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Reconfigurable Photovoltaic Waterpumping System

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Abstract

This paper reports the design and hardware realisation of a photovoltaic water pumping system in which a high-gain SEPIC converter conditions the array output, a battery buffers the intermittency of the resource, and a sinusoidal-PWM inverter drives a three-phase induction motor coupled to a centrifugal pump, with a digital signal controller providing the gating. The converter, tracking, drive and hydraulic relations are consolidated, including the affinity laws which explain why such a system continues to deliver water at reduced irradiance rather than simply stopping. The paper is then explicit about a gap that is decisive for this class of system. A water pumping system is judged by the water it delivers, being volume per day against head and the specific energy in watt-hours per cubic metre, yet the campaign recorded no hydraulic quantity whatever: no flow rate, no delivered head, no daily volume and no pumping duration. Nor was any electrical quantity logged at the array, the converter or the motor terminals, so neither conversion efficiency nor drive efficiency can be evaluated, and the high-gain claim in the project's own title is unquantified. This revision develops the affinity argument quantitatively and, in doing so, qualifies it: at half rated shaft power a centrifugal pump delivers 79 per cent of rated flow, which supports the design's case, but the developed head falls to 63 per cent, and since a pump delivers nothing at all once the developed head drops below the static lift, there exists a minimum irradiance below which the system produces no water rather than reduced water. For a static lift at seventy per cent of rated head that threshold is 59 per cent of rated power. The static lift is not stated in the record, so the part-load claim cannot be assessed for this installation. A specific-energy floor is also computed, giving the lowest value physically attainable at a stated head, so that any future measurement has something to be judged against. The ANFIS tracker is identified as not evidenced, the reconfigurability named in the title is found to be undefined, and a four-instrument measurement plan is given.

Nomenclature

Symbol	Meaning
V_{pv}, I_{pv}, P_{pv}	Array voltage (V), current (A) and power (W)
D	Converter duty ratio
V_{in}, V_o, V_{dc}	Converter input, converter output and DC-link voltage (V)
Q, H	Volumetric flow rate (m^3/s) and total delivered head (m)
H_{static}	Static lift, the vertical distance the water must be raised (m)

ρ, g	Water density (kg/m^3) and gravitational acceleration (m/s^2)
P_{hyd}	Hydraulic power (W)
η_p, η_m, η_c	Pump, motor and converter efficiency
η_{inv}, η_{tot}	Inverter efficiency and overall array-to-water efficiency
N	Pump rotational speed (rev/min)
E_s, V	Specific energy consumption (Wh/m^3) and volume delivered (m^3)
f, m_a	Inverter frequency (Hz) and modulation index
P_{drive}, P_{bat}	Drive input power and battery power (W)

Introduction

Irrigation pumping is among the most compelling applications of photovoltaic power, because the resource and the demand coincide: water is needed most when the sun is strongest, and a storage tank is far cheaper than an equivalent electrical store [1], [2]. Displacing diesel pumping also removes a recurring fuel cost and its associated emissions from agricultural operation.

The engineering problem is the interface. An array delivers variable DC at a voltage generally below what a three-phase motor drive requires, so a high-gain DC-DC stage is needed; and the motor must continue to operate usefully as the resource varies rather than stalling. This paper reports a system addressing both: a high-gain SEPIC converter feeding a sinusoidal-PWM inverter driving a three-phase induction motor, with a battery buffering intermittency and a digital signal controller providing the gating.

The design is documented fully. The paper is then explicit about the fact that the campaign, despite building a working drive, produced no hydraulic measurement, which is the quantity by which a pumping system is judged.

1. Problem Statement

Photovoltaic pumping is a mature field with an established figure of merit: water delivered per day against head, and the energy required per cubic metre. Prototype reports in the electrical literature frequently characterise the converter and the drive in detail and then omit the hydraulic outcome entirely, which leaves the system's actual purpose unevaluated. This paper addresses that omission directly for its own campaign, and additionally shows that the part-load argument such systems rely on is itself conditional on a hydraulic quantity the record does not state.

2. Objectives

The specific objectives of the work are as follows:

- To consolidate a model spanning the electrical and hydraulic domains, including the affinity laws that govern part-load pumping.
- To state explicitly that no hydraulic or electrical quantity was measured, and hence that the high-gain claim in the title is unquantified.
- To develop the part-load argument numerically, and to identify the condition under which it fails.
- To compute the lowest specific energy physically attainable at a stated head, so that a future measurement has a benchmark.
- To identify the undefined reconfigurable element and state what a reconfigurable array would need to demonstrate.
- To specify the minimal instrumentation sufficient to produce a pumping result.

