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Using Wind Energy to Carry out Basketball Special Physical Fitness Training—Calculation and Research on Aerodynamic Efficiency of Integrated Wind Turbine in Stadiums and Gymnasiums

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Abstract. This study investigates the feasibility of using wind energy for basketball special physical fitness training by combining wind turbines in stadiums and gyms. The investigation focuses on measuring the aerodynamic efficiencies of the combined wind turbine systems. It starts with an analysis of wind energy utilization for fitness training, which signifies the potential benefit of harnessing the renewable energy in sports facilities. The investigation into the aerodynamic efficiency of the combined wind turbine systems, considers factors such as speed of wind, size of turbine, and energy output. Numerical simulation and measurements are conducted to determine the optimal design and placement of wind turbines in stadiums and gymnasiums. The results demonstrate the potential of wind energy to supplement traditional power sources in sports facilities, and provide sustainable energy solutions while boosting fitness and environmental awareness. The study reveals that with an average speed of 8 m/s, a properly integrated wind turbine system in a stadium or gymnasium can generate approximately 11-23% of the facility's electricity demand. This translates to an annual energy production of 510-1200 kWh per turbine, depending on the specific location and design considerations. The aerodynamic efficacy of the integrated wind turbine system is estimated to be around 40-50%, indicating a significant potential for energy savings and environmental impact reduction.

Key words. Wind Energy Utilization, Integrated Wind Turbine Systems, Aerodynamic Efficiency, Sports Facilities, Renewable Energy, Fitness Training.

1. Introduction

An interesting concept that involves both engineering and sports science is the harnessing of wind energy for basketball and special physical fitness training through integrated wind turbines in stadiums and gymnasiums. The aerodynamic efficiency of such a system would depend on various factors, and a comprehensive study is necessary to evaluate its feasibility. Wind is the fastest demanding energy source nowadays. The global wind power capacities peak at least 50% every year. For example, the European Union's target is to meet 25 percent of its demand from renewables by 2014. Over 70 percent of the global installations are in Europe. Install capacities may reach a level of 1.4 million GW by 2026. The global focus on clean and renewable energy has significantly increased interest in wind energy. Wind turbines, which convert wind energy into electricity, have seen rapid development worldwide. Blades, a critical component of wind turbines, account for approximately 20% of the entire machine's cost. Their effective design, high quality, and reliable performance are crucial for maximizing wind energy utilization and ensuring the stable operation of wind turbines. The design of wind turbine blades primarily focuses on aerodynamic performance and structural characteristics of the airfoils. The suitability of utilizing renewable energy sources can differ significantly among countries, influenced by factors such as geographic location, sunlight exposure, resource availability, national energy strategies, management practices, and the duration of sports facility operations. In sports facilities, energy is essential for maintaining the artificial environmental conditions necessary for various activities.

In high-level basketball facilities, the majority of energy consumption (around 97-98%) is allocated to heating dressing rooms, auxiliary service areas, public facilities, offices, and providing hot water for bathrooms. Within this thermal energy usage, 73-79% is dedicated to air conditioning and ventilation systems, with the remaining portion used for hot water production. Given these considerations, and recognizing that an open-air sports facility or sports complex is a structurally and functionally complex entity, energy-efficient strategies during the planning stages often draw inspiration from bio-architecture principles.

2. Literature Survey

Dincer [1] focus on a comprehensive review of wind energy, addressing its status, potential, and policy analyses. The study highlights the increasing attractiveness of wind energy as a clean renewable resource, with countries implementing various incentive policies to boost their installed capacity. The paper also discusses the challenges faced, current developments, and offers recommendations for enhancing wind power capacity.

Zhou *et al.* [2] focus on optimizing the management of merchant wind energy farms with grid-level storage in a deregulated electricity market with stochastic wind speeds and electricity prices, including negative prices. They formulate the problems as Markov decision processes and propose heuristic approaches to approximate the optimal policy. Their study evaluates these heuristics against the optimal policy and assesses the impact of negative prices on the values and environmental benefits of storage.

Shoaib *et al.* [3] focus on investigating the wind characteristics of Jhampir, Pakistan, to determine its wind energy potential. They analyze three years of wind speed data using Weibull distribution and various estimation methods. The study concludes that Jhampirs is a suitable site for a wind power plant, with calculated annual energy yields ranging from 10054 kWh to 4572 kWh for different seasons.

Burke *et al.* [4] focus on the cost competitiveness and increasing adoption of solar and wind electricity generation technologies, particularly in India and Indonesia. The paper highlights the challenges posed by entrenched fossil fuel interests, regulatory barriers, and grid management issues, and discusses strategies such as reverse auctions, tax reforms, regulatory improvements, and grid management enhancements to promote renewable energy uptake.

Kumar *et al.* [5] examine the impact of onshore wind electricity generation on land use, habitats, and natural capital in Scotland, considering the Scottish Government's renewable energy plan. The study identifies areas of least habitat and soil sensitivity to wind development, highlighting the importance of avoiding sensitive peatlands. It also discusses the potential for Scotland to achieve carbon-neutral, nuclear-free electricity generation through renewables, with a focus on onshore wind, and explores the need for additional low carbon dispatchable energy sources during wind lulls.

