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3D-Printed Permanent Magnet Alternator-Based Hybrid Energy System

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Abstract—**This paper presents a hybrid renewable energy system that combines a low-speed, axial-flux, coreless permanent magnet alternator, driven by a vertical-axis wind turbine, with a 30 W photovoltaic (PV) panel. The alternator is built largely from 3D-printed parts and is intended to generate three-phase AC at low rotational speed without a mechanical gearbox. The system rectifies its output and combines it with the PV output on a common DC bus. A battery management system (BMS) provides protected charging and storage, and an inverter supplies 230 V AC to the load. The paper describes the architecture, the construction of the alternator, the power electronics, the operating logic and the components used, and reports the progress of the hardware prototype, which has been fabricated and assembled. A comparison with published 3D-printed energy harvesters and a test plan for the remaining performance evaluation are also given. The aim is a low-cost, lightweight and reliable solution for small-scale renewable generation.**

Index Terms—permanent magnet alternator, axial flux, coreless stator, 3D printing, hybrid renewable energy, vertical-axis wind turbine, solar photovoltaic, battery management system.

I. Introduction

The growing demand for clean and sustainable energy has encouraged the development of solar and wind power systems. Solar generation depends on the availability of sunlight and wind generation on variations in wind speed, so a combination of the two can give a steadier supply than either alone. Conventional wind alternators generally need high rotational speeds and a mechanical gearbox, which adds losses, maintenance and system complexity.

Axial-flux coreless permanent magnet machines are attractive for small, low-speed turbines because the absence of an iron core removes cogging torque and iron loss, and a large number of poles can be placed on a disc [1]. Additive manufacturing offers a fast and inexpensive way to produce the rotor, stator housing and supporting structure of such machines [2]–[3], [8].

This work proposes a 3D-printed, low-speed, axial-flux coreless permanent magnet alternator integrated with a PV source, a power combining unit, a BMS and a grid-compatible inverter. The objectives are: (i) to design and fabricate a 3D-printed permanent magnet alternator (PMA); (ii) to generate power efficiently at low rotational speed; (iii) to integrate the alternator with a solar PV panel for hybrid generation; and (iv) to improve overall efficiency and reliability through intelligent energy management.

II. Literature Review

Several studies have used 3D printing for electromagnetic energy conversion; those most relevant to this work are summarised in Table I.

TABLE I
Summary of Related 3D-Printed Energy Harvesters

Ref	Device and approach	Reported result
[2]	Low-speed PM generator; PLA parts and permanent magnets	Charged a battery; 1.136 V at battery terminal
[3]	Coreless generator; PLA stator housing and rotor, 4 coils, 8 magnets	5 W maximum at 6000 rpm
[4]	Electrodynamic harvester for power lines; FEM-optimised, printed NdFeB polymer-bonded magnet	93 mW, 2.6 mW/cm³; distortion power factor improved by 55%
[5]	Inkjet 3D-printed MEMS vibration harvester, volume under 1 cm³	About 24 µW; up to 600 µW/cm³; resonance 95–340 Hz

Soemphol and Angkawisittpan [2] built a low-speed permanent magnet generator from PLA and magnets and showed that it could charge a battery under low-speed rotation, demonstrating 3D printing as a practical low-cost route for small alternators. Herawan et al. [3] printed the stator housing, rotor and other parts of a coreless alternator in PLA, with four copper coils and eight alternately polarised magnets, and measured a maximum of 5 W at 6000 rpm under different speeds and loads; a related study examined the effect of the number of magnetic poles on the rotor [7]. Wang et al. [4] used finite element optimisation and a 3D-printed NdFeB polymer-bonded magnet to improve a power-line energy harvester, and Kawa et al. [5] printed a sub-cubic-centimetre MEMS electromagnetic harvester with several spring designs. Reviews of coreless axial-flux machines [1], additively manufactured electrical machines [8], composite printing for harvesters [6] and 3D-printed vibration harvesters [9] describe both the opportunities and the challenges of the approach.

Most of the reported devices deliver milliwatt-level power or are tested at high speed, and few are combined with a second energy source and a battery-backed inverter. This work addresses that gap with a low-speed printed alternator in a complete hybrid system.

