From Frontier Research Progress to Education: Using Series-End Winding Motor Drives as Example

Dong JIANG, Zicheng LIU, Min ZHOU, Lanhua ZHANG, Wei SUN, and Wenli XU

***Abstract*—Capable and highly motivated engineering students are constantly on the lookout for opportunities to engage in cutting-edge research. However, effectively translating the progress made in such research into educational content presents a formidable challenge for both researchers and educators alike. An example of Google Little Box Challenge by university team is introduced at first. Then, this article endeavors to showcase an attempt at integrating the latest research advancements in the domains of power electronics and motor drives into education, with the innovative series-end winding motor drives (SWMD) serving as a prime illustration. Recent breakthroughs in topology, control algorithms, and reliability have been swiftly adopted by students in the development of high-performance drives for applications such as drones, electric vehicles, and magnetic bearings. These efforts have culminated in remarkable achievements and significant milestones in various competitions. This study proposes a methodology for bridging the gap between recent research progress and education, particularly tailored to meet the needs of students possessing strong capabilities and intrinsic motivation. The case study centered around the novel SWMD not only elucidates the educational approach but also demonstrates its tangible outcomes as manifested through diverse student contest implementations.**

***Index Terms*—Contests, drone, education, electrical vehicle, magnetic bearing research, series-end winding motor drives.**

I. Introduction

In scientific research, advances at the frontier are often assumed to be distant from education. However, many recent research findings have been integrated into classrooms and educational laboratories in electrical engineering, becoming a powerful driving force for training graduate and undergraduate students to pursue further studies.

As early as 1925, the California Institute of Technology studied the relationship between research and engineering education, highlighting the importance of research in training undergraduate students for the future [1]. In recent years, studying how to deliver engineering research concepts and results to students has become increasingly important in various areas of electrical and computer engineering [2]–[4].

A notable example is the recent progress of artificial intelligence (AI). In 2022, formal AI curricula were implemented in secondary education, significantly enhancing students' understanding of AI [5]. Additionally, at the end of 2022, ChatGPT was released as an innovative chatbot. Soon after, similar technology was used to assist students in learning programming skills [6].

Unlike software or algorithm-based research, which is more aligned with students' course projects, advancements in hardware—especially high-power hardware—are typically more distant from undergraduate coursework. Even in graduate-level courses, while conveying the basic concepts of cutting-edge research in hardware is manageable, implementing and expanding these results in the classroom can be quite challenging.

The major barrier between frontier research in hardware and education is the significant effort required to develop novel prototypes for specific applications for students. However, for students with ambition and motivation to work in related fields, the opportunity to engage with frontier research can serve as strong encouragement and valuable training of future research.

The best opportunities for this purpose are scientific contests for graduate and undergraduate students. These contests should not have rigidly defined procedures but should offer relatively open approaches to the contest goals. Such contest allows frontier research results to be applied to specific problems, providing a platform for students to solve challenges independently. This process effectively achieves the overall training goals for students.

Just as many top athletes develop their skills through high-level competition from a young age, top talents in electrical engineering can similarly grow through education based on frontier research.

A good example is the Google Little Box Challenge, which took place during the 2014−2015 period. In July 2014, Google and IEEE launched this contest, offering $1 million to the winner for designing and developing a small kW-scale single-phase inverter with a power density greater than 50 W/in^3, while meeting specifications for efficiency, electromagnetic compatibility (EMC), and thermal performance. Over 2,000 teams from around the world registered for the contest, and 18 teams were selected to attend the final testing at the National

Manuscript received January 18, 2025; revised August 30, 2025; accepted October 12, 2025. Date of publication December 30, 2025; date of current version December 2, 2025. This work was supported in part by the National Natural Science Foundation of China (NSFC) under the grant 52477189. *(Corresponding author: Zicheng Liu.)*

D. Jiang, Z. Liu, M. Zhou, W. Sun, and W. Xu are with Huazhong University of Science and Technology, Wuhan 430074, China (e-mail: jiangd@hust.edu.cn; liuzc@hust.edu.cn; minzhou0729@hust.edu.cn; sunwei77@hust.edu.cn; wenli_xu@hust.edu.cn).