Aut Carbajales-Dale *et al.* [6] investigate the potential for generating electrical power from human metabolic energy output within an exercise facility, comparing it to solar photovoltaic energy. The study highlights the historical shift from metabolic energy to fossil fuels and the environmental impacts of this transition. The research demonstrates that 40 members can contribute 3-5% of the gym power demand through rowing workouts, with a 33-year payback period for the conversion of rowing machines.

Musharraf *et al.* [7] introduce the concept of Energy Generating Gymnasiums System (EGGS) as a renewable energy solution, highlighting the increasing global energy demand and the shift towards renewable resources. The study proposes converting human expended energy in gyms into electrical energy, emphasizing the potential for clean and sustainable energy generation. EGGS is envisioned to address energy crises and potentially enable surplus energy to be sold back to utilities, leveraging the concept of humans as a source of renewable energy.

Rashid *et al.* [8] review less-implemented energy sources to address the increasing energy demand and diminishing conventional sources. The study emphasizes the need for proper management of conventional energies and the exploration of different sources. It suggests that less-implemented energy sources, along with renewables and conventional sources, can significantly contribute to overcoming energy scarcity. The review highlights the potential of these sources and outlines implementation techniques and challenges, aiming to popularize them for a cleaner environment and sustainable energy production.

Thyagaraj Naidu [9] explore the integration of human motion-based energy harvesting as a renewable energy source within a smart cities framework. The depiction evaluates equipment and applications for converting human motion into energy, aiming to address urban energy shortages and meet smart energy management initiatives.

Mehmood *et al.* [10] introduce Gym-ANM, a Python package for designing RL environments for network management (ANM) tasks in electricity networks. The package enables the implementation of new environments and interaction with existing ones, with a focus on ANM challenges. Table 1 shows the summary of the literature review.

Table 1. Summary of Literature Review

Sl. No	Author and Citation	Techniques	Advantages	Disadvantages
1.	Dincer [1]	A comprehensive review of wind energy status, potential, and policy analyses.	Highlights the increasing attractiveness of wind energy as a clean renewable resource, and various incentive policies boosting installed capacity.	Challenges faced, current developments, and recommendations for enhancing wind power capacity.
2.	Zhou *et al.* [2]	Optimizing the management of merchant wind energy farms with grid-level storage in a deregulated electricity market with stochastic wind speeds.	Formulating problems as Markov decision processes, proposing heuristic approaches for optimal policy approximation.	Evaluating heuristics against the optimal policy, assessing the impact of negative price on values and environmental benefits of storages.
3.	Shoaib *et al.* [3]	Investigating wind characteristics of Jhampir, Pakistan, to determine wind energy potential.	Analyzing three years of wind speed data using Weibull distribution and various estimation methods.	Concluding Jhampir is suitable for wind power plants, with calculated annual energy yields.

Sl. No	Author and Citation	Techniques	Advantages	Disadvantages
4.	Burke *et al.* [4]	Examining cost competitiveness and increasing adoption of solar and wind electricity generation technologies.	Highlighting challenges posed by entrenched fossil fuel interests, regulatory barriers, and grid management issues.	Discussing strategies like reverse auctions, tax reforms, regulatory improvements, and grid management enhancements.
5.	Kumar *et al.* [5]	Examining the impact of onshore wind electricity generation on land use, habitats, and natural capital in Scotland.	Identifying areas of least habitat and soil sensitivity to wind development, discussing potential for carbon-neutral electricity generation.	Exploring need for additional low carbon dispatchable energy sources during wind lulls.
6.	Aut Carbajales-Dale *et al.* [6]	Investigating potential for generating electrical power from human metabolic energy output within an exercise facility.	Comparing human metabolic energy output to solar photovoltaic energy, demonstrates gym members' contribution to power demand.	Demonstrating a 33-year payback period for conversion of rowing machines.
7.	Musharraf *et al.* [7]	Introducing Energy Generating Gymnasiums System (EGGS) as a renewable energy solution.	Proposing conversion of human expended energy in gyms into electrical energy, addressing energy crises.	Envisioning potential for surplus energy to be sold back to utilities, leveraging humans as a source of renewable energy.
8.	Rashid *et al.* [8]	Reviewing less-implemented energy sources to address increasing energy demand and diminishing conventional sources.	Emphasizing need for proper management of conventional energies and exploration of different sources.	Suggesting less-implemented energy sources can significantly contribute to overcoming energy scarcity, outlining implementation techniques and challenges.
9.	Thyagaraj Naidu [9]	Exploring integration of human motion-based energy harvesting as renewable energy sources within smart cities framework.	Evaluating equipment and applications for converting human motion into energy, aiming to address urban energy shortages.	Aiming to meet smart energy management initiatives.
10.	Mehmood *et al.* [10]	Introducing Gym-ANM, a Python package for designing RL environments for network management tasks in electricity networks.	Enabling implementation of new environments and interaction with existing ones, focusing on ANM challenges.	Providing a tool for designing RL environments for network management tasks in electricity networks.

3. Proposed Methodology

Figure 1 depicts the basketball training stages they are identifying the training goals, selecting the training Environment and developing the training protocols. Here our main aim is to identify the training goals, we are mainly focusing on the basketball special fitness training, those are integrated with the wind turbine for the enhanced advancement for the betterment of the methodology and the second thing is the selection of the training environment, in their environment should be very accessible to windy regions to reach the goals and developing the training protocols and implementing that is very needed and that particular data's are stored. Aerodynamic efficacy is a crucial measure that assessing a design to generation of aerodynamic forces for efficient training parameters.