3. Scope and Delimitation

The study covers the electrical and hydraulic modelling, the prototype as documented, and the specification of the instrumentation that was absent. It excludes any claim of flow rate, delivered head, daily volume, specific energy, converter gain, conversion efficiency, drive efficiency or tracking efficiency for this build, because none was measured. It excludes the ANFIS tracker, which is not evidenced in the constructed controller, and any claim of reconfigurability, for the reason given in Section V-E.

4. Contributions

1. A consolidated model spanning the electrical and hydraulic domains, including the affinity laws that govern part-load pumping.
2. An explicit statement that no hydraulic or electrical quantity was measured, and hence that the high-gain claim in the title is unquantified.
3. A numerical development of the part-load argument, new to this revision, together with the identification of a minimum power below which the pump delivers no water at all rather than reduced water.
4. A computed specific-energy floor, new to this revision, giving the lowest value attainable at a stated head so that a future measurement can be judged against something.

5. Identification of the undefined reconfigurable element and a statement of what a reconfigurable array would need to demonstrate.
6. A minimal instrumentation plan, being one flow meter, one pressure gauge and two current sensors, sufficient to produce a pumping result.

The remainder of the paper is organised as follows. Section II reviews related work. Section III develops the relations. Section IV describes the prototype. Section V reports the results and their honest reading. 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

Chandel and colleagues [1] review photovoltaic pumping technology and establish the performance conventions this paper adopts: systems are compared by daily water delivery at a stated head and by specific energy consumption, not by converter metrics alone. Broader reviews of solar pumping practice [2] document the same conventions in field deployments.

On motor selection, the report's own reasoning follows the literature: DC machines are simple to control but require brush maintenance, brushless DC machines remove that at the cost of electronics, and induction machines are robust and maintenance-free but need a drive capable of variable-frequency operation [3]. That trade-off motivates the sinusoidal-PWM inverter used here.

On conversion, the SEPIC topology provides non-inverting step-up or step-down operation with continuous input current, which suits a photovoltaic source whose ripple should be kept small about the maximum power point [4], [5]. For tracking, Esram and Chapman [6] compare algorithms and define tracking efficiency; neuro-fuzzy trackers are reported to improve convergence at the cost of complexity, and the conventional baselines against which such a claim must be tested are given in the same comparison. The hydraulic relations and affinity laws follow standard pump engineering [7].

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

Ref.	Year	Focus and scope	Method and validation	Relation to this work
[1]	2015	PV water pumping review	Survey; field performance	Defines the figures of merit used
[2]	—	Solar pumping practice	Field deployments	Reporting conventions
[3]	—	Motor selection for PV pumping	Comparative studies	Motivates the induction-motor drive
[4]	2001	Converter analysis	Textbook	SEPIC transfer function and losses
[5]	—	High-gain SEPIC variants	Analysis; experiment	The converter stage adopted
[6]	2007	MPPT comparison	Review; simulation	Tracking efficiency definition; conventional baselines
[7]	—	Pump handbook	Engineering reference	Hydraulic and affinity relations

An entry appearing in an earlier draft as a citation for neuro-fuzzy tracking named no publication; it has been removed and the argument reattributed in the text to the tracking comparison at [6]. Entries [2], [3] and [5] 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. Hydraulic Objective

The useful output of the system is hydraulic power,

$$P_{hyd} = \rho g Q H \quad (1)$$

and the overall efficiency from array to water is the product of the stages,

$$\eta_{tot} = \frac{P_{hyd}}{P_{pv}} = \eta_c \eta_{inv} \eta_m \eta_p \quad (2)$$

with the field figure of merit being the specific energy consumed per unit volume delivered,

$$E_s = \frac{\int P_{elec}\,dt}{V} \quad [\mathrm{Wh/m^3}] \quad (3)$$

Equations (1) to (3) all require the flow rate and the delivered head, which is why Section V-B identifies their absence as decisive.

Equation (3) is stated here with the delivered volume in the denominator. The relation as it appears in the source record omits that denominator, which would make the left-hand side an energy rather than a specific energy and would not carry the units the record itself assigns to it. The omission is presumed to be a transcription error and is corrected.

2. SEPIC Conversion Stage

The SEPIC provides non-inverting output with the ideal transfer function

$$\frac{V_o}{V_{in}} = \frac{D}{1-D} \qquad (4)$$

so it steps down below a duty ratio of one half and up above it, as Fig. 1 shows. Its continuous input current is the property that recommends it for a photovoltaic source, since input ripple translates directly into excursion about the maximum power point and hence into tracking loss. High-gain variants extend Eq. (4) using coupled inductors or voltage-multiplier cells, and the record describes the converter as high-gain without stating which mechanism is used or what gain is achieved.

