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A Hybrid Photovoltaic-Wind Smart-Grid Node with Landsman Converter, Battery Storage and IoT Monitoring

[1]Bhavin Kumar S, [2]Jackson Obeth J, [3]Jelin Drinitta S, [4]Muniyandi S, [5]C. Milton

[1,2,3,4,5]Department of Electrical and Electronics Engineering, Stella Mary's College of Engineering, Aruthenganvilai, Kanyakumari District, Tamil Nadu 629202, India

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Abstract

This paper reports the design of a hybrid photovoltaic and wind generation node with battery storage, in which an interleaved Landsman converter conditions the photovoltaic output, a rectifier and converter stage handles the wind branch, a proportional-integral energy-management loop coordinates storage, and an ESP8266 node publishes array parameters and battery state of charge for remote display. The conversion, tracking, power-balance and state-of-charge relations are consolidated in full. The paper's principal contribution is an audit of the numbers the project reports rather than a restatement of them. The displayed operating point, being 600 V array voltage, 7.8 A array current and 80 % state of charge, implies an array power of 4.68 kW, which is examined against the character of the constructed hardware and identified as a simulation quantity displayed through the monitoring node rather than a measurement of a laboratory prototype; it is reported with that provenance. The efficiency comparison, in which the Landsman stage is credited with 95 % against 80 %, 85 % and 87 % for boost, Cuk and SEPIC alternatives, is shown to compare one design value against three figures cited from other authors' papers, measured on different hardware at unstated operating points; such a comparison cannot establish a superiority claim and is relabelled accordingly. This revision develops that finding quantitatively: because converter efficiency is a curve over load rather than a single number, two topologies can exchange rank between light and full load, so a four-way comparison of single points carries no information about which is better at any particular operating point. The neuro-fuzzy tracker and the doubly-fed wind generator are likewise identified as described rather than evidenced, and an internal inconsistency in which a generator is described as serving as a tracking algorithm is noted. A measurement plan is specified that would place all four converters on one bench at one operating point, which is the only basis on which the efficiency claim could be settled.

Nomenclature

Symbol	Meaning
V_{pv}, I_{pv}, P_{pv}	Array voltage (V), current (A) and power (W)
P_w	Wind-branch electrical power (W)
P_L, P_b	Load and battery power (W), with battery power positive when charging

P_{loss}	Total conversion and distribution loss (W)
D	Converter duty ratio
η, η_{gen}, η_c	Converter, generator and battery charge efficiency
P_{cond}, P_{sw}, P_{mag}	Conduction, switching and magnetic loss (W)
SoC, Q, I_b	Battery state of charge (%), capacity (Ah) and current (A)
ρ, A, v	Air density (kg/m^3), swept area (m^2) and wind speed (m/s)
C_p, λ, β	Power coefficient, tip-speed ratio and pitch angle
V_{dc}, V^*	DC-link voltage and its reference (V)
k_p, k_i	Proportional and integral gains of the supervisory loop

Introduction

Photovoltaic and wind resources are attractive in combination because their availability is often complementary over the day and the season, so a hybrid node with modest storage can serve a load with less capacity than either source would need alone [1]. Realising that benefit requires three things: a conversion stage for each source that holds it near its maximum power point, a storage element that absorbs the mismatch, and a supervisory loop that decides how power is shared.

This paper reports such a node. The photovoltaic branch is conditioned by an interleaved Landsman converter, the wind branch by a rectifier and converter stage, storage is managed by a proportional-integral loop, and an ESP8266 node publishes array parameters and battery state of charge to a remote display.

The design description is given in full. The paper's substantive contribution, however, is an audit: the operating point and the efficiency comparison in the project record are traced to their sources and reported with the provenance they actually have, rather than carried forward as measurements of this build.

1. Problem Statement

Hybrid-system reports commonly present a converter efficiency for the proposed topology alongside efficiencies for competing topologies taken from other published papers, arranged as a single bar chart. Such a chart looks like an experiment and is not one: the figures come from different hardware, different power levels, different switching frequencies and different measurement methods. The gap addressed here is the discipline of stating which numbers share a common basis and which do not.