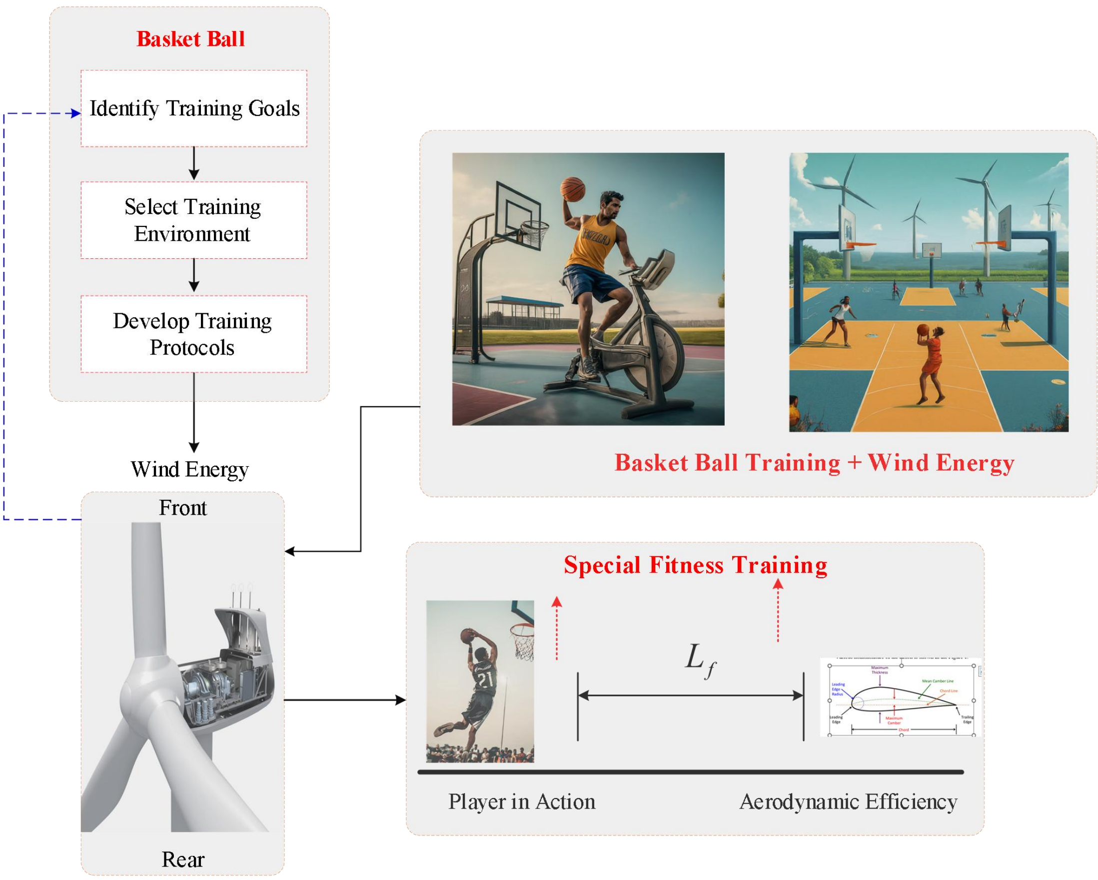

Figure 1. Proposed Methodology of Basketball Assisted Wind Energy (Special Fitness Training)

Calculation of the aerodynamic efficiency for the special fitness training is noted and that is recorded. Recorded value is then matched with the Aruduno parameters for the future traceability and improved performance.

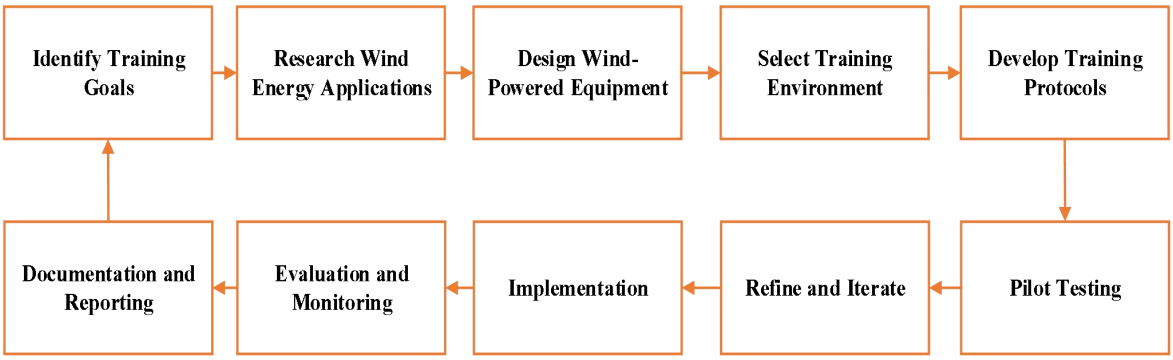

Figure 2. Data Collection Methods for the Proposed Methodology

Figure 2 depicts the data collection methods for the proposed methodology. It starts with identifying the training goals and researching wind energy applications, In here our application is linked with the basketball special fitness training and the designing of the wind equipment and that is custom-made for the tailored applications and the training Environments are favorable conditions etc and finally documentation and reporting are for the future purpose.