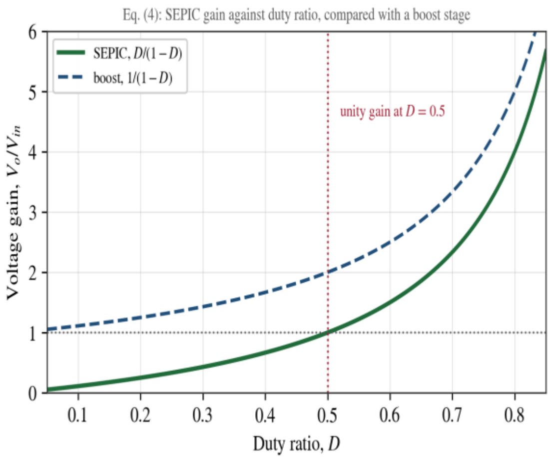

Figure 1: SEPIC voltage gain against duty ratio from Eq. (4), compared with a boost stage.

3. Drive and Affinity Laws

The inverter applies variable-frequency, variable-voltage excitation, held at approximately constant flux,

$$\frac{V}{f} \approx \text{constant} \qquad (5)$$

so that the machine develops rated torque capability across its speed range. The pump then follows the affinity laws [7],

$$\frac{Q_2}{Q_1} = \frac{n_2}{n_1}, \quad \frac{H_2}{H_1} = \left(\frac{n_2}{n_1}\right)^2, \quad \frac{P_2}{P_1} = \left(\frac{n_2}{n_1}\right)^3 \qquad (6)$$

Equation (6) is the reason a photovoltaic pump remains useful in weak sunlight: because power falls with the cube of speed while flow falls only linearly, a system at half power still delivers a substantial fraction of its rated flow. Section V-C evaluates this numerically and identifies the condition under which the argument fails.

4. Storage Buffering

The battery absorbs the mismatch between array output and drive demand,

$$P_{pv} = P_{drive} + P_{bat} + P_{loss} \qquad (7)$$

allowing the pump to ride through cloud transients rather than stalling and restarting, which is mechanically and electrically stressful.

Prototype

1. Architecture

Fig. 2 shows the system. The array feeds the SEPIC converter under maximum power point control; the converter output supports the DC link, which is buffered by the battery and inverted by a three-phase sinusoidal-PWM bridge driving the induction motor and its centrifugal pump. A digital signal controller generates the converter and inverter gating through opto-isolated drivers, supplied from a regulated auxiliary rail. The two items shown as absent at the foot of the figure are the ones on which the whole of Section V turns.

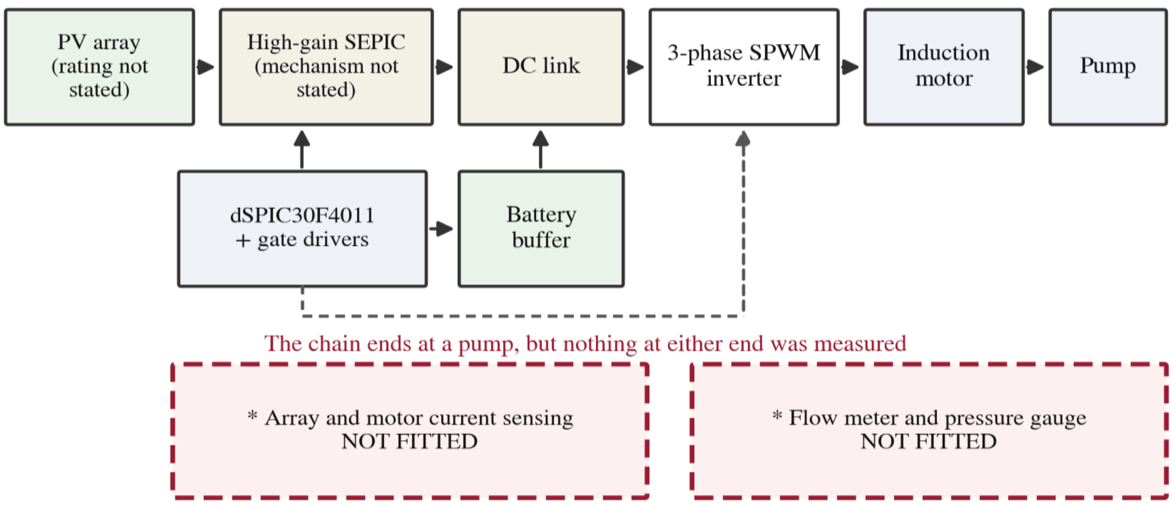

Figure 2: System architecture. The chain ends at a pump, but no hydraulic instrumentation was fitted and no electrical quantity was logged.

