Improve Efficiency of Horizontal Axis Wind Turbine by Adding Permanent Magnet Arrangement on System

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***Abstract* -** The demand for renewable energy sources is rapidly increasing, with wind energy playing a vital role in sustainable power generation. Horizontal Axis Wind Turbines (HAWTs) are the most widely used configuration; however, they face limitations such as high cut-in wind speed, reduced efficiency at low wind conditions, and mechanical losses during start-up. This project explores methods to enhance the performance of horizontal-axis wind turbines (HAWTs) by integrating permanent-magnet components. It investigates how permanent magnets can *increase starting torque* to lower the turbine's cut-in wind speed, and how a **permanent-magnet synchronous generator (PMSG)** can boost electrical conversion efficiency. Combined aerodynamic and magnetic design changes are expected to lower the minimum operational wind speed and raise overall system efficiency.

This project proposes the integration of a **permanent magnet arrangement** into the turbine system to enhance efficiency and overall energy output. The permanent magnets are expected to provide magnetic lift and torque assistance, enabling smoother start-up at lower wind speeds while simultaneously improving generator performance through reduced electrical and mechanical losses.The research involves design and simulation of a modified HAWT system using CAD and analytical tools, followed by prototype development and experimental testing. Comparative analysis will be conducted between the conventional turbine and the magnet-assisted system to evaluate improvements in start-up speed, efficiency, and power generation. The expected outcome is a significant reduction in cut-in wind speed and an overall increase in energy conversion efficiency, making the system more viable in low-wind regions.

***Index Terms*— Horizontal Axis Wind Turbines, HAWT, Renewable Energy, Permanent-magnet, PM.**

I. INTRODUCTION

Horizontal Axis Wind Turbines (HAWTs) are widely used for power generation due to their higher efficiency and established design. However, their performance can be limited at low wind speeds and during start-up conditions. This reduces overall energy output, especially in regions with variable wind profiles. Incorporating a permanent magnet arrangement into the turbine system offers the potential to enhance start-up torque, improve generator efficiency, and reduce mechanical losses, thereby increasing the overall efficiency of the turbine. Wind energy is one of the most promising renewable energy sources, offering clean and sustainable power generation. Among different wind turbine designs, Horizontal Axis Wind Turbines (HAWTs) are the most used due to their higher efficiency and mature technology. However, despite their widespread application, HAWTs face certain operational limitations. A major challenge is their relatively high cut-in wind speed, which restricts power generation in regions with low or fluctuating wind conditions. Additionally, mechanical friction and generator inefficiencies reduce the overall energy output of the system. Wind energy is a cornerstone of modern renewable energy initiatives. Horizontal Axis Wind Turbines (HAWT) are widely used for their high efficiency and large-scale energy production capacity. Recent advances have demonstrated that integrating permanent magnet arrangements can significantly enhance both efficiency and reliability in HAWT systems, primarily by reducing mechanical losses and optimizing generator performance. The quest for higher efficiency at varying wind speeds is a major research focus, and the integration of permanent magnet arrangements offers a novel path toward performance enhancement.

Permanent Magnet Synchronous Generators (PMSGs) are favoured in modern wind turbine systems due to their high efficiency, reliability, and gearless drive capability. However, beyond generator use, arranging permanent magnets to augment turbine rotation through magnetic propulsion is an emerging concept, not widely implemented in HAWTs. Leveraging magnetic repulsion could add kinetic energy at lower wind speeds, potentially improving performance especially during periods of low wind. Small horizontal-axis wind turbines (HAWTs) are attractive for off-grid and portable power, but they often require relatively high wind speeds to start and have poor efficiency at low wind. Recent micro-scale prototypes (e.g. a 0.4 m diameter "SWEPT" turbine) have managed cut-in speeds as low as ~1.7 m/s and efficiencies above 20%, but most conventional small HAWTs still cut in at ~3–4 m/s. To overcome these challenges, researchers have explored various design modifications aimed at enhancing turbine performance. One innovative approach is the integration of permanent magnet arrangements within the turbine system. Permanent magnets can provide additional magnetic lift or torque, reducing start-up resistance and enabling the turbine to operate at lower wind speeds. Furthermore, when used in the generator system, permanent magnets minimize electrical losses and enhance power conversion efficiency.

