - The SI units of torque N m in Table 5 are given
- Table 6: rotor diameter and swept area are not relevant or even applicable properties of a wind turbine nacelle (as stated in the caption).
  - rotor diameter and swept area are removed.
  - Font size and style have been made the same (bold) in figure captions.
- Figure 6: the boxes "test bench" and "DUT" appear to be offset
  - Figure 6: the boxes "test bench" and "DUT" appear to be offset: has been made in the same position
- • Formatting of the paper is generally satisfactory, but leaves room for improvement: o Font size and style changes in figure captions when including a citation (e.g. Table 6, Figure 6). •
  - Font size and style in Figure 6 and Table 6 captions had been made similar
-

Section 5

- Figure 7: The torque level numbers given in the plot appear to be offset and are difficult to match with the plot.
  - Avg. torque values are represented in the plot by using the solid line.
  - Figure 7: Torque is given with symbol "M", despite using "T" for torque in the rest of the paper.
  - In Figure 7, the torque symbol "M" has been substituted with "T"
- Figure 8: font is hard to read in A4
  - The font in Figure 8 has been made bigger and is now easy to read in the A4-sized print version. It's recommended to check out the reference paper for a better understanding.
- Figure 9: torque "M" vs "T"
  - In Figure 9, the torque symbol "M" has been substituted with "T"
- Figure 10: for better comparability between (a) and (c) as well as (b) and (d) the authors might use the same scale. Font sizes are too small.
  - In Figure 10 same scale has been made. The font sizes are bigger now.

- The introduction to section 5.2 is not fully understandable to the reviewer (lines 305-310:
  - The introduction to section 5.2 has been rewritten to enhance clarity.
-
  - o What do you mean by "It also shows the losses when the number of operating points decrease"? – Figure 11 does not show any losses.
  - Description of figure 11 has been reformulated.
  - o Line 307f: How does interpolation facilitate to "improve the evaluation process"? Interpolation is independent of the new iso-efficiency map method.
  - By enabling accurate efficiency determination through interpolation at any operating point, they serve to improve the evaluation process. In conclusion, interpolation

within the iso-efficiency map method enriches the evaluation process by offering a more significance and precise picture of efficiency. This, in turn, empowers better-informed decision-making and optimization of system performance.

  - Line 309f: figure 11 does not show efficiency, therefore it can not "offer guidance for informed decisions regarding the DUT's efficiency".
- This line has been removed.

- Line 317: in contrast to the "warm state" (thermally stable), the "cold state" could require some more introduction and/or definition. By running a test, the "cold state" would not be at a constant temperature due to heating up during execution of the test runs. Do all "cold state" measurements start at the same reference temperature? What if tests last for different durations (i.e. the end of the test at "cold state" has a higher or lower temperature compared to another one in "cold state")? This might be elaborated in more words.
  - To analyse the effect of machine temperature on efficiency determination, the iso-efficiency map measurements were performed twice in generator mode: once in the cold and once in the warm state (with thermal stability) of the DUT. As for the direct efficiency determination acc. to IEC 60034-2-1, the measurements are taken in a steady state (with thermal stability). Thermal stability is achieved once the rate of temperature change is ≤ 1 K per half hour at the hottest point. However, unlike the warm state (which is thermally stable), there are no specific requirements for the cold state. In this paper, measurement values in the cold state are taken as soon as the DUT is connected to the grid. However, stable working conditions must be ensured before the measured values at an operating point are taken. The main purpose of cold and hot state measurements is to demonstrate how efficiency varies with changes in the temperature of the DUT.

- Figure 12: The caption states that "measured mechanical parameters of torque and rotational speed" are included, but they are not visible in the figure.
  - New figure 12 has plotted with torque values.
- Page 16, line 335: How does "measuring under thermal steady state conditions" (directly) allow to "assess the effects of temperature-related factors" – since it is only one measurement, no influence of temperature could be derived?
  - On the other hand, thermal variations can affect the resistance of windings, losses in the core, and other factors that influence efficiency. Thermal steady-state conditions refer to a state in which the temperature of the machine and its surroundings remains constant over time

- Figure 13 and Figure 14 show the same or similar data as before but in a different format. It should be explained in the text or in the figure caption how this matrix-style depiction (fig 13) or characteristic map style (fig14) has been derived from the measurements undertaken.
  - Furthermore, the efficiency of DUT in generator mode on the SSTB, as a function of variable speed drives (converter) in its full operating range is studied. The direct efficiency determined for a thermally stable (warm) generator is illustrated for the case without converter (**Error! Reference source not found.** (a)) and the case with converter (**Error! Reference source not found.** (b)). In the iso-efficiency map style, the case without a converter (**Error! Reference source not found.** (a)) is derived from measurements taken at measurement points MP and MP1, as shown in the experimental setup (**Error! Reference source not found.** (a)). Conversely, the case with a converter (**Error! Reference source not found.** (b)) is derived from measurements taken at measurement points MP and MP3, also shown in the experimental setup (**Error! Reference source not found.** (a)).