2. Apparatus

Table 2 lists the prototype as documented.

Table 2. Prototype as Documented

Item	Type / rating	Quantity
PV array	Rating not stated in the record	1
DC-DC stage	High-gain SEPIC; mechanism and gain not stated	1
Storage	Battery; capacity not stated in the record	1
Inverter	Three-phase, sinusoidal PWM	1
Motor	Three-phase induction; rating not stated	1
Pump	Centrifugal; rated flow and head not stated	1
Controller	dSPIC30F4011	1
Gate drivers	Opto-isolated	6 or more
Auxiliary supply	Bridge and regulator, 5 V and 15 V	1

The pump's rated flow and head and the static lift of the installation are all absent from the record. The first two prevent Eqs. (1) to (3) being evaluated even from nameplate data; the third is what makes the part-load analysis of Section V-C indeterminate for this installation.

Results

1. What the Campaign Established

The hardware was constructed and energised, and the drive operated the motor and pump. That is the observed result, and it is reported without extension. Fig. 3 shows the position by category.

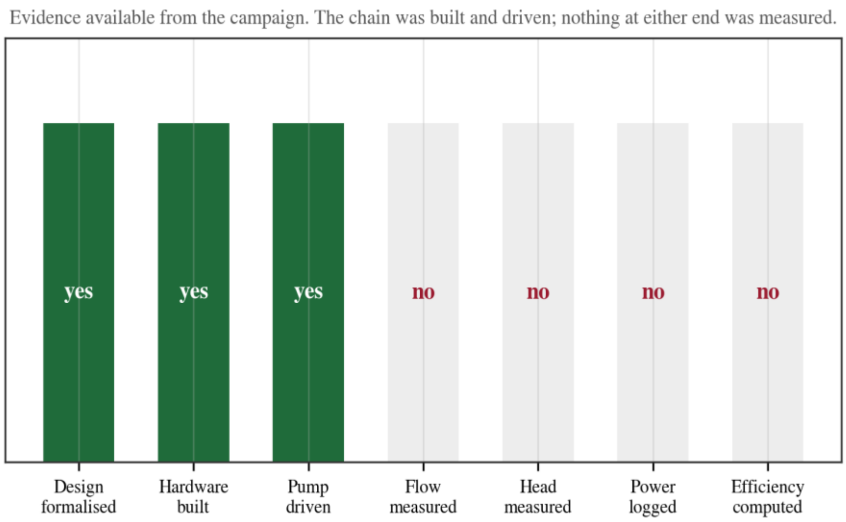

Figure 3: Evidence available from the campaign. The chain was built and driven; nothing at either end was measured.

2. Why No Pumping Performance Is Reported

A pumping system is evaluated on what it delivers. The campaign recorded no hydraulic quantity at all: no flow rate, no delivered head, no daily volume and no run duration. Consequently hydraulic power in Eq. (1) cannot be computed, overall efficiency in Eq. (2) is unavailable, and the specific energy consumption of Eq. (3), the figure by which such systems are actually compared, does not exist for this build.

Nor was any electrical quantity logged. Without array voltage and current the input power is unknown and no tracking efficiency can be computed; without converter input and output measurements the conversion efficiency and, more pointedly, the gain that the project's title calls high are both unquantified; without motor terminal measurements the drive efficiency is unavailable. Accordingly no efficiency, gain, flow or energy figure appears in this paper, and none is estimated.

3. The Part-Load Argument, and Where It Fails

The affinity relations of Eq. (6) carry the design's central practical claim, that the system keeps pumping usefully as irradiance falls. Because they are exact for a geometrically similar pump, the claim can be developed numerically without any measurement, and doing so both supports and qualifies it. Table 3 evaluates Eq. (6) across the power range and Fig. 4 plots it.

Table 3. Part-Load Behaviour from the Affinity Laws (Computed Here)

Shaft power	Speed	Flow rate	Developed head
100 %	100 %	100 %	100 %
75 %	90.9 %	90.9 %	82.5 %
50 %	79.4 %	79.4 %	63.0 %
25 %	63.0 %	63.0 %	39.7 %
10 %	46.4 %	46.4 %	21.5 %

Computed from Eq. (6), which is exact for a geometrically similar pump at constant efficiency. Real pump efficiency falls somewhat away from the best efficiency point, so the flow figures are slightly optimistic. Nothing in this table was measured on this prototype.