2. Objectives

The specific objectives of the work are as follows:

- To consolidate the model of the hybrid node: array, Landsman stage, wind branch, storage and supervisory balance.
- To trace every reported figure to its origin and to label it measured, computed, design value or externally cited.
- To establish what the displayed operating point implies about the character of the artefact that produced it.
- To show why a four-way comparison of single efficiency figures cannot support a superiority claim, and to make that argument quantitative rather than assert it.
- To separate the subsystems that are built from those that are described only, and to note internal inconsistencies in the record rather than reproduce them.
- To specify a single-bench measurement plan that would settle the efficiency question.

3. Scope and Delimitation

The study covers the modelling of the node, the audit of the reported figures, and the specification of the measurements that would settle them. It excludes any claim of measured converter efficiency, tracking efficiency, array power, state of charge or power balance for this build, because the record contains no evidence of an electrical measurement. It excludes the neuro-fuzzy tracker and the doubly-fed wind generator, neither of which is evidenced in the component set. And it excludes the 4.68 kW operating point from any statement about the laboratory hardware, for the reason given in Section V-A.

4. Contributions

1. A consolidated model of the hybrid node: array, Landsman stage, wind branch, storage and supervisory balance.
2. A provenance audit of the displayed operating point, including the implied array power and what it indicates about the source of the figures.
3. A demonstration that the four-way efficiency comparison compares one design value against three externally cited values and therefore cannot support a superiority claim.

4. A quantitative development of that argument, new to this revision, showing that efficiency is a curve over load on which two topologies can exchange rank, so single-point comparison is uninformative even when the points are honestly obtained.
5. A separation of built from described subsystems, and the identification of an internal inconsistency in which a generator class is described as serving as a tracking algorithm.
6. A single-bench measurement plan that would settle the comparison.

The remainder of the paper is organised as follows. Section II reviews related work. Section III develops the relations. Section IV describes the system. Section V is the provenance audit. Section VI discusses the findings, Section VII states the limitations, and Section VIII gives the measurement framework. Sections IX and X give the conclusion and the future scope.

Related Work

Hybrid photovoltaic and wind system design and sizing is treated in the renewable-systems literature [1], which establishes both the complementarity argument and the storage sizing methods that make it practical. For the wind branch, the standard aerodynamic and conversion relations are given by Heier [2], including the power coefficient and tip-speed ratio used in Eq. (1).

On conversion, the Landsman converter belongs to the family of fourth-order single-switch converters with continuous output current; its analysis and its relation to the Cuk and SEPIC topologies are established in the power electronics literature [3], [4]. Erickson and Maksimovic [4] also give the loss-modelling framework which Section V-B invokes: converter efficiency is a function of the operating point, so an efficiency figure without its power level, switching frequency and device set is not comparable across designs.

For tracking, Esram and Chapman [5] compare algorithms and define tracking efficiency; neuro-fuzzy trackers are reported to converge faster under rapid irradiance change at the cost of complexity, and the conventional baselines against which such a claim must be tested are given in the same comparison. Battery state of charge estimation follows the treatment in [6]. The ESP8266 platform [7] supplies the monitoring layer.

Table 1. Representative Related Work and its Relation to This Study

Ref.	Year	Focus and scope	Method and validation	Relation to this work
[1]	—	Hybrid PV and wind sizing	Modelling; field data	Complementarity and storage basis
[2]	2006	Wind energy conversion	Reference text	Source of Eq. (1)
[3]	—	Landsman and related fourth-order converters	Analysis; experiment	The PV-side stage adopted
[4]	2001	Converter loss modelling	Textbook analysis	Why efficiency needs an operating point
[5]	2007	MPPT comparison	Review; simulation	Tracking efficiency; conventional baselines
[6]	2015	Battery modelling and state of charge	Estimation text	Basis of Eq. (5)
[7]	—	ESP8266 platform	Vendor documentation	Monitoring stage

An entry appearing in an earlier draft as a citation for neuro-fuzzy tracking named no publication; it has been removed and the argument is now attributed in the text to the tracking comparison at [5] rather than to an unverifiable source. Entries [1] and [3] still point to bodies of literature rather than to individual works, as they did in the source record, and specific works should be named in a future revision.