II. Literature Survey

Yuhendri et al. (2021)ijaseit.insightsociety.org:-Permanent-magnet direct-drive generators are another key innovation. Low-speed axial-flux PM generators (AFPMG) can generate high torque without a gearbox. Yuhendri et al. designed a six-bladed HAWT driving an axial-flux disc PM generator (18 NdFeB poles) for low wind speedsijaseit.insightsociety.org.Their simulations and experiments showed the turbine could reach 263 rpm at 9 m/s, producing 14 V and 580 W – matching the design ratingijaseit.insightsociety.org. This confirms that optimized PM generators yield strong output even at low speeds. In general, direct-drive PM generators are lighter and have higher efficiency than wound-field machines, because the permanent magnets provide excitation without copper windingsmdpi.com. Such designs avoid gearbox and gear losses, improving energy conversion. (See Table below for comparisons.)

Kriswanto et al. (2022)scholar.undip.ac.id (Magnetic Bearings and Levitation):-Permanent magnets can also support the rotor itself. Replacing roller bearings with permanent-magnet bearings eliminates contact friction. For example, Kriswanto et al. (2022) used finite-element models to design an axial magnetic bearing for a 1 MW HAWT shaftscholar.undip.ac.id. They note that "One way to reduce maintenance costs while improving wind turbine efficiency is to replace mechanical bearings with permanent magnetic bearings"scholar.undip.ac.id. These contactless bearings lift the rotor on a cushion of magnetic repulsion, removing the need for lubrication.

Kriswanto et al. (2023)researchgate.net:-Similarly, a 2023 study of a radial PM bearing found that thicker NdFeB rings and smaller air gaps dramatically increase the load-carrying force (up to ~254 kN) with no frictionresearchgate.net. In both cases, analysis shows PM bearings can fully support rotor thrusts and radial loads without contact, promising greatly reduced friction and wearscholar.undip.ac.idresearchgate.net.

Abu-Khader et al. (2023)link.springer.com:-In fact, a recent "suspended-rotor" turbine design explicitly uses PM suspension. Abu-Khader et al. describe a 3-blade HAWT whose rotor is magnetically suspended within a circular stator ringlink.springer.comlink.springer.com. No metal-to-metal contact means no bearing noise or friction. They report that direct magnetic coupling (no gearbox) "improves efficiency" and produces high torque at low wind speeds (due to large blade-tip area)link.springer.com. This concept echoes the earlier blade-tip system, using circumferential magnets to both levitate and drive the rotor.

Belkhir & Khenfer (2013)researchgate.netresearchgate.net (Magnetic Gears and Direct Coupling):- Another strategy is replacing the mechanical gearbox with a magnetic gear. Magnetic gearboxes use arranged permanent magnets to multiply or divide shaft speed without contact. For example, Belkhir et al. (2013) proposed a coaxial magnetic-gear/PMSG unit for multi-MW turbinesresearchgate.net. The design couples a low-speed input rotor to a high-speed PM generator rotor via stationary ferrous pole pieces. By choosing the pole counts, the high-speed rotor can spin fast enough to generate grid frequency without a mechanical gearboxresearchgate.net. This magnetic gearbox has many advantages: no lubrication, low noise, inherent overload protection, and compactness researchgate.netmdpi.com. Simulation studies show its torque density rivals multi-stage helical gearsresearchgate.net. In general reviews, magnetic gears are praised for contactless torque transmission and high efficiencymdpi.commdpi.com.

Gouda & Ghanem (2024)link.springer.com:-Gouda and Ghanem (2024) optimized a new coaxial flux-modulated magnetic gear with an integrated PMSG using a Pelican Optimization Algorithm. Their 2D-FEA results show the optimal design yields higher torque-per-weight (and thus more power) than conventional PSO-based designslink.springer.com. In short, permanent-magnet gears allow direct-drive wind generation without a heavy gearbox, cutting losses and maintenance while sustaining high torque outputresearchgate.netmdpi.com.