A. Design of Wind Energy Source

Wind energy stands as a crucial renewable resource, poised to meet a significant portion of the world's energy needs [11]. This sustainable energy source harnesses the kinetic energy of the wind through turbines, converting it into electricity for diverse applications. Modern turbines are comprised of three essential components: blades, rotor, and generator. Additionally, wind turbines integrate various systems such as wind alignment controls, safety brakes for high winds, and monitoring systems to assess and track performance. The representation of these aspects is encapsulated in the following equations.

$$\frac{d\omega_r}{dt} = \frac{1}{2H_g}[k_{sh}\theta_{tw} + C_{sh}\omega_{base}(\omega_t - \omega_r) - T_e] \quad (1)$$

$$\frac{d\theta_{tw}}{dt} = \omega_{base}(\omega_t - \omega_r) \quad (2)$$

$$\frac{d\omega_t}{dt} = \frac{1}{2H_t}[T_m - k_{sh}\theta_{tw} - C_{sh}\omega_{base}(\omega_t - \omega_r)] \quad (3)$$

where ω_t represents the turbine's mechanical speed, ω_r represents mechanical speed of rotor, H_g represents inertia of generator, H_t represents inertia of turbine, θ_{tw} represents the torsional angle of the shaft, and C_{sh} represents damping coefficient, k_{sh} represents shaft coefficient, T_m represent mechanical torques, T_e represent electrical torques, d/dt represent the rate of changes with respect to time (t), ω_{base} the base angular velocity.

B. Calculation of the Aerodynamic Efficiency of Wind Turbines

The wind turbines, equipped with rotor blades, a generator, and supporting systems, operate by harnessing wind energy. Its performance is elucidated through mathematical equations, often referencing established sources for details. Basically, the equation shows the wind turbine speed and acceleration change over time $ac(t)$, taking into account things like the motor power and gear ratios [12], [13].

$$ac(t) = \frac{T_m(t) I_g \eta_g}{mr} - g\mu\cos\theta(t) - g\sin\theta(t) - \frac{1}{2m}\rho A C_d v^2(t) \tag{4}$$

Where, motor torque is indicated as T_m, gear ratio is denoted as I_g, the efficiency of the mechanical transmission system is expressed as η_g, 'm' denotes vehicle total mass, 'r' indicates radius, 'g' specifies gravity acceleration, coefficient related to friction is expressed as μ, road grade is indicated as θ, frontal area of the turbines is expressed as 'A', air density is expressed as ρ, aerodynamic drag coefficient is denoted as C_d, 'v' denotes speed. The equation related to the acceleration is expressed as:

$$\left(v(i+1) - v(i)\right)/\Delta t = ac(i+1) \tag{5}$$

where, sampling sequence is expressed as 'i', sampling interval is denoted as Δt. Hence by combining the equations (6) and (7), and it is rewritten as follows:

$$v(i+1) = v(i) + u_f(i+1)\Delta t + u(i+1)\Delta t \tag{6}$$

In equation (7), $u_f(i+1)$ and $u(i+1)$ is formulated by:

$$\begin{cases} -g\mu\cos\theta(i+1) - g\sin\theta(i+1) - 0.5\rho A C_d v^2(i+1)/m = u_f(i+1) \\ T_m(i+1) I_g \eta_g/(mr) = u(i+1) \end{cases} \tag{7}$$

Since DC motor efficiency fluctuates during operation, directly impacting vehicle powertrain efficiency, optimizing its operating points is vital for maximizing energy savings. Ideally, the motor should run consistently in its high-efficiency zone [14], [15]. However, real-world motors exhibit complex, non-linear behavior influenced by both torque and speed, making it difficult to create an accurate mathematical model of their efficiency. DC motor efficiency η_m equation is as follows:

$$\eta_m = P_o / P_i \tag{8}$$

where, output power is specified as P_o, and input power is indicated as P_i. Calculation of the output power is determined as:

$$P_o = T_m \omega \tag{9}$$

where, the motor's angular velocity is indicated as ω. Then, the equation is derived as follows:

$$\omega = v i_g / r \tag{10}$$

C. Criteria for Energy Efficiency in Wind Mill

The formulation related to energy saving requirement of Windmill is formulated as follows:

$$E = \sum_{k=1}^{N} \frac{P_o(i)\Delta t}{\eta_m(i)} \tag{11}$$

Therefore, in the vehicle-following scenarios, the energy-saving goal for the Windmill is defined as:

$$\max \eta_m(i) \tag{12}$$

$$sub\ to\ L(i) > L_{\min}(i) \tag{13}$$

At the core of energy-saving Windmill-following control lies operating the DC motor at its peak efficiency, while adhering to safety requirements [16].