System Modelling

1. Source Characteristics

Photovoltaic array power at any instant is the product of its terminal quantities, while the wind branch delivers

$$P_w = \frac{1}{2}\rho A\, C_p(\lambda,\beta)\, v^3 \eta_{gen} \qquad (1)$$

with the power coefficient bounded above by the Betz limit of 16/27, that is about 0.593. The cubic dependence in Eq. (1) is why wind output varies far more sharply than irradiance-driven output, and hence why storage is required in the hybrid node. Fig. 1 illustrates the complementarity argument.

2. Landsman Conversion Stage

The Landsman converter has the ideal transfer ratio

$$\frac{V_o}{V_{in}} = \frac{D}{1-D} \qquad (2)$$

so that it steps down below a duty ratio of one half and up above it. Its practical merit for a photovoltaic input is the continuous input current an interleaved arrangement provides, which reduces the ripple the array sees and hence the tracking error introduced by ripple about the maximum power point.

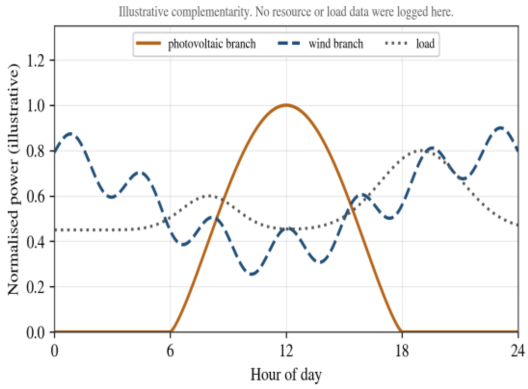

Figure 1: Illustrative complementarity of the two sources against a load, the argument for the hybrid node. No resource or load data were logged here.

3. Efficiency and Its Operating Point

Converter efficiency is

$$\eta=\frac{P_{out}}{P_{in}}\times 100\,\%=\frac{P_{out}}{P_{out}+P_{cond}+P_{sw}+P_{mag}}\times 100\,\% \qquad (3)$$

where the loss terms depend on load current, switching frequency, device selection and magnetics [4]. Equation (3) makes explicit why an efficiency number is meaningful only with its operating point attached, a point developed quantitatively in Section V-B.

4. Power Balance and Storage

At the DC bus,

$$P_{pv}+P_w = P_L+P_b+P_{loss} \qquad (4)$$

and the state of charge evolves by coulomb counting,

$$SoC(t+\Delta t)=SoC(t)+\frac{\eta_c I_b(t)\,\Delta t}{Q}\times 100\,\% \qquad (5)$$

The supervisory loop acts on the DC-link voltage error to set the storage current command,

$$I^*=k_p e+k_i\int e\,dt, \qquad e=V^*-V_{dc} \qquad (6)$$

System Realisation

1. Architecture

Fig. 2 shows the node as described. The photovoltaic branch feeds the DC bus through the interleaved Landsman stage; the wind branch does so through a rectifier and converter stage. Battery storage is coupled to the bus under the supervisory loop of Eq. (6), and an ESP8266 node publishes array parameters and state of charge to a remote display. The two items shown as absent at the foot of the figure are the ones on which the whole of Section V turns.