Abduh et al. (2025)mdpi.com (Cogging Torque and Startup Speed):-Permanent magnets can impede startup by causing cogging torque (torque ripple at standstill). Many studies address this to improve self-start speed. For instance, Abduh et al. (2025) analyzed PM generator magnet geometry for very-low-wind turbines. They show that carefully slotting the edges of rotor magnets can drastically cut cogging torque (by ~99%), recovering magnetic flux and boosting efficiencymdpi.com. In practice, minimizing cogging (via skew, Halbach arrays, or magnet shaping) allows a PM-driven HAWT to self-start at very low wind. (Experts note that low cogging torque is key to reducing cut-in speedmdpi.comlink.springer.com.) Likewise, a PM generator with a coreless or Halbach magnet array inherently has low cogging and so can start at lower wind speeds. In sum, magnet configuration in the generator and rotor is tuned (e.g. flux-weakening shapes, fractional-slots) to maximize torque and cut-in performancemdpi.comlink.springer.com.

Sivamani et al. (2019)researchgate.netresearchgate.net:-Recent studies have explored diverse ways to embed permanent magnets in horizontal-axis wind turbines (HAWTs) to boost performance. For example, blade-tip power systems use permanent magnets on the rotor periphery instead of a central gearbox. One prototype placed permanent magnets along the blade tips and matched coils on an outer stator, eliminating the conventional gearbox and bearingsresearchgate.netresearchgate.net. The authors report that this design reduces frictional losses and power loss, bringing the mechanical and electrical power coefficients closer togetherresearchgate.net. In practice, the rotor is magnetically levitated (no metal contact) so that wind-driven rotation directly induces current in the coilsresearchgate.netresearchgate.net. This "blade tip power system" demonstrated that a small HAWT (7–10 m/s wind) could run with frictionless magnetic bearings, simplifying the drivetrain and improving efficiencyresearchgate.netresearchgate.net.

Różowicz et al :-Cogging-torque reduction: A dominant theme is minimizing cogging torque in PM machines so the turbine can start at lower wind speeds. For example, Bai et al. use a slotless toroidal stator in an axial-flux PM generator; this completely removes iron-tooth cogging and "decreases the starting and cut-in speeds" of the turbinemdpi.com. Multi-pole rotor designs also help: Różowicz et al. built a 36-pole direct-drive PM generator whose cogging (breakaway) torque is <1% of rated torque, enabling startup around 2 m/s windmdpi.com. Likewise, numerous fractional-slot and magnet-skewing techniques (dual-skew, magnet shaping, asymmetric magnet placement) are reported in the literature as effective ways to reduce coggingmdpi.commdpi.com. Overall, the consensus is that extreme cogging reduction (often >98% reduction) is needed to allow reliable self-start at low Reynolds numbermdpi.comdocs.nrel.gov.

Liu and Cheng (2003):-Magnetic bearings and frictionless supports: Some works also insert PM-based magnetic bearings or couplings to cut mechanical drag. Liu and Cheng (2003) showed that replacing a conventional shaft bearing with an axial permanent-magnet bearing in a wind turbine "significantly reduce[s] the starting torque," thereby lowering the cut-in wind velocitymagneticbearings.org. By levitating the rotor, PM bearings eliminate lubrication losses and bearing friction, which not only aids startup but can raise overall machine efficiency. Such magnetically levitated rotors remain an active research area, though most published examples are on vertical-axis turbinesmagneticbearings.org.

Różowicz's:-Direct-drive and high-pole PM generators: Directly coupling the rotor to a high-pole-count PM generator can also provide high self-start torque. PM generators inherently produce torque even without external excitation, but many poles (and a large diameter) are needed for low-speed operation. Różowicz's 4 kW gearless generator uses 36 permanent magnets and runs at ~167 rpm, yielding ample torque at low wind and requiring very low coggingmdpi.com. The trade-off is that many poles or large rotors increase weight, but the small machines surveyed often target <85–90% efficiency at rated conditionsmdpi.commdpi.com.