4. Implementation

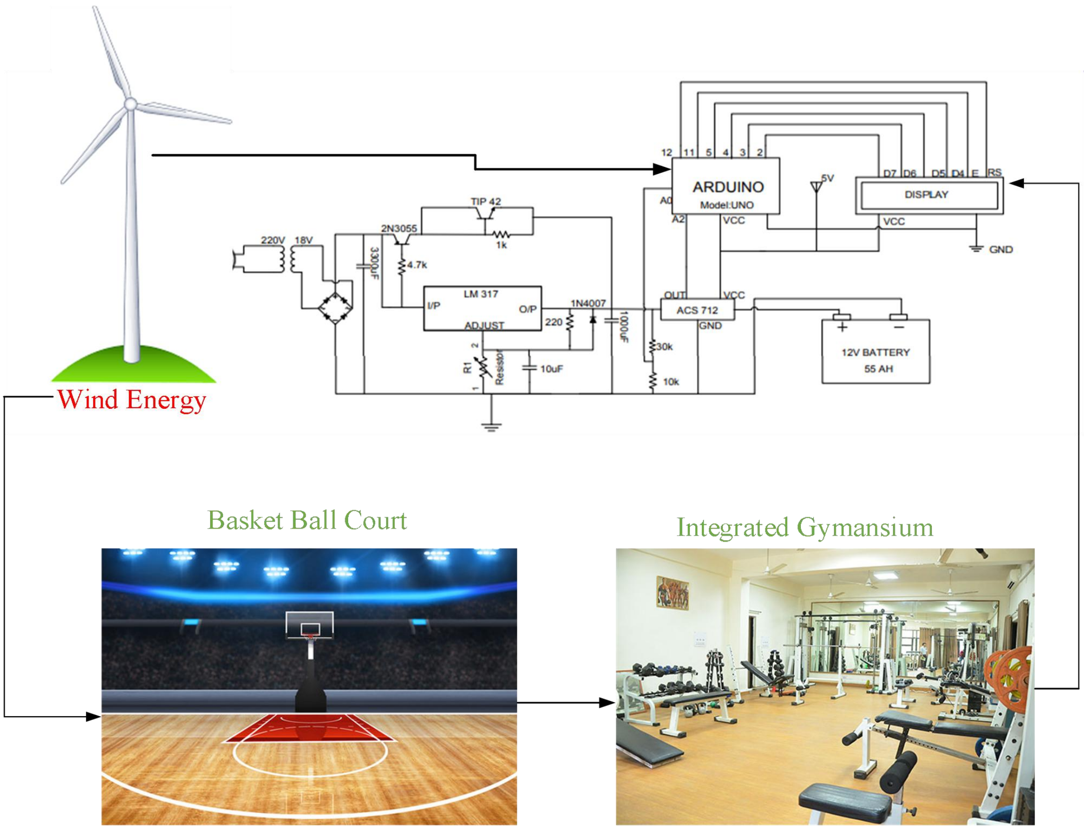

Figure 3. Arduino Integration for Data Collection

Basketball fitness and gymnasiums are popular venues for physical exercise and conditioning, offering diverse equipment and activities to accommodate various fitness levels and preferences. In a gymnasium setting, a stationary exercise machine can effectively harness the human body's musculature to convert mechanical to electrical energy. The system comprises four main components, as illustrated in Figure 3. Initially, mechanical energy is translated into electrical energy using a coupling belt that turns an alternator. To ensure efficiency and simplicity, a three-6-phase 600W, 320V, 60Hz permanent magnet alternator is utilized. The coupling belts are constructed from rubber to minimize slip loss. Additionally, the temporary exercise machine features a gear system enabling users to adjust the range of revolutions per minute (RPMs), facilitating easier initiation of pedaling and allowing users to progressively increase resistance as momentum is gained. This design aims to optimize energy conversion and user experience, making it suitable for individuals of varying fitness levels utilizing basketball fitness routines or gymnasium workouts.

In the setup utilizing 220V alternators for power generations, the inclusion of a transformer becomes imperative to step down the generated voltages to match the requirements of the charge controller’s circuits. The transformer is equipped with multiple tapings on both the high voltage and low voltage sides. Specifically, within this system, the 240/28V tapping configuration is employed. Additionally, a bridge rectifier circuit serves to convert the AC input powers into DC output powers, ensuring compatibility with the subsequent stages of the system's operation. Subsequently, a charge controller circuit is employed to precisely convert the generated DC powers into a forming that can be efficiently managed. The design and implementation charges controller circuit, depicted in Fig. 2, offers adjustable output voltage for enhanced flexibility. To store the electrical power effectively, a 14 V Lead acid battery is utilized in the system. For monitoring purposes, an ACS714 current sensor and voltage dividers are integrated to measure currents and voltages, respectively. Notably, the 2N3055 power transistor handles the significant current draw. Calculations of various parameters such as voltages, current, pedalings times, and calories burned by the user are performed by an ARDUINO (UNO), with the results displayed on an LCD screen. This integrated approach eliminates the need for additional instruments to measure user-generated calories, enhancing the simplicity and efficiency of the system.

5. Results and Discussions

Evaluating the efficiency of a wind turbine's power electronics circuit is pivotal for gauging the system's overall performance, refining design, and establishing the cooling system's sizing requirements. Initially, measuring the efficiency of each individual component is imperative to determine the turbine's overall efficiency.

A. Transformer Efficacy

Utilizing 260VA, 220/20V step-down transformers, the secondary side yields an output voltage of 18V and a current of 8.09A, resulting in an output power of 129VA. This power corresponds to 54% of the rate outputs, indicating the transformers operate at partial its full loads with unit power factors due to the battery ' s nearly resistive nature (excluding the smoothing capacitor). Copper loss (Wcu) of 13.6W and core loss (Wi) of 7.6W are determined through short circuits and open circuits tests. With the transformers operating at half its rate outputs, the efficacy is measured at 93.79%, with an overall loss of 8.23%.