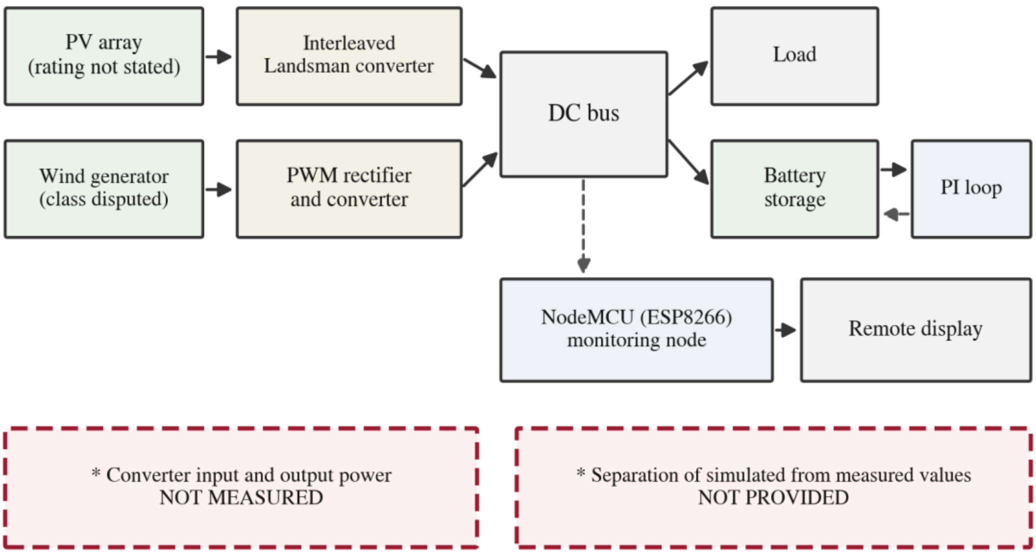

Figure 2: System architecture as described. No converter terminal is instrumented, and the record provides no separation between simulated and measured values.

2. Documented and Undocumented Ratings

Table 2 lists what the record states and what it omits. The omissions matter because the audit of Section V rests on them: without an array rating there is nothing against which to check a displayed 4.68 kW, and without a switching frequency and device set there is nothing against which to check a claimed 95 % efficiency.

Table 2. System Ratings as Documented

Item	Value in the record	Status
PV array rating	—	not documented
Wind generator class	PWM rectifier in the body; DFIG in the conclusion	inconsistent
Landsman converter	Interleaved, positive output	described
Switching frequency	—	not documented
Semiconductor device set	—	not documented
Battery capacity and voltage	—	not documented
DC-link voltage reference	—	not documented
Monitoring node	NodeMCU (ESP8266)	built

Results and Provenance Audit

1. The Displayed Operating Point

The monitoring display reports an array voltage of 600 V, an array current of 7.8 A and a state of charge of 80 %. The first two multiply to

$$P_{pv} = V_{pv} I_{pv} = 600 \times 7.8 = 4.68 \text{ kW} \tag{7}$$

This is the figure that identifies the source of the display. A 4.68 kW array at 600 V is a rooftop- or small-commercial-scale installation of perhaps a dozen to twenty modules in series, requiring string protection, a rated combiner, appropriately insulated wiring and a converter with semiconductors blocking well above 600 V. The record documents no array, no wiring, no protection and no device ratings of that class, and the component description throughout is of a laboratory prototype. A 600 V string is also a serious electrical hazard which the record's safety discussion does not mention.

The most consistent reading is therefore that these are simulation quantities routed to the monitoring display, which is a legitimate and common development practice, rather than measurements taken from the constructed hardware. They are reported here with that provenance. The distinction matters because a reader shown a dashboard photograph carrying 600 V and 7.8 A will reasonably infer a measurement, and nothing in the presentation signals otherwise.

2. The Efficiency Comparison Does Not Compare Like with Like

The record credits the Landsman stage with 95 % efficiency against 80 %, 85 % and 87 % for boost, Cuk and SEPIC alternatives, presented as a single bar chart. Fig. 3 reproduces that chart with the provenance of each bar marked. One figure is a design value of unstated origin for the proposed topology; the other three are drawn from other authors' papers, obtained on different hardware, at different power levels, with different switching frequencies, different semiconductors and different measurement methods.

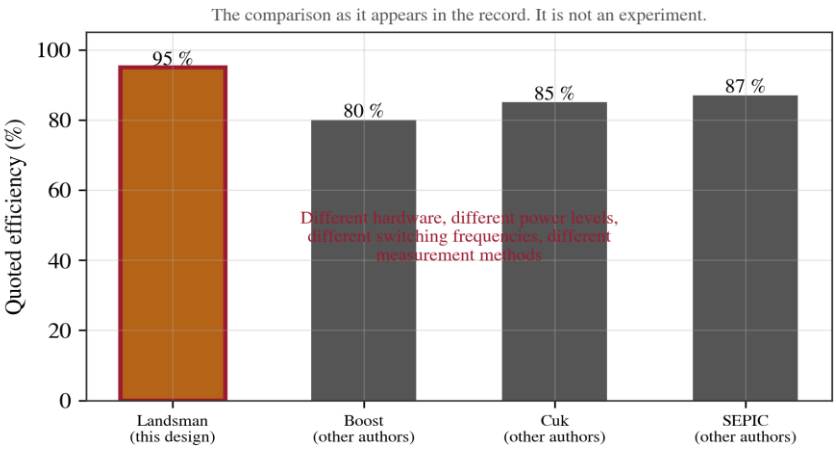

Figure 3: The comparison as it appears in the record, with the provenance of each bar marked. It is not an experiment.