Park et al. (2023):-High efficiency, power density: Axial-flux PM machines (AFPMs) are especially attractive in small HAWTs. An AFPM places large-area stator windings between two magnet disks, offering high torque and power density in a compact form. For example, Bumby and Martin (2005) built a coreless axial-flux PM generator (plastic stator, disk rotors) that delivered 1–2 kW at very low speeds with >90% electrical efficiencydurham-repository.worktribe.com. Park et al. (2023) also note that AFPM machines "have…better efficiency and higher torque-to-weight ratio" than equivalent radial-flux typesmdpi.com. In general, axial designs can exploit high-grade NdFeB magnets on rotor discs to concentrate flux and avoid stator iron losses, yielding high efficiency in small-scale units.

Bai et al.'s AFPM(2005):-Slotless and YASA machines: Several recent studies use slotless stator or air-core designs to remove iron losses entirely. Bai et al.'s AFPM generator had a toroidal (fruit-ring) winding core with no teethmdpi.com, which gave "simple stator assembly [and] elimination of the cogging torque"mdpi.com. Air-cored or slotless designs (often called YASA-type machines) sacrifice some flux but avoid iron saturation and copper fill issues. Results from prototypes show that removing the stator iron does not prevent achieving high torque: the cited 2005 coreless prototype still produced 1 kW at 300 rpm thanks to its 16 magnets per discdurham-repository.worktribe.com. Slotless generators consistently score high efficiency (>90%) and very low acoustic noise, making them appealing for residential or off-grid HAWTs.
Park's 1 kW direct-drive AFPM or Różowicz's 4 kW:-Direct drive vs. induction: Multiple sources affirm that PMG technology tends to out-perform traditional induction or wound-rotor machines in efficiency. As one industry review notes, PMSGs "do not need an excitation current, making them more efficient and less

likely to overheat" than comparable machinesturbit.com. This matches experimental comparisons (e.g. self-excited induction vs. PMSG) where PMSGs usually achieve higher efficiency at partial load. However, PM generators are more expensive (rare-earth magnets) and require careful design to handle demagnetization and core losses at high speed. In practice, most small HAWT designs now assume a PMSG: e.g. Park's 1 kW direct-drive AFPM or Różowicz's 4 kW ring generatormdpi.commdpi.com.

Bumby & Martin's 2005 AFPM:- Case studies and prototypes: The literature includes several prototype reports. Bumby & Martin's 2005 AFPM (described above) validated the air-cored approachdurham-repository.worktribe.com. Różowicz et al. built and tested their 4 kW PM generator, emphasizing its very low breakaway torque and direct-drive operationmdpi.com. Park et al. (2022–23) performed multi-parameter optimization of a 1 kW AFPM, achieving a 25% higher power-to-weight ratio than earlier 3 kW machinesmdpi.com. Across these studies, reported efficiencies are typically 70–90% in the intended speed range. Importantly, nearly all examples are small (≤5 kW), direct-drive machines designed for low-speed HAWTs or even micro-hydropower usemdpi.comdurham-repository.worktribe.com

Table 1. Comparison between literature survey

Reference (Year)	***Turbine/Application***	***PM Arrangement***	***Method***	***Outcome/Notes***
Sivamani *et al.* (2019)researchgate.netresearchgate.net	Small HAWT (roof-top)	Blade-tip PM generator + maglev bearings	Experimental (lab)	Gearbox and bearings replaced by tip PMs; **reduced losses**, matched mechanical/electrical Cpresearchgate.net.
Yuhendri *et al.* (2021)ijaseit.insightsociety.org	Small HAWT (10 m/s winds)	Axial-flux PMSG (18 PM poles)	Sim+Exp	Direct-drive AFPM produced 14 V/580 W at 9 m/s; reached 263 rpm, validating low-speed, high-torque designijaseit.insightsociety.org.
Kriswanto *et al.* (2022)scholar.undip.ac.id	1 MW HAWT (industrial)	Axial PM bearing	FEM Simulation	Designed axial magnetic bearings to support 199.5 kN thrust; **no contact** improves efficiency and cuts maintenancescholar.undip.ac.id.
Kriswanto *et al.* (2023)researchgate.net	1 MW HAWT	Radial PM bearing	FEM Simulation	Modeled radial bearings; thicker NdFeB rings and small gaps gave 254 kN radial support without frictionresearchgate.net.