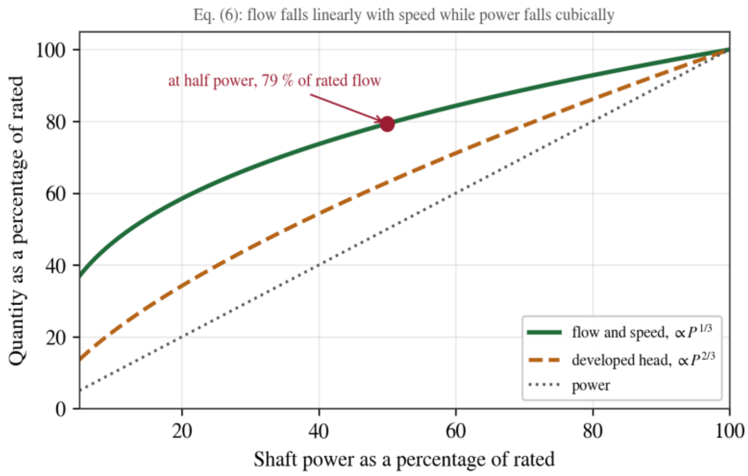

Figure 4: Affinity relations of Eq. (6). Flow falls linearly with speed while power falls cubically, so partial irradiance still yields useful flow.

The first column supports the design. At half rated shaft power the pump still turns at 79 per cent of rated speed and delivers 79 per cent of rated flow, which is the property that makes solar pumping practical and which a fixed-speed diesel set cannot offer.

The last column qualifies it, and this qualification does not appear in the source record. Developed head falls as the square of speed, so at half power it is 63 per cent of rated and at quarter power only 40 per cent. A centrifugal pump delivers nothing at all once its developed head falls below the static lift, because it can no longer raise water to the outlet. There is therefore a threshold power below which the system produces no water rather than reduced water, obtained by setting the developed head equal to the static lift in Eq. (6):

$$\frac{P_{min}}{P_{rated}} = \left(\frac{H_{static}}{H_{rated}}\right)^{3/2} \quad (8)$$

Table 4 evaluates this and Fig. 5 plots it.

Table 4. Minimum Shaft Power Below Which Pumping Ceases (Computed from Eq. (8))

Static lift as a fraction of rated head	Minimum shaft power	Remark
20 %	8.9 % of rated	Shallow lift; the system pumps across almost the whole day
30 %	16.4 % of rated	Useful operation from early morning
50 %	35.4 % of rated	Pumping confined to the middle of the day
70 %	58.6 % of rated	A narrow window around solar noon
80 %	71.6 % of rated	Pumping only near peak irradiance

Computed from Eq. (8), which follows from the head relation in Eq. (6) with the friction component of the total head neglected. Including friction head, which itself scales with the square of flow, would raise the thresholds slightly. The static lift of this installation is not recorded, so no row of this table can be identified as the applicable one.

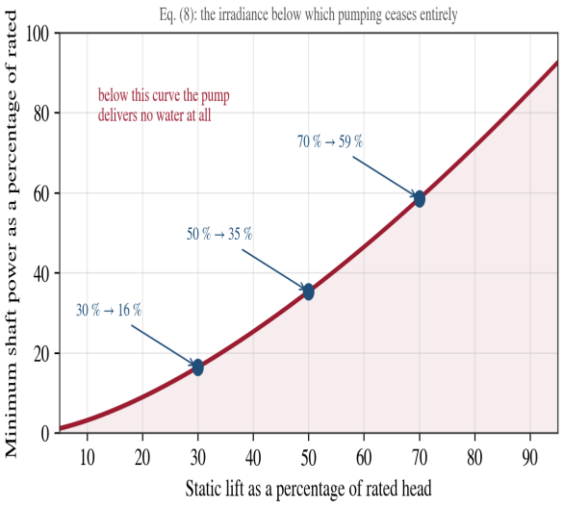

Figure 5: Minimum shaft power below which pumping ceases entirely, from Eq. (8), against the static lift expressed as a fraction of rated head.

The practical consequence is that the part-load claim is not a property of the drive alone but of the drive and the well together. On a shallow lift the system pumps across nearly the whole solar day; on a deep one it may pump only for a few hours around noon and deliver nothing at all outside that window, however well the converter tracks. Since the static lift is not stated in the record, the claim cannot be assessed for this installation, and stating it is the single cheapest addition the authors could make to their own case.