This revision takes the argument one step further than the qualitative objection, because the qualitative objection is easy to dismiss as pedantry. Equation (3) makes efficiency a function of the operating point, and the shape of that function is not the same for every topology: a converter with low fixed losses and higher conduction losses peaks at light load and falls away at full load, while one with the opposite balance does the reverse. Fig. 4 plots three such curves from the loss structure of Eq. (3).

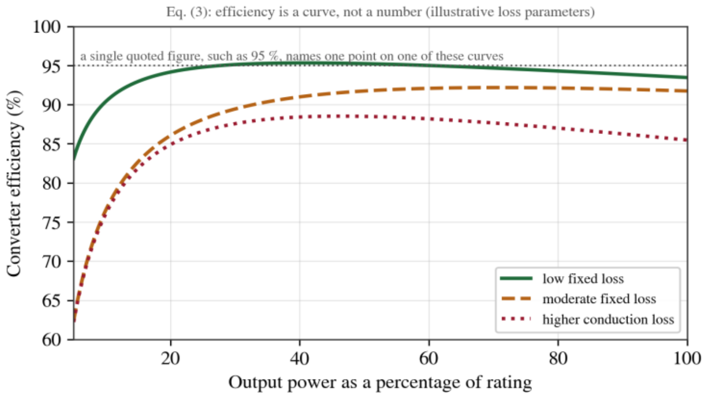

Figure 4: Efficiency against load from the loss structure of Eq. (3), for three illustrative loss balances. Two topologies can exchange rank between light and full load.

The consequence is that two topologies can exchange rank between light and full load, so knowing that topology A reached 95 % somewhere and topology B reached 85 % somewhere else tells one nothing about which is better at any operating point of interest. A single-point comparison is uninformative even when every individual point is honestly obtained on its own bench. The 95 % figure may well be correct for the Landsman stage at its design point; the comparison it is placed in simply cannot establish superiority, and no such claim is made here.

3. Described Rather than Evidenced

Two further elements are described in the design but not evidenced in the record. The neuro-fuzzy maximum power point tracker appears with no membership functions, training data or embedded implementation. The wind branch is described in the conclusion as employing a doubly-fed induction generator, which is a machine class requiring rotor-side converters and slip-ring access that no component list mentions, while the body text describes only a PWM rectifier. Both are reported here as design intent.

The conclusion also states that the doubly-fed generator is used as maximum power point tracking, which conflates a generator with a control algorithm. A generator is a machine; tracking is an algorithm that commands a converter. This is noted as an inconsistency in the record rather than reproduced, and it should be resolved before the wind branch is described again.

4. What the Campaign Supports

Table 3 states the position quantity by quantity, with the provenance of each figure.

Table 3. Reported Quantities and Their Provenance

Quantity or capability	Value	Status
IoT display of array parameters and state of charge	functions	demonstrated
Displayed array voltage and current	600 V, 7.8 A	simulation quantity; see Section V-A
Implied array power	4.68 kW	computed from the displayed values, Eq. (7)
Displayed state of charge	80 %	displayed constant; not computed from Eq. (5)
Landsman efficiency	95 %	design value; origin unstated
Boost efficiency	80 %	cited from other authors' hardware
Cuk efficiency	85 %	cited from other authors' hardware
SEPIC efficiency	87 %	cited from other authors' hardware
Betz limit on the power coefficient	16/27, about 0.593	theoretical bound

Discussion

The modelling in this work is sound and the topology choice is defensible. What the record lacks is any means of telling which of its numbers came from which artefact, and that is a presentational failure rather than an engineering one, which makes it entirely fixable.