Abu-Khader *et al.* (2023)link.springer.com	Low-speed HAWT (4.3 m dia.)	Magnetically suspended rotor	CFD simulation	Prototype "suspended-rotor" design: rotor levitated by magnets, no gearbox. **Direct coupling** improved efficiency; high torque at low windlink.springer.com.
Abduh *et al.* (2025)mdpi.com	Small PM generator	Slotting of PM edges	FEM Simulation	Showed **~99% reduction in cogging torque** via edge-slot magnets, greatly improving PM generator performance at low speedsmdpi.com.
Gouda & Ghanem (2024)link.springer.com	MW-scale HAWT gearbox	Coaxial flux-modulated PM gear + PMSG	Optimization /FEA	Optimized PM gearbox:pelican algorithm yields higher torque/weight and power than PSO designs, enhancing output.link.springer.com
Hash *et al.* (2023)mdpi.commdpi.com (review)	Wind turbine powertrain	Magnetic gear technology	Literature review	Conclude MGs allow **contactless high-efficiency transmission**: quiet, maintenance-free, isolation, overload-protectedmdpi.commdpi.com.
Belkhir & Khenfer (2013)researchgate.netresearchgate.net	2 MW offshore HAWT	PM magnetic gear + PMSG	Simulation	Eliminated mechanical gearbox; magnetic gearing with NdFeB allowed high-speed output. Noted advantages: **no oil, quiet, high torque density**researchgate.netresearchgate.net.

III. RESEARCH GAPS

Although significant advancements have been made in the design of Horizontal Axis Wind Turbines (HAWTs) and the use of permanent magnet synchronous generators (PMSGs), several unresolved challenges remain:

Start-up Performance at Low Wind Speeds :- Most small- to medium-scale HAWTs still exhibit relatively high cut-in wind speeds (≈3–4 m/s), limiting their usability in low-wind regions. While techniques such as magnet skewing and pole shaping reduce cogging torque, there is no standardized or universally optimized permanent magnet arrangement specifically designed to maximize start-up torque without compromising efficiency.

Integration of Magnet Arrangements with Blade Dynamics :- Current studies often examine magnet arrangements or blade aerodynamics in isolation.There is limited research on the combined effect of permanent magnet placement and blade design on overall system performance, particularly at prototype scale.

Trade-off Between Cogging Reduction and Power Density :- Methods to minimize cogging torque (e.g., auxiliary magnets, skewing) sometimes reduce generator flux density, leading to lower electrical output. Research lacks systematic approaches to balance cogging torque minimization with maintaining or increasing generator efficiency.

Applicability to Small-Scale and Decentralized Systems :- Most advanced PMSG-based solutions target utility-scale turbines. There is insufficient experimental work on cost-effective permanent magnet enhancements tailored for small-scale or community-level HAWTs, which are critical for decentralized renewable power in low-wind rural areas.

Experimental Validation and Prototyping:-Many studies rely heavily on simulation (e.g., FEM, CFD, or electromagnetic modelling).There is a research gap in prototype-based testing to validate the real-world effectiveness of permanent magnet arrangements in improving both start-up and operational efficiency.While permanent magnets are commonly employed in wind turbine generators (Permanent Magnet Synchronous Generators – PMSGs), their direct role in improving turbine start-up performance and overall aerodynamic efficiency has been less explored. Most existing studies focus on blade design optimization, gearless transmission systems, or electronic controls to improve turbine efficiency, but there is limited research on integrating permanent magnet arrangements into the mechanical structure of HAWTs to reduce start-up torque and enhance low-speed performance.Furthermore, comparative experimental studies between conventional HAWTs and magnet-assisted systems are scarce, creating a gap in both theoretical understanding and practical implementation .This research seeks to address these gaps by investigating the integration of permanent magnet arrangements within HAWTs, analysing their impact on cut-in wind speed, torque generation, and overall system efficiency.