4. A Benchmark for the Specific Energy

Equation (3) has no value for this build, but it does have a floor that can be computed, so that a future measurement is not reported in isolation. Raising one cubic metre of water through a head H requires a hydraulic energy of the density times gravity times the head, and dividing by the overall efficiency of Eq. (2) gives

$$E_{s,\min} = \frac{\rho g H}{3600\,\eta_{tot}} \quad [\mathrm{Wh/m^3}] \tag{9}$$

Table 5 evaluates this and Fig. 6 plots it. At perfect efficiency the floor is about 2.7 Wh per cubic metre per metre of head; a well-designed photovoltaic pumping system reaches perhaps forty to fifty per cent overall from array to water, so a realistic expectation is roughly six to seven times the head in watt-hours per cubic metre.

Table 5. Lowest Specific Energy Attainable at a Given Head (Computed from Eq. (9))

Delivered head	Thermodynamic floor	At 45 % overall efficiency	At 30 % overall efficiency
5 m	13.6 Wh/m^3	30.3 Wh/m^3	45.4 Wh/m^3
10 m	27.3 Wh/m^3	60.6 Wh/m^3	90.8 Wh/m^3
20 m	54.5 Wh/m^3	121.1 Wh/m^3	181.7 Wh/m^3
40 m	109.0 Wh/m^3	242.2 Wh/m^3	363.3 Wh/m^3

Computed from Eq. (9). The thermodynamic floor assumes an overall efficiency of unity and is therefore unattainable; the efficiency values in the remaining columns are stated assumptions used to indicate a realistic band, not measurements of this system. A measured specific energy below the floor for its head would indicate an error in the measurement rather than an achievement.

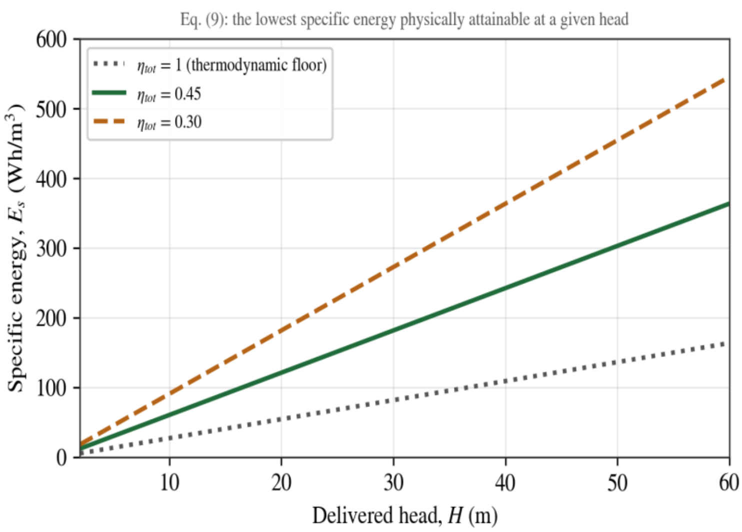

Figure 6: Specific energy against delivered head from Eq. (9), at three overall efficiencies. The dotted line is a physical floor, not an attainable value.

5. The Undefined Reconfigurable Element

The title describes a reconfigurable photovoltaic system. In the pumping literature, reconfiguration ordinarily means switching the series-parallel arrangement of array modules so that the string voltage suits the operating condition, for example favouring series connection at low irradiance to keep the drive above its minimum voltage, and parallel connection at high irradiance for current. The record contains no switching matrix, no reconfiguration logic and no criterion for changing configuration, and the block diagram shows a single fixed array. The term is therefore unsupported by the build as documented.

Demonstrating it would require, at minimum, a switch network with its ratings stated, a decision rule with its thresholds, and paired trials showing delivered volume with reconfiguration enabled and disabled under comparable irradiance. It is worth noting that the analysis of Section V-C gives reconfiguration a clear purpose it would otherwise lack: a series configuration at low irradiance raises the drive voltage and therefore the attainable speed, which is precisely what pushes the operating point back above the cutoff of Eq. (8). If reconfiguration is to be pursued, that is the effect it should be measured against.

6. What the Campaign Supports

Table 6 states the position quantity by quantity.

Table 6. Built, Described and Indeterminate Quantities

Quantity or capability	Value	Status
Hardware constructed	yes	demonstrated
Motor and pump driven	yes	demonstrated
Flow at half rated power	79 % of rated	computed, Eq. (6)
Cutoff power at 70 % static lift	59 % of rated	computed, Eq. (8)
Specific-energy floor at 20 m head	54.5 Wh/m^3	computed, Eq. (9)

Discussion

The electrical engineering in this work is competently done and the topology choices are well motivated. What the campaign lacks is any connection between the drive it built and the water the system exists to move, and that gap is more consequential here than in most of the prototypes of this kind, because the figure of merit is entirely hydraulic.