B. Alternator Efficacy

To assess the efficacy of the alternators, 850-watt DC motors served as the main movers. The input powers of the prime movers were determined using voltage and current readings obtained via voltmeters and DC ammeters. Coupling loss was evaluated by measuring the speed and torque of both the DC motor and alternator. The coupling efficiency between the DC motors and generators was determined to be 98.46%, with a corresponding coupling loss of 3.69%.

C. Coupling Belt Efficiency

An efficient coupling typically achieves efficiencies above 99% [5]. In this particular setup, the coupling belting efficacy was measured at 97.26%, with a corresponding coupling belt loss of 2.34%.

D. Cycle Gears Efficacy

With a gear ratio of 5.34, the gear demonstrates an efficacy of 97% [6], with a corresponding gear loss of 8%. Regarding the rectifier circuits and charge controller circuits, their efficiency was assessed under various input and output conditions, resulting in an average efficiency of 8.73%.

E. Overall System Efficiency

The overall efficiency of the system is determined by subtracting all losses, resulting in a total efficiency of 49.03%.

F. Outcome of Gym Survey

The outcome of the gym surveys indicates that, on average, each gym session involves approximately 22 minutes of playing per person. With an average daily attendance of 100 members, about 55 members engage in pedaling activities. Consequently, each gym accumulates 1000 minutes of pedaling time per day. From experimental observations, it's established that the output voltage remains constant at 16.2V, with an average output current of 5.1A, resulting in an average output power of 64.34 Watts. Consequently, a gym can harvest approximately 2.054 kWh of energy daily, with a market price of $10.56 leading to monthly savings of $ 304.7 per gym. Considering the presence of over 100 gyms in the area, the monthly savings for the entire community amount to $. 30269.4.

Table 2. Survey Table of Gymnasium Survey Integrated with Solar (Special Fitness Training)

S.No	Numbers of Players	Work Hours (Hour)	Numbers of Source	Secondary Power Sources	Monthly Electricity Bills (Primary + Secondary)	Average Member/Day	Daily Loads (Hour)
[1]	346	13	1	Generators	6000+3000	123	6
[2]	31	46	0	Batteries	6000	68	4
[3]	43	32	2	Batteries	4000	24	1
[4]	417	19	2	Batteries	70000	46	3
[5]	112	18	0	Generators	4200	84	4-6

Table 2 offers insights into the operational dynamics and energy consumption patterns of entities, which could be relevant for integrating wind energy solutions into venues like stadiums and gymnasiums, particularly for activities such as basketball and special physical fitness training. Understanding the player attendance rates, operational hours, and power requirements of such facilities is crucial for designing and implementing efficient wind turbine systems. By analyzing the average number of players per hour, working hours, and monthly electric bills, one can assess the energy demands of these venues [17], [18]. This information becomes invaluable when evaluating the feasibility and potential savings associated with integrating wind turbines for power generation. Moreover, insights into the types of power sources used, such as batteries or generators, can inform decisions regarding backup systems or grid integration strategies. Ultimately, this data can guide calculations and research on the aerodynamic efficiency of integrated wind turbine solutions tailored to the specific needs and operational characteristics of stadiums and gymnasiums, facilitating sustainable energy practices in sports and fitness training environments [19]. Figure 4 shows the analysis of aerodynamic efficacy using the proposed approach for Case 1. The arrival time of EVs is considered at the previous day's end and wind power is charged at the beginning of the next day. In the time period of 0 to 3 hours, the charging power is lower with the value of 68kW. The maximum integration of stadium power output is 176kW and happens at 16 to 18 hours. Energy efficiency data are collected from the integration of Arduino.

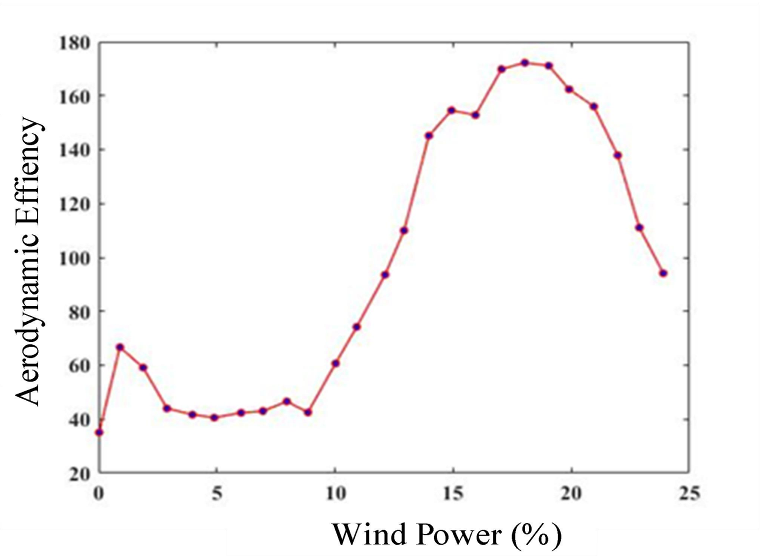

Figure 4. Analysis of Aerodynamic Efficacy Using Proposed Approach

The analysis of Energy output for Case 1 is shown in Figure 4. The Basketball fitness (efficacy) time is 100% [20]. In every time instant from 0 to 24-hour time period, the SOC of the proposed technique is 30%, 40% and 50%.