L. Zhang is with Apple Inc. Cupertino, CA, USA (email: Lanhua_zhang@apple.com).

Digital Object Identifier 10.24295/CPSSTPEA.2025.00038

TABLE I
MAJOR SCIENTIFIC CONTESTS IN CHINA

Title	Area	Major Targets
National Challenge Cup: Scientific Track	Nation-wide, organized by China Youth League, Chinese Scientific Association and Ministry of Education	Open topic, face to all university students, show scientific contribution, every two years (2021, 2023, 2025...).
National Challenge Cup: Business Track		Open topic, face to all university students, show scientific contribution for starting new business, every two years (2020, 2024, 204...).
China International College Student Innovation Competition	Nation-wide, organized by China Youth League and Ministry of Business	Open topic, face to all university, show business planning for novel technologies.
The China Graduate Electronics Design Contest	Nation-wide, organized by Ministry of Education and Chinese Institute of Electronics	Open topic, face to all graduate students, show electronics innovative results, held every year.
Huawei e-campaign	Industry Organized	With given area for topic, face to all university students, held every year.
Sungrow university innovation contest	Industry Organized	With given area for topic for power electronics and renewable energy, held every year.

Renewable Energy Laboratory (NREL). The final winner was CE+T Power's Red Electrical Devils from Belgium.

Many university-based teams performed exceptionally well in this contest. Many frontier research results in power electronics topologies, control, package, integration, and thermal management were implemented by students in pursuit of the specifications for this single-phase inverter [7]−[10]. To overcome the major barrier of power density due to 2nd order power pulsation in single-phase inverters, many university teams adopted the recent achievement of the active 2nd order power filter used in the Rolls-Royce project [11].

The Virginia Tech FEEC team achieved the highest ranking among university teams in the final contest (3rd place). The team's experience with novel GaN devices provided a solid foundation for high-density design [12]. The Texas A&M team learned from the active 2nd order power filter method and proposed the novel active power decoupling stage for compensating double line frequency ripple [13]. The University of Tennessee team introduced a novel 2nd order notch filter in the DC-link to mitigate 2nd order power pulsation [14]. The ETH Zurich team utilized Pareto optimization of the Power Pulsation Buffer (PPB) in their prototype to improve the power density [15]. The University of Illinois team implemented recent research results on switching capacitor converters to develop their prototype using a relative different approach [16].

These examples demonstrate that, under the goal of a contest, university students are motivated to actively learn about recent research results and incorporate them into design and development. During this process, students' R&D capabilities, teamwork spirit, and hands-on experience are developed more effectively than through regular classroom training. This approach helps eliminate the major barrier between hardware-based research and learners.

Based on the authors' research and education experience over the past 10 years, a notable example has emerged. Recent research on novel series-end winding motor drives (SWMD) has shown great promise for high-performance motion control across a wide speed range [17]. This research has inspired many motivated students to apply SWMD in various applications, addressing specific problems and generating new ideas.

Major national innovation contests in China have provided excellent opportunities for students to collaborate, gaining experience and re-inventing frontier research results. The tradition of student innovation contest serves as a crucial platform for working on novel technologies and showcasing results. Major contests related to electrical engineering in China with relatively open topics are listed in Table I, serving as the key platforms discussed in this paper.

Government-organized nationwide contests typically feature open topics for student competition. The National Challenge Cup, the most significant contest for university students, has a history of over 30 years. It features a scientific track in odd years and a business track in even years, encouraging innovation in product development. The China Graduate Electronics Design Contest, held annually, allows graduate students to compete on open topics in the field of electronics. Major industries in China also host their own contests with specific topics, such as the Google Little Box. Similar contests are likely held in other countries.

This paper summarizes and analyzes examples of student work from various contests, set against the backdrop of recent SWMD research, demonstrating the transfer of frontier research to education. Part II briefly introduces the research on SWMD as a foundation. Part III discusses the application of SWMD by students in heavy drone propulsion systems. Part IV presents another example of SWMD applied to electrical vehicle implementation by students. Additionally, SWMD has been applied to active magnetic bearing drives by students, as discussed in Part V. Part VI provides a summary of the entire paper.