1. The Instrumentation Gap Is Small and the Result Is Large

Four instruments would close it: a flow meter in the delivery line, a pressure gauge at the outlet, and current sensors at the array and at the motor. Logged across a single clear day, they would yield the delivered volume, the head, the specific energy of Eq. (3) and the overall efficiency of Eq. (2), which together constitute a result directly comparable with the diesel systems this technology sets out to displace. No other instrument is required, and none of the four is expensive relative to the hardware already built.

2. Qualitative Position

Table 7 sets out the structural properties that can be asserted, each with the relation or source that supports it.

Table 7. Qualitative Properties and Their Basis

Feature	Property	Basis
SEPIC stage	Steps up or down; continuous input current	Eq. (4)
Induction motor	Maintenance-free; requires a drive	[3]
Constant volts per hertz	Rated torque capability across the speed range	Eq. (5)
Affinity laws	Useful flow at reduced power	Eq. (6), Table III
Static lift	Sets a power below which no water is delivered	Eq. (8), Table IV
Battery buffer	Rides through cloud transients	Eq. (7)
Specific energy	Bounded below by the head	Eq. (9), Table V
Hydraulic metering	Converts a working drive into a pumping result	Eqs. (1) to (3)

Limitations

The following limitations bound every claim made in this paper.

- No hydraulic quantity was measured. Flow rate, delivered head, daily volume, run duration and specific energy are indeterminate for this build, not merely uncertain, and none is estimated.

- No electrical quantity was logged, so conversion efficiency, drive efficiency and tracking efficiency are unavailable, and the converter gain described as high in the title is unquantified.
- The pump's rated flow and head, the static lift of the installation, the array and motor ratings, the switching frequency and the converter's high-gain mechanism are all undocumented, so the design is not reproducible from this paper.
- The affinity figures in Table III assume a geometrically similar pump at constant efficiency. Real pump efficiency falls away from the best efficiency point, so the flow figures are slightly optimistic.
- The cutoff thresholds in Table IV neglect the friction component of the total head, which would raise them slightly, and none of the rows can be identified as applicable because the static lift is not recorded.
- The specific-energy figures in Table V are a physical floor and two assumed efficiencies. They are a benchmark for a future measurement, not a result of this work.
- The ANFIS tracker is described but not evidenced in the constructed controller, so every claim resting on it is design intent.
- The reconfigurability named in the title has no switching network, decision rule or criterion in the record and is excluded from every claim.

Proposed Measurement Framework

Fig. 7 shows the instrumentation the design requires. It is deliberately minimal: four sensors, logged across one day, produce every figure the campaign lacks.

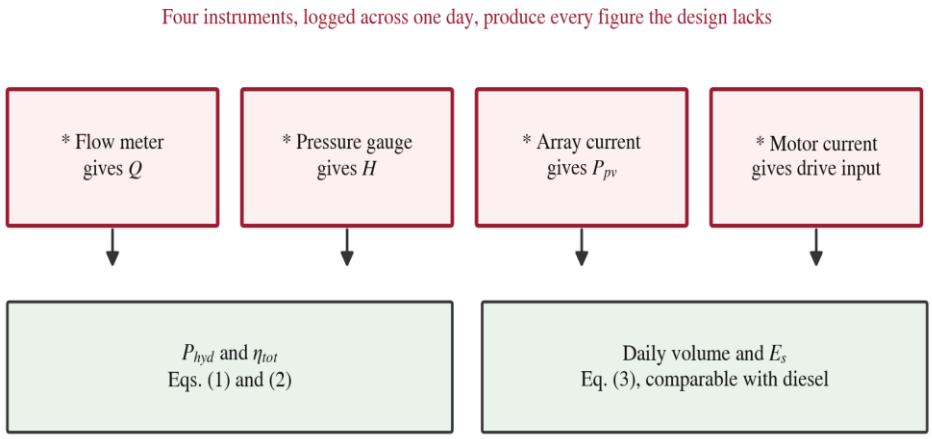

Figure 7: Measurement framework. Blocks marked with an asterisk are the additions required to evaluate Eqs. (1) to (3).

1. Measurement Plan

Table 8 sets out the measurements required, and Table 9 gives the context values that are relations or assumptions rather than results.