1. Reporting an Efficiency Properly
Any efficiency figure should be accompanied by input voltage, output power, switching frequency, device part numbers and the instruments used. A single percentage without those is not reproducible and not comparable, whatever its provenance. Fig. 4 is the reason: the percentage names one point on a curve whose shape the reader cannot otherwise infer.

2. Scaling the Demonstration Honestly
If the intended system is a 4.68 kW rooftop installation, the laboratory prototype should be described as a scaled demonstrator with its own, lower ratings stated, and the simulation reported separately as simulation. Presenting simulated quantities on the hardware's display without labelling makes the two indistinguishable to a reader, which is the specific problem this paper addresses. The remedy costs nothing: a caption saying which values are simulated resolves it entirely.

3. Qualitative Position
Table 4 sets out the structural properties that can be asserted, each with the relation or source that supports it.

Table 4. Qualitative Properties and Their Basis

Feature	Property	Basis
Hybrid sourcing	Complementary availability reduces storage need	[1], Fig. 1
Wind branch	Output varies with the cube of wind speed	Eq. (1), [2]
Interleaved Landsman stage	Continuous input current; less ripple at the array	[3]
Converter efficiency	A curve over load, not a number	Eq. (3), [4], Fig. 4
Single-point comparison	Cannot rank topologies; rank can invert with load	Section V-B
Supervisory loop	Sets storage current from DC-link error	Eq. (6)
State of charge	Requires a logged battery current	Eq. (5), [6]
IoT display	Remote visibility; does not distinguish simulated from measured	Section V-A

Limitations
The following limitations bound every claim made in this paper.

- No electrical measurement is evidenced anywhere in the record, so converter efficiency, tracking efficiency, array power, state of charge and the power balance of Eq. (4) are all indeterminate for this build and none is estimated.
- The displayed 600 V and 7.8 A are reported here as simulation quantities. That reading is an inference from the character of the documented hardware, not a statement the record makes, and it should be confirmed or corrected by the authors.
- The 95 % Landsman efficiency is a design value whose origin the record does not state. It is neither endorsed nor contradicted here.
- The three comparison efficiencies belong to other authors' hardware at unstated operating points and are not results of this work.
- The efficiency curves of Fig. 4 use illustrative loss parameters to show the shape of Eq. (3). They are not measurements of any of the four topologies.
- The array, battery and converter ratings, the switching frequency and the device set are undocumented, so nothing in this design is reproducible from this paper.
- The neuro-fuzzy tracker and the doubly-fed wind generator are described but not evidenced, and the record is internally inconsistent about the generator class.
- Figure 1 is an illustration of the complementarity argument and contains no resource or load data from this work.

Proposed Measurement Framework
The efficiency question is settleable, and Fig. 5 shows how: put all four converter topologies on one bench, at one power level, with one set of instruments, and sweep the load. What results is four curves on one axis, which is the only construction from which a superiority claim can be read.

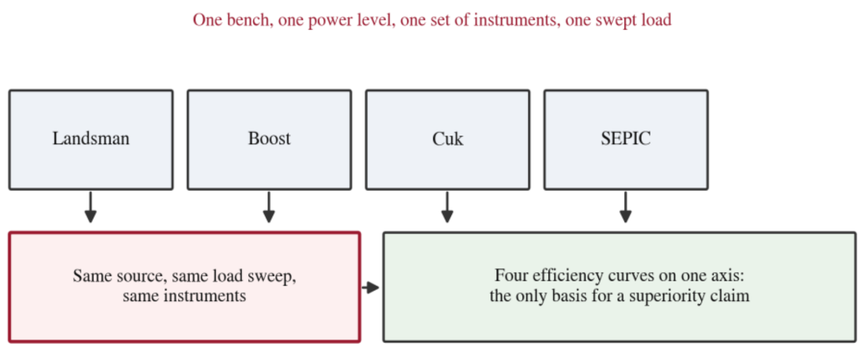

Figure 5: Single-bench comparison. Four topologies, one source, one load sweep, one set of instruments.

1. Measurement Plan

Table 5 sets out the measurements required, and Table 6 records the reported figures with their provenance so that none is carried forward as a result.