IV. MOTIVATION

This project's motivation is to use a special permanent-magnet arrangement in the HAWT's generator/rotor to assist start-up torque and improve output at low speed. For example, the target is to lower the cut-in speed and raise the power coefficient by optimizing the magnet circuit and reducing resistive torques. Ultimately, a small prototype HAWT will be built and tested to validate the concept.This project focuses on investigating the effectiveness of incorporating permanent magnet arrangements in HAWTs to improve efficiency, reduce cut-in wind speed, and increase total energy output. Through simulation, prototype development, and experimental analysis, the study aims to demonstrate that permanent magnet integration can provide a cost-effective solution for optimizing wind energy systems, making them more reliable and suitable for diverse operating conditions, particularly in low-wind regions.Traditional enhancements in HAWT efficiency focus on blade aerodynamics, active/passive control systems, and advanced generation technologies. Adding permanent magnets for propulsion has shown promise in vertical axis wind turbines (VAWTs), where magnetic arrangements increase rotational momentum and reduce cut-in speed. Adapting and optimizing similar magnetic assistance in HAWTs can bridge gaps for sites with suboptimal wind resources. Additionally, studies comparing stator windings and pole arrangements in PMSGs for HAWTs confirm that generator design significantly impacts system efficiency. However, the synergy of direct magnetic propulsion with electromagnetic generation in HAWTs remains under-researched.

V. Problem Definition

Conventional HAWTs face challenges in harnessing energy at low wind speeds due to higher cut-in wind speeds, mechanical friction, and inefficiencies in the generator system. This reduces annual energy production and limits their applicability in low-wind regions. An innovative design using permanent magnets can help overcome these limitations by improving power conversion efficiency and reducing start-up losses. Horizontal Axis Wind Turbines (HAWTs) are widely deployed for wind energy generation, but their performance is often constrained by **high cut-in wind speed, low efficiency in variable wind conditions, and mechanical/electrical losses**. These issues result in underutilization of available wind resources, particularly in low-wind-speed regions. Traditional methods to improve turbine efficiency, such as aerodynamic blade modifications or advanced control systems, often increase system complexity and cost, making them less feasible for small-scale or distributed applications. Therefore, there is a pressing need for a **cost-effective and practical solution** that enhances HAWT performance without significantly increasing system complexity or manufacturing expenses. Conventional HAWTs face inefficiencies due to mechanical friction in bearings and suboptimal conversion of mechanical to electrical energy through traditional generators. This results in higher maintenance costs and lower overall efficiency, especially under variable wind conditions. The integration of permanent magnets could provide a low-friction, high-efficiency alternative. Conventional small HAWTs suffer from high **start-up losses** and low-wind inefficiency. The turbine must overcome bearing friction, aerodynamic drag and generator cogging torque before it can spin. In machines with permanent magnets, the cogging torque (attraction between rotor magnets and stator teeth) is a major resistive torque that can hinder start-up. In fact, studies show resistive torques must be less than ~1% of rated torque to avoid delaying start-up. Many small PM generators have significant cogging at standstill, raising the cut-in wind speed. In addition, at low wind speeds the power coefficient of a HAWT drops sharply. Thus the **problem** is: how to reduce the required start-up torque and increase power at low RPM. If the HAWT can start spinning at lower wind speed and maintain torque, it will generate useful power over a broader range of conditions. In short, we must overcome drivetrain and cogging losses so the turbine blades begin turning at minimal wind, and at the same time harness more wind power when speeds are modest.

VI. Objectives

We use permanent magnet at moving wheel in circular pattern on turbine shaft and other side we use permanent magnet at stationary wheel mounted on moving wheel in a such way that to reduce starting inertia by Magnets repulsion for continuous motion of wheel.

Evaluate the enhancement in HAWT efficiency by integrating a permanent magnet propulsion arrangement.

To reduce start-up wind speed requirements using magnetic lift/torque assistance.

To compare performance (power output, efficiency, cut-in speed) between conventional HAWTs and modified systems.

Optimize the placement, orientation, and strength of permanent magnets for maximal kinetic energy contribution.

Build a small prototype HAWT with the new permanent-magnet generator design.

Test the prototype in controlled conditions to measure cut-in speed, torque vs. RPM, and electrical output, comparing against the conventional design.

VII. Expected Outcomes

Reduction in cut-in wind speed of the HAWT.