Table 8. Measurement Plan Required to Produce a Pumping Result

Measurement	Method	What it yields
Flow rate	Flow meter in the delivery line	Q, and with head the hydraulic power of Eq. (1)
Delivered head	Pressure gauge at the outlet, plus the surveyed static lift	H, and the applicable row of Table IV
Array power	Voltage and current sensing at the array	P_{pv}, and tracking efficiency
Drive input power	Current sensing at the motor terminals	Drive efficiency; with the array, the converter efficiency
Full-day trial	Log all four from sunrise to sunset	Daily volume, specific energy by Eq. (3), and the part-load behaviour of Eq. (6) demonstrated rather than assumed

Document the converter	Passive values, switching frequency and the high-gain mechanism	The gain the title claims, stated and checked
Define reconfiguration	Switching matrix with a stated decision rule, and paired trials	Delivered volume with and without reconfiguration
Implement or withdraw the tracker	Embed the ANFIS tracker and compare against perturb-and-observe on identical hardware	Attribution of any tracking improvement

Table 9. Illustrative Figures (Relations and Assumptions, Not Results)

Item	Value	Status
SEPIC unity gain point	D = 0.5	from Eq. (4)
Affinity exponent for power	cube of speed	standard relation [7]
Flow at half rated power	79 % of rated	computed, Eq. (6)
Cutoff power at 70 % static lift	59 % of rated	computed, Eq. (8)
Specific-energy floor per metre of head	about 2.7 Wh/m^3	computed, Eq. (9)
Assumed overall efficiency band	30 to 45 %	assumption for the benchmark

The computed entries follow from stated relations. No performance quantity was measured in this campaign.

Conclusion

A photovoltaic water pumping system combining a high-gain SEPIC converter, battery buffering and a sinusoidal-PWM inverter driving a three-phase induction motor and centrifugal pump was designed and built around a digital signal controller. The electrical and hydraulic relations were consolidated, including the affinity laws which explain why such a system continues to deliver useful flow at reduced irradiance rather than stalling. The hardware was constructed and the pump was driven.

Beyond that, the campaign supports no quantitative claim, and the gap is decisive for this class of system: no flow rate, delivered head, daily volume or run duration was recorded, so hydraulic power, overall efficiency and specific energy consumption, the figure by which pumping installations are actually compared, are all indeterminate. No electrical quantity was logged either, so the conversion efficiency and the very gain described as high in the project title remain unquantified.

This revision developed the part-load argument numerically and, in doing so, qualified it. At half rated shaft power the pump delivers 79 per cent of rated flow, which supports the design's case; but developed head falls as the square of speed, to 63 per cent at half power and 40 per cent at quarter power, and a centrifugal pump delivers nothing once developed head falls below the static lift. There is therefore a threshold irradiance below which the system yields no water at all rather than reduced water, at 59 per cent of rated power for a static lift at seventy per cent of rated head and at 16 per cent for a shallow lift at thirty per cent. The static lift is not recorded, so the applicable threshold cannot be identified, and stating it is the cheapest addition the authors could make to their own argument. A specific-energy floor was also computed, at about 2.7 watt-hours per cubic metre per metre of head at unit efficiency, so that a future measurement has a benchmark rather than standing alone.

The ANFIS tracker was identified as described but not evidenced, and the reconfigurability named in the title was found to have no switching network, decision rule or criterion in the record, with a statement of what demonstrating it would require and of the specific purpose the cutoff analysis gives it. The instrumentation needed to close all of this is modest, being a flow meter, a pressure gauge and two current sensors logged across a single day, and would convert a working drive into a pumping result that could be compared with the diesel systems the technology sets out to displace.

Future Work

Several extensions follow directly from the limitations above.

- Fit hydraulic instrumentation-Install a flow meter and a pressure gauge so that Eqs. (1) to (3) become evaluable, and survey and record the static lift of the installation.
- Log the electrical quantities-Add current sensing at the array and at the motor terminals so that conversion and drive efficiency can be computed and the converter's actual gain stated.
- Run a full-day trial-Record from sunrise to sunset so that the part-load behaviour predicted by Eq. (6) and the cutoff predicted by Eq. (8) are demonstrated rather than assumed, and so that a daily

volume and specific energy can be reported.

- Define reconfiguration-Either implement a switching matrix with a stated decision rule and show paired results, measured against the cutoff effect identified in Section V-E, or remove the term from the system description.
- Implement or withdraw the ANFIS tracker-Embed and evaluate it against perturb-and-observe on identical hardware, or state that conventional tracking is used.
- Document the converter design-Record the passive values, switching frequency and the high-gain mechanism employed, without which the title's central claim cannot be checked.

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