III. System Description and Methodology

A. Architecture

The proposed system (Fig. 1) is a hardware project. A vertical-axis wind turbine (VAWT) drives a three-phase alternator, whose AC output is converted to DC by a rectifier. The solar panel supplies DC directly. A voltage balancer/combiner joins the two sources on a common DC bus, which feeds the BMS and battery bank and the inverter. The inverter output passes through a transformer to the AC load.

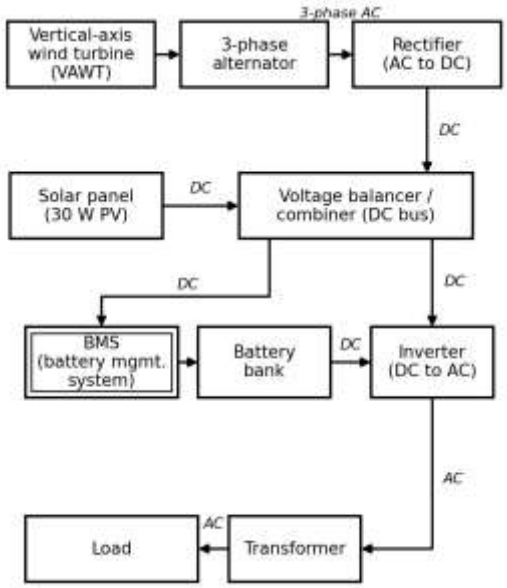


Fig. 1. Block diagram of the proposed hybrid energy system.

B. Axial-Flux Coreless Alternator

The alternator (Fig. 2) has rotor discs carrying neodymium (N52) magnets of alternating polarity and a coreless stator of enamelled copper coils connected as a three-phase winding. The rotor and stator supports, the magnet disc and the VAWT parts are 3D printed. The shaft is lightweight and electrically insulating and runs in deep-groove ball bearings (6202/6203 class); a rigid, vibration-resistant frame of mild steel or aluminium carries the assembly. The machine is rated 350 W and is designed for charging at about 24 V DC.

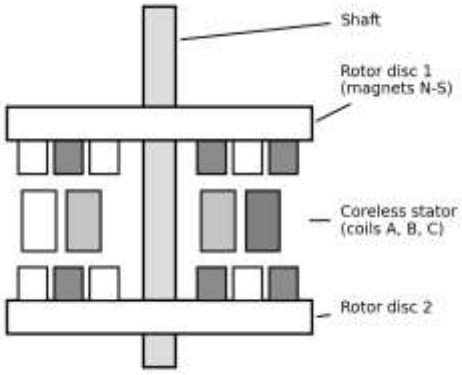


Fig. 2. Schematic of the axial-flux coreless alternator (rotor discs with magnets of alternating polarity and a coreless three-phase stator).

The following standard relations guide the design. The EMF induced in a coil of N turns by a changing flux Φ is

$$e = -N\,\mathrm{d}\Phi/\mathrm{d}t \qquad (1)$$

and the electrical frequency of a machine with P poles at speed n (rpm) is

$$f = P\,n\,/\,120 \qquad (2)$$

so a high pole count lets the machine produce a usable voltage and frequency at low speed without a gearbox. For a three-phase bridge rectifier the mean DC voltage is approximately

$$V_{dc} \approx (3\sqrt{2}/\pi)\,V_{LL} \approx 1.35\,V_{LL} - 2V_D \qquad (3)$$

where V_{LL} is the rms line-to-line voltage and V_D is the diode drop.

C. Power Electronics and Storage

The rectifier converts the alternator output to DC. The PV panel supplies variable DC, which a DC–DC converter regulates to the voltage needed for charging, and a diode prevents reverse current. The voltage balancer/combiner merges both sources on the DC bus. The BMS protects the battery during charging and discharging, and the inverter converts the battery's 12 V DC to 230 V AC for the load.

D. Operating Logic

The operating flow of the system is shown in Fig. 3. Energy from both sources is rectified and combined. If the battery is full, the BMS limits or stops charging; otherwise it charges the battery bank. If the battery voltage falls to the low cut-off, the load is disconnected for under-voltage protection; otherwise the inverter supplies the AC load.