II. Research to Contest: International Experience

Before presenting the examples of SWMD in student contests, an international example is used to see how the world leading research group of power electronics did for the contest. There are many technical contests for students in electrical engineering in the world. As mentioned in Part I, the Google

Little Box Challenge in 2014−2015 is a unique and influential example. Although it is not a contest just for students, the example of an university students team can share a good experience.

More than 2,000 teams from across the world registered for Google's $1 million Little Box Challenge, an open competition to design and build a small kilowatt-scale inverter with a power density greater than 50 watts per cubic inch. Virginia Tech ECE's Future Energy Electronics Center team was the only U.S. team to place in the top three—and the only student team. L. Zhang, X. Zhao, and R. Born, advised by ECE professor Jin-Sheng (Jason) Lai, competed in the January 2016 challenge to drastically decrease the size of a power inverter.

The Future Energy Electronics Center (FEEC), part of the Bradley Department of Electrical and Computer Engineering at Virginia Tech, promotes and develops energy-efficient electronic technologies for the transportation and industrial automation industries. The Center's capabilities include modeling, simulation, and design and test of power-electronics devices, components, circuits, and systems.

VT FEEC's overall approach was to create a two-stage inverter design: a DC/DC stage that stepped down the voltage and actively canceled the 120 Hz input ripple, followed by a DC/AC stage. Four-phase interleaved DC/DC stage reaches efficiency higher than 99% and DC/AC stage is HERIC topology with good EMI performance to reduce the stress on EMI filter design. Meanwhile, The enclosure we used was made entirely out of copper. The lid served as the heat sink for the DC/DC stage and the rest of the case served as the heat sink for the DC/AC stage PCB. Originally, we had hoped to reach such a high efficiency that the case-as-heatsink would be enough and we wouldn't require any forced-air cooling. In the end, however, we added a handful of 0.1W micro-fans for some forced air cooling. The thin, top-cooled GaN Systems transistors allowed us to place the devices on the bottom of the PCB and directly connect to the case-as-heatsink while the remaining components were populated on the top of the PCB and faced the inside of the box.

Several experiences have been summarized by the FEEC teams for their success in this contest:

(1) Hands-On Experience and Skill Development: The challenge provided students with practical experience in hardware design, problem-solving, and systems engineering, helping them develop valuable technical and project management skills.

(2) Networking and Career Opportunities: Students gained exposure to industry professionals and Google engineers, opening doors for mentorship, internships, and job opportunities while boosting their professional visibility.

(3) Portfolio and Recognition: Participation in the contest gave students a notable addition to their resumes, enhancing their credibility and showcasing their ability to innovate, making them more attractive to potential employers.

FEEC team is based on the strong background of high density power electronics converter of the research group for few decades. 99% efficiency milestone in research projects has been successfully delivered to the Google's targets. This experience has inspired us that the research achievements can be combined with certain targets or applications, to train students with the platform of technical contests. This process can give students an opportunity to learn organization, management, teamwork, and real-problem solving. The examples of SWMD for students contests are based on that.

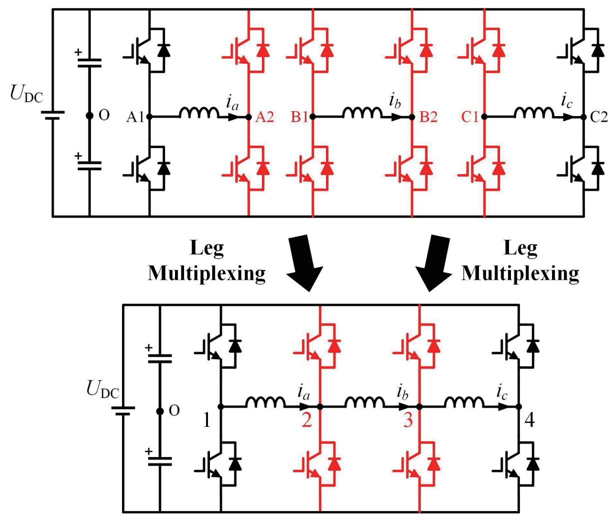

Fig. 1. From open-winding to SWMD.