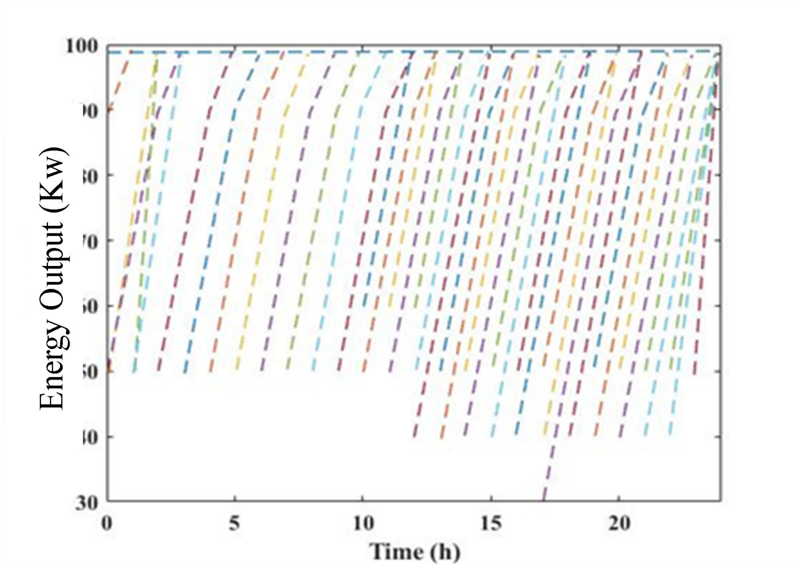

Figure 5. Analysis of Energy Output

Hourly reactive power for Case 3 using proposed approaches is shown in Figure 5. It mainly tells about when the Q is in positive value which means the reactive power is inserted into the fitness training. The negative value specifies absorption of Q from the drop in energy values [21].

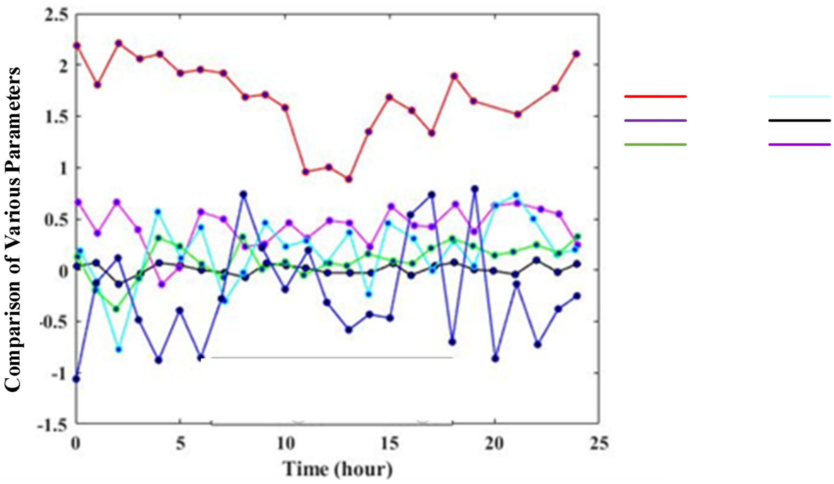

Figure 6. Comparison of Various Parameters

Analysis of active and reactive power using proposed approach is provided in Figure 6. Active Power for Case 4 greatly contributes to minimizing the objective function with optimized besides maximized active power in various parameters of 1.5MW at the time instant of 16 hours [22], [23], [24].

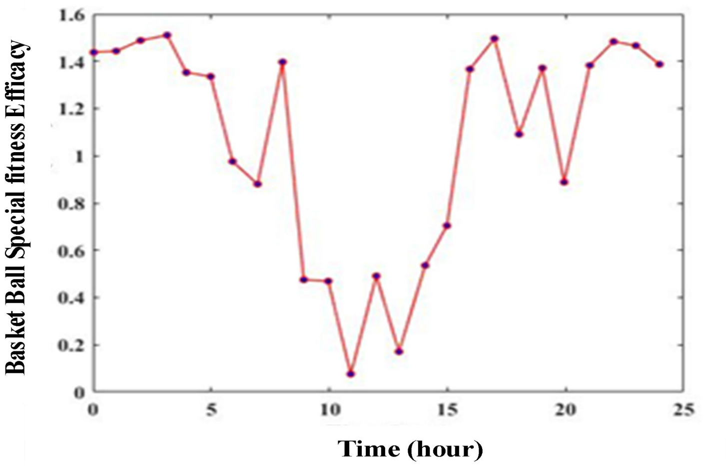

Figure 7. Analysis of (a) Special Fitness training (P)

Figure 7 illustrates the BBSFE analysis for Case 4. The second and the third cases can track the similar trend of BBSFE so they have not been revealed at this point.