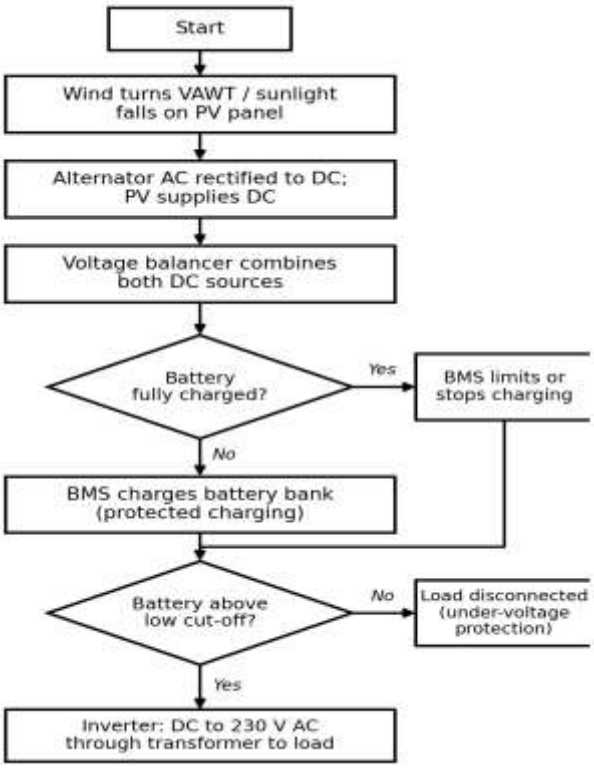


Fig. 3. Operating flowchart of the proposed system.

E. Components

TABLE II
Main Components of the Prototype

Component	Description
Alternator	3-phase axial-flux coreless PM, 350 W, low rpm, about 24 V DC charging
Magnets	Neodymium, N52 grade, sized to the rotor design
Stator coils	Enamelled copper, 3-phase, wire gauge from calculated current
3D-printed parts	Rotor and stator structure, VAWT, magnetic disc
Shaft and bearings	Light insulating shaft; deep-groove ball bearings (6202/6203)
Mounting frame	Mild steel or aluminium, rigid, vibration resistant
Solar panel	30 W PV panel, DC source
Diode, DC–DC converter	Blocks reverse current; regulates PV voltage
Inverter	12 V DC to 230 V AC

IV. Progress and Results

A. Prototype Development

The development has followed the workflow of Fig. 4. The literature survey, problem statement, block and circuit design, and component selection are complete, and the 3D-printed alternator and the power-electronics board have been fabricated and assembled. Fig. 5 shows the prototype: the rotor disc and shaft (a), the alternator assembly with its stator coils (b), the circuit board carrying the converter module, a microcontroller module, a battery pack, a transformer and a lamp load (c), and the 30 W solar panel with the board (d).

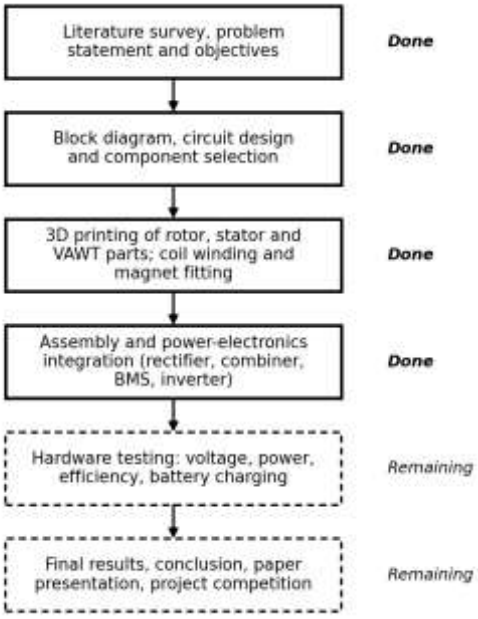


Fig. 4. Development flowchart and project status (as of the progress seminar, 25 September 2026).