Improved power conversion efficiency at low and moderate wind speeds.
Higher energy output compared to conventional turbines.
Demonstration of the feasibility of permanent magnet arrangements for future wind energy applications.
Lower cut-in wind speed:- The new design should spin up at a notably lower wind speed than the baseline. For example, achieving <2 m/s start-up (versus ~3–4 m/s) would confirm success.
Higher low-speed power:- At moderate winds (2–5 m/s), the prototype should generate more torque and electrical power than a standard PM generator of the same size.
Reduced cogging and losses: -Measured cogging torque at standstill should be significantly reduced (ideally <1% of rated torque). This will be evident in smoother start-up behaviour.
Validations of design tools:-The simulations (BEM, FEA) used in the design should match the experimental performance, providing confidence in the modelling approach.
Project prototype:- A working small HAWT prototype, complete with data on its performance curves, demonstrating the feasibility of the magnet arrangement.
Documentation:- A detailed report with design analysis, test results, and recommendations for small-scale wind turbine design.

VIII. Application

Small-scale distributed wind power systems.
Improved rural and remote power generation systems.
It could power **off-grid sensors, lighting or telecom** in remote areas, where winds are often mild.
One application is vehicle or trailer-mounted turbines: for example, a 600 W HAWT was mounted on a truck to help power an evaporative cooler, yielding 140–294 Wh at 60–100 km/h. Our design could enhance such mobile or marine turbines, allowing energy capture even when wind is weak.
In agriculture, small turbines could help run water pumps or solar hybrids on farms.
In urban settings, rooftop HAWTs with this technology could contribute to microgrids. Educationally, the prototype would serve as a teaching tool in renewable energy labs.
More broadly, any small wind system (camping, telecom towers, marine buoys) would benefit from lower cut-in speeds and better use of gentle breezes.
Hybrid renewable energy setups in low-wind regions.

IX. Description of The Proposed Work

Literature Review:- analyse existing research on permanent magnet applications in wind turbines.
Design Development:- Develop a CAD model of the modified HAWT system with permanent magnet arrangements.
Simulation:- Use software tools (ANSYS, MATLAB/Simulink, or similar) to simulate magnetic flux, torque improvement, and power output.
Prototype Fabrication:- Build a scaled-down prototype of the turbine with the permanent magnet system. Prototype fabrication of selected permanent magnet arrangements will be carried out, and performance tests (output power, vibration, noise, and reliability) will be conducted under controlled and field conditions. Fabricate scaled HAWT shaft and rotor hub with integrated permanent magnet arrangement.
Magnet Arrangement:- Design an array of Neodymium magnets positioned on the rotor hub and a stationary base, oriented for maximum repulsion without causing mechanical interference.
Test Conditions:- Assess performance at varied wind speeds, recording rotational speed, cut-in speed, torque, and electrical output.

Instrumentation:-Employ high-precision torque sensors, anemometers, and data acquisition systems for accurate measurement.
Testing & Analysis:- Conduct experiments under controlled wind tunnel conditions and compare results with conventional turbines.
Result Evaluation:- Analyse performance improvements in terms of start-up speed, efficiency, and power generation.
Data Analysis and Optimization:-Optimization of design parameters for maximum efficiency, using both simulation and empirical results.
Placement Optimization:- Experiment with different magnet configurations to avoid negative interference with generator operation.

X. CONCLUSIONS

The proposed project aims to enhance the performance of Horizontal Axis Wind Turbines by integrating permanent magnet arrangements. This innovative approach is expected to provide a cost-effective and efficient solution for improving wind energy utilization, especially in areas with low wind availability.Recent experiments and simulations consistently report higher power output per weight and improved start-up performance when permanent magnets are applied in innovative ways. Adding a permanent magnet arrangement primarily through adopting PMSGs, magnetic bearings, and possibly magnetic levitation provides well-documented efficiency improvements for horizontal axis wind turbines, especially under low and variable wind speed conditions. This project will investigate adding or rearranging permanent magnets in a small HAWT generator to overcome start-up inertia and boost low-wind performance. By careful aerodynamic and electromagnetic design, and by building a prototype to test the concept, we aim to demonstrate a tangible efficiency gain. The expected result is a low-cost improvement in micro-wind turbines' viability, extending their operational range to lighter winds. If successful, this approach can be applied to many small HAWT designs to help maximize the clean energy harvested from available winds.

XI. ACKNOWLEDGMENT

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