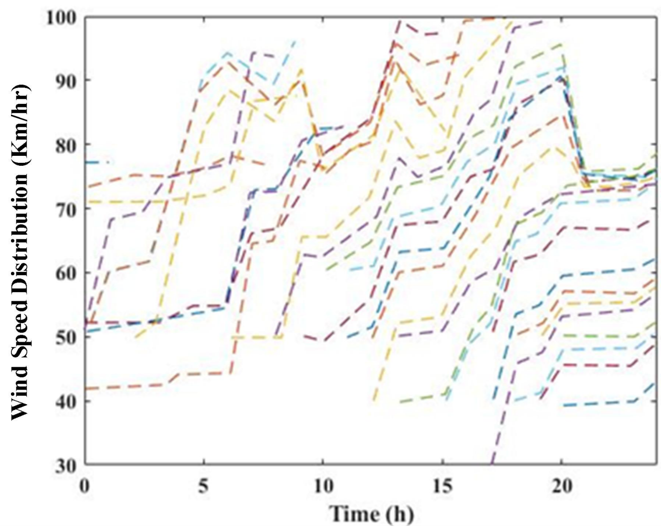

Figure 8. Analysis of Wind Speed Distribution

Wind Speed Distribution and power in the tie-line for every hour are provided in Figure 8. Wind speed value for the proposed technique is higher (2.66pu) in the time duration of 22 hours [25], [26]. The tie-line power of the proposed technique is also showing the optimum result of 0.86.

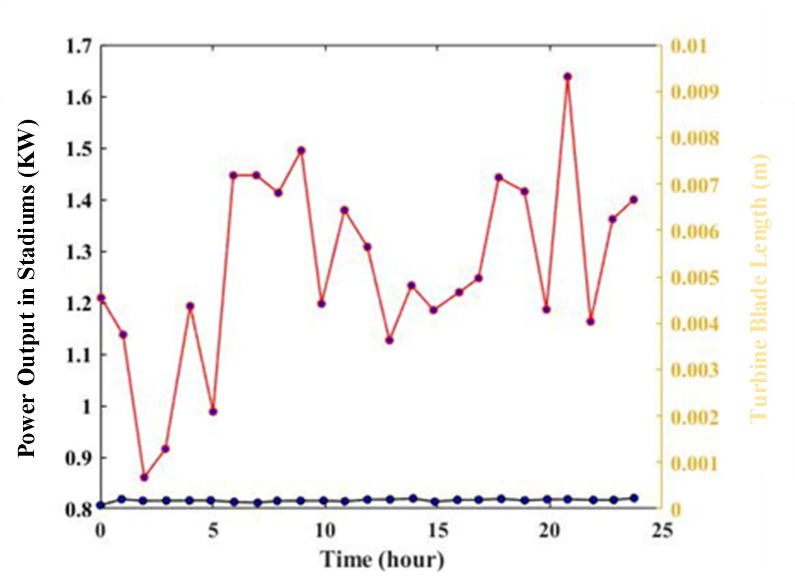

Figure 9. Analysis of PO and Tie Line Power in Regard to Autonomous MG Case

The autonomous Power outputs in blade length integrated with the blade efficiency utilization of the proposed technique are depicted in Figure 9.

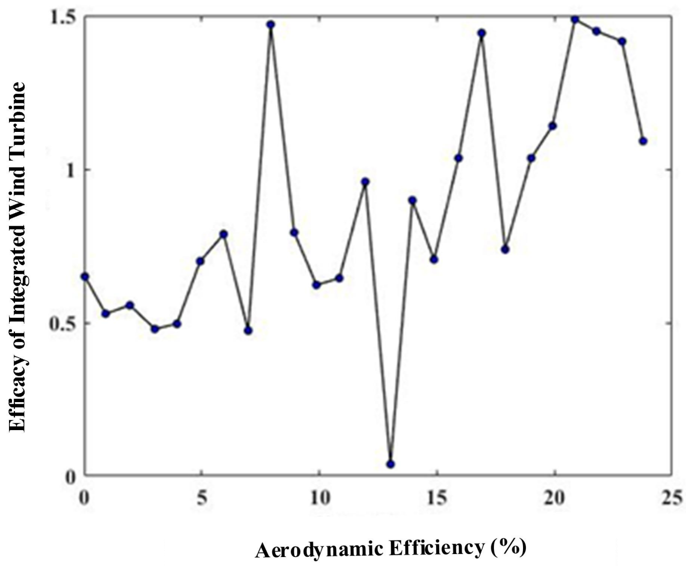

Figure 10. Efficacy of Integrated Wind Turbine

The optimal Efficacy in regard to autonomous data from arduino case is displayed in Figure 10. To obtain the best objective function, the Q optimally absorbs and injects the required power into the gymnasium.

6. Conclusion

The wind turbine system for basketball special physical fitness training capitalizes on existing equipment in stadiums and gymnasiums, such as stationary bikes and IPS batteries, which collectively constitute 71% of the total system cost. This perspective suggests that a gym equipped with these items would incur a cost of Tk. 12030 for the entire setup, with a return on investment expected in slightly over 3 years. The research focused on designing and implementing a human exercise power system aimed at charging a 12V, 55AH battery, emphasizing low production costs and high safety standards. Although the initial prototype exhibited a conversion efficiency below 50% due to significant losses in the alternator, potential efficiency gains could be achieved by upgrading the alternator. Despite this limitation, the research successfully validated the concept of harnessing electrical energy from human power, particularly within gymnasium settings. The prototype effectively met most of the established requirements, affirming the feasibility of generating electrical power from stationary exercise bikes. This approach could potentially extend to other gym equipment like treadmills, enabling substantial electrical power generation in cities. Overall, the utilization of wind energy for fitness training not only yields cost savings but also offers a sustainable, eco-friendly power source that reduces strain on national grids while enhancing reliability for consumers.

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