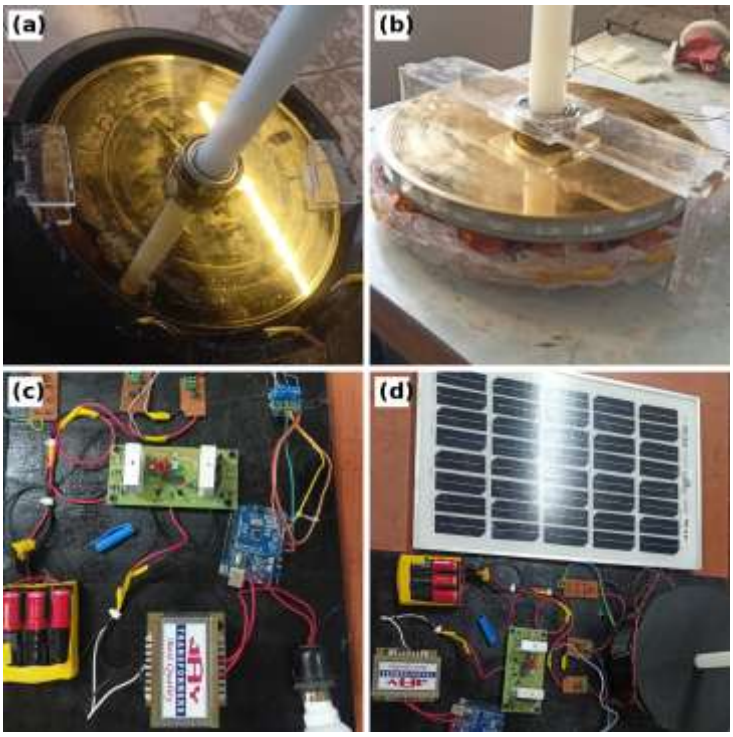


Fig. 5. Hardware prototype: (a) rotor disc and shaft; (b) alternator assembly with stator coils; (c) circuit board, battery pack, transformer and lamp load; (d) 30 W solar panel and board.

B. Benchmark Against Published Work

Fig. 6 compares the power levels reported for 3D-printed electromagnetic harvesters [3]–[5] with the design ratings of this system. The comparison is between reported measurements and design ratings; measured output of the present prototype is not yet available and is the subject of the planned tests.

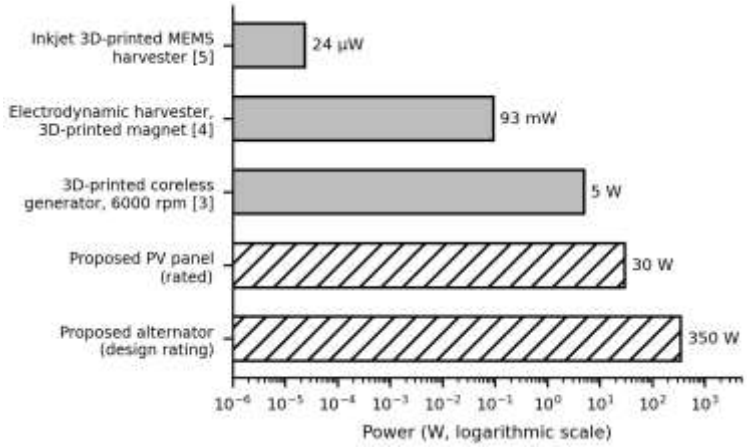


Fig. 6. Reported maximum power of 3D-printed harvesters [3]–[5] and design ratings of the proposed system (hatched bars).

C. Test Plan

The remaining stage is performance evaluation (Table III). Results will be recorded at several rotor speeds, with and without the PV source.

TABLE III
Planned Tests and Status

Test	Quantity recorded	Status
Open circuit	Phase voltage and frequency vs rpm	Planned
Load test	Voltage, current and power vs rpm	Planned
Rectifier output	DC bus voltage, with and without PV	Planned
Battery charging	Charging voltage and current via BMS	Planned
Inverter output	AC voltage and load power	Planned
Efficiency	$\eta = P_{out}/P_{in}$	Planned

V. Discussion

The hybrid arrangement is expected to improve reliability because the solar and wind sources are independent and both feed one storage bank. Printing the rotor, stator support and turbine parts reduces weight and cost and shortens fabrication time, and the coreless, gearless construction avoids cogging, iron loss and gearbox maintenance. Printed polymer parts, however, have limited stiffness and temperature tolerance, so air-gap accuracy, vibration and heating of the coils need attention during testing [8].

Several ratings must also be matched during testing: the 350 W alternator is designed for about 24 V charging, the PV panel is rated 30 W and the inverter takes a 12 V input. The achievable output will in practice be set by the wind speed seen by the small VAWT, so measured power at low speed is the key result to be established.

VI. Conclusion and Future Work

A hybrid system combining a 3D-printed, low-speed, axial-flux coreless permanent magnet alternator with a 30 W PV panel, BMS and inverter has been designed, and its hardware prototype has been fabricated and assembled. The architecture, operating logic and test plan have been defined. The remaining work is performance testing, covering generated voltage and power versus speed, battery charging and inverter output, followed by the final results and conclusions.

Acknowledgment

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