- Page 19, line 375f: figure 16 does not show “each component’s contribution from equation 10”, but just the overall sum.
  - The graphical representation illustrates the total sum of relative expanded MU, which comprises both the MU attributed to operating point instability and the MU from static calibration values.
- Line 377: it is unclear to the reviewer, what the “low values of the torque measurement (about 10%)” refer to.
  - about 10 % of the rated torque
- Figure 18: It should be highlighted that is the key figure to validation of the iso-efficiency map method.
  - Figure 18 has been made bigger and the symbol has been made similar so that it could be relatable to the other section of the paper.

Section 6

- As stated in general comments, it is unclear why such a short section 6 is a benefit to the paper (please see suggestions above).

Section 7

- Page 23, line 448f: The iso-efficiency method is applied to wind turbine drive trains / power trains, not to “wind turbine testing and [the] analysis of possible influencing factors”. It is still a very important contribution, but the application should be described more precisely here.
  - The iso-efficiency map method is a valuable tool for wind turbine drivetrains efficiency testing and the analysis of possible influencing factors.
- Page 23, line 457: it is unclear, how the iso-efficiency map method would be applied during the development process of a wind turbine, since it requires (prototype) testing of the system.
  - Using the validated iso-efficiency map method guide improves the reliability of determining a nacelle's efficiency on a test bench within an uncertainty interval. The application of the iso map method has proven highly beneficial for traceable efficiency determination in this context.

Technical corrections

- The paper shows several occurrences of double parentheses in text expressions, which should be avoided (e.g. p2, line 45).
  - Has been corrected.
- Page 2, line 38f: The source for the EMPIR project WindEFCY might be chosen in a more elegant way to avoid the n.d. (not dated) mention in the reference.
  - Has been corrected.
- Page 3, line 58: references to IEC 60034-2-1 and IEC 60034-2-3 are given in different styles, both of which leave room for improvement (identical wording in text and ref for the first, see also line 61; wrong ref style for the latter)
  - The references to IEC 60034-2-1 and IEC 60034-2-3 are made identical styles
-
- Page 4, line 74: units are irrelevant should not be given in the text since equations 1 and 2 are dimensionless.
  - All the units has been removed
  - Original: where n is the operating speed in rotations per minute (rpm), T is the torque in N·m, and the electrical quantities are represented (as voltage U, current I, and power factor λ = cos ϕ).

- Changed: where n is the operating speed, T is the torque, and the electrical quantities are represented (as voltage U, current I, and power factor λ = cos ϕ).

- Equation 3: both terms in the root should have equal sizing of the square brackets.
- Equation 3 uses subscripts for terms (e.g. eta_d_G), while eq. 4 uses a version with underscores. This applies to several occurrences in the paper and should be harmonized.
  - Equation 3 has been changed as requested.
- P5 line 110: (Song et al. 2023) is not the proper reference to show what the iso-efficiency map method is (see two lines above).
  - In an iso-efficiency map, the efficiency is a function of rotational speed n and torque T, with rotational speed plotted on the abscissa and torque on the ordinate, as also adopted in (Song et al., 2023).
- P6, line 140: "test benches for wind turbines" might include rotor blade tests, etc. Be more precise, e.g. "NTBs".
  - NTB has been used
- P15, line 298f: use proper symbol formatting with subscripts instead of underscores.
  - In Figure symbol with subscripts has been used. The font sizes are bigger now.

- Figure 11: the caption state 45 measurement points, but there are only 43 as stated in the other text.
  - 45 measurement points replaced with 43 measurement points
-
- Line 326: instead of referencing Fig12a it should be Fig13a.
  - It has been changed and corrected now
- Line 340: the highest efficiency of 91.968% can not directly be seen from figure 14. Why does this value have 3 fractional digits, while all others have 2?
  - It has been changed into 2 digits after decimal
- Figure 15 is hard to read
  - Figure 15 is replaced with bigger size and high resolution.

Line 421: Figure 9 does not show a difference of 4.9°K, but rather of 5.3°K (107.9 – 102.6)

  - Has been corrected.

- Line 421: Figure 9 does not have subfigure a)
  - Has been corrected to figure 9
- Line 423: Figure 12 does not have subfigure a)
  - Has been corrected to figure 12
- Figure 18: style of the symbols is not uniform and should be improved in this figure
  - Figure 18 symbols has been changed and made uniform as fig 15 and fig 10
- Line 438: "iso-efficiency map method"
  - iso method ->iso-efficiency map