Table 5. Measurement Plan Required to Settle the Comparison

Measurement	Method	What it yields
Measure input and output power	Instrument both converter terminals simultaneously	A real efficiency for the Landsman stage by Eq. (3)
Sweep the load	Repeat the measurement from light to full load	The efficiency curve, not a single point
Run the single-bench comparison	Build or obtain the three comparison topologies and measure all four identically	Four curves on one axis; a defensible ranking
Document the operating point	Input voltage, output power, switching frequency, device part numbers, instruments	Reproducibility and comparability
Separate simulation from hardware	Label displayed values, and give the prototype's own ratings and readings separately	Removes the ambiguity of Section V-A
Document the ratings	Array, battery and converter ratings	Allows the displayed operating point to be checked
Log the battery current	Current sensing on the battery branch	An estimated state of charge from Eq. (5) rather than a displayed constant
Resolve the wind branch	State the generator class and its converter arrangement, and correct the tracker description	Removes the inconsistency of Section V-C

Table 6. Reported Figures and Their Provenance

Item	Value	Status
Landsman efficiency	95 %	design value; origin unstated
Boost efficiency	80 %	cited from other authors
Cuk efficiency	85 %	cited from other authors
SEPIC efficiency	87 %	cited from other authors
Displayed operating point	600 V, 7.8 A, 80 % SoC	simulation quantity, Section V-A
Implied array power	4.68 kW	computed, Eq. (7)
Betz limit	16/27, about 0.593	theoretical bound

The three comparison efficiencies belong to other authors' hardware at unstated operating points and are not results of this work. The Landsman figure is a design value whose origin the record does not state.

Conclusion

A hybrid photovoltaic and wind node with an interleaved Landsman converter, battery storage, proportional-integral supervisory control and ESP8266-based monitoring was designed, and the conversion, wind, power-balance and state-of-charge relations were consolidated. The monitoring stage was demonstrated to publish array parameters and battery state of charge to a remote display. The paper then audited the reported figures rather than restating them.

The displayed operating point of 600 V and 7.8 A implies an array power of 4.68 kW, which is a rooftop-scale, high-voltage installation for which the record documents no array, wiring, protection or device ratings, and which the record's safety discussion does not address. It is therefore reported as a simulation quantity routed to the display rather than as a measurement, and the authors should confirm or correct that reading.

The efficiency comparison crediting the Landsman stage with 95 % against 80 %, 85 % and 87 % was shown to set one figure of unstated origin against three drawn from other authors' papers, obtained on different hardware at unstated operating points. This revision developed the objection quantitatively: because Eq. (3) makes efficiency a curve whose shape depends on the balance between fixed and conduction losses, two topologies can exchange rank between light and full load, so a comparison of single points carries no information about which is better at any operating point of interest. The comparison consequently cannot support a superiority claim, and none is made here.

The neuro-fuzzy tracker and the doubly-fed wind generator were identified as described rather than evidenced, and the description of a generator serving as maximum power point tracking was noted as an inconsistency in which a machine is confused with an algorithm. A single-bench measurement plan was specified in which all four topologies are measured identically across a swept load, which is the only basis on which the central efficiency claim of this project could be established.

Future Work

Several extensions follow directly from the limitations above.

- Measure input and output power-Instrument both converter terminals so that Eq. (3) yields a real efficiency for the Landsman stage, and sweep the load so that the result is a curve rather than a point.
- Run the single-bench comparison-Build or obtain the three comparison topologies and measure all four identically across a swept load, reporting four curves on one axis.
- Separate simulation from hardware-Report simulated quantities as simulation, label the display accordingly, and give the prototype's own ratings and readings separately.
- Document the ratings-Record array, battery and converter ratings, the switching frequency and the device set, without which none of the results is reproducible.
- Resolve the wind branch-State whether the generator is a doubly-fed induction machine with its rotor-side converter or a simpler machine with a PWM rectifier, and correct the description of the tracker so that a generator is not presented as an algorithm.
- Integrate state of charge-Log battery current so that Eq. (5) produces an estimated state of charge rather than a displayed constant.

Acknowledgment

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