III. The Frontier Research of SWMD

The scientific research on SWMD has been supported by the Natural Science Foundation of China (NSFC) under the grant 51877091 from 2019 to 2022. The initial purpose of this research was to develop novel motor drives with zero-sequence current control capability for reluctance motors. Progress has been made in advancing from open-winding motor drives to SWMD to reduce the number of power electronics devices, as shown in Fig. 1 [17]. However, the proposed novel topology of SWMD has proven to be more valuable than just for reluctance motor drives. It could serve as an alternative for open-winding motor drives for all types of AC motors, offering numerous advantages.

SWMD has been with systematical progress since its proposing in 2018. The space vector PWM of the four-leg SWMD has been developed together with the field-oriented control (FOC) considering zero-axis. It has been further extended to multi-phase SWMD. Beside HUST, City University of Hongkong is another major contributor for the progress of SWMD. This concept has been well recognized by academia now.

The most notable advantage of SWMD is its significantly wider speed range compared to regular voltage source inverter-based motor drives, achieved by adding just one extra phase-leg. With the same DC-link voltage, SWMD can produce 70% more output phase voltage in the motor windings. Fig. 2 illustrates the experimental results of the torque-speed curve for SWMD and Y-connected VSI.

Moreover, with the increase in maximum voltage output on

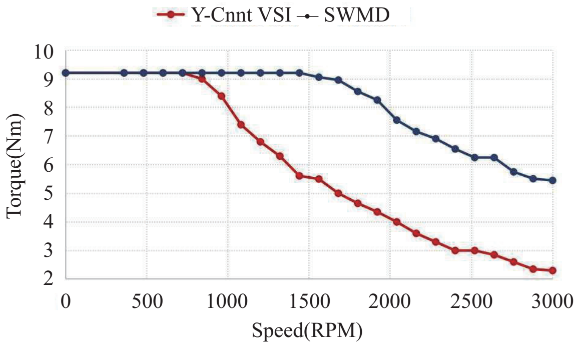

Fig. 2. Comparison of experimental results for torque-speed curve between regular VSI and SWMD [17].

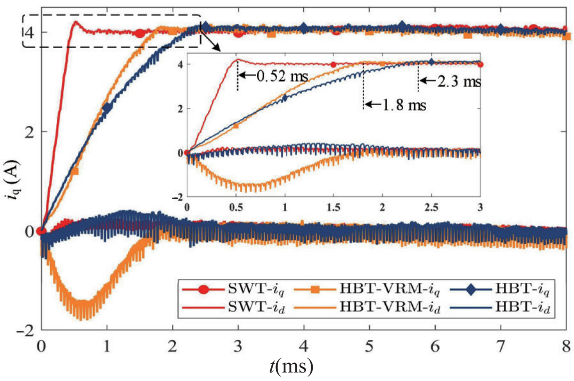

Fig. 3. Current step response comparison [17].

the motor windings, the dynamic performance of SWMD is also improved. Faster step responses can be achieved with the series winding topology (SWT) compared to the half-bridge topology (HBT), as shown in Fig. 3.

Additionally, due to the relatively independent winding connections in SWMD, enhanced fault-tolerant capabilities can be achieved. Automatic fault-tolerant control systems have been developed for SWMD [18].

Starting with the three-phase SWMD concept, the research has been extended to multi-phase SWMD, known as the "N+1 inverter". The N+1 inverter can achieve performance similar to a 2N-phase-leg open-winding motor drive using only N+1 phase-legs. Key technologies for the N+1 inverter include optimized phase sequence theory and carrier-based PWM methods [19]–[20].

Drawing on the similarity between rotational motors (tangential force) and magnetic levitation (radial force), the SWMD concept has also been applied to series-end winding magnetic bearing drives. Using this novel concept, N-axis magnetic bearing can be driven with nearly half the number of devices required for regular magnetic bearing drives [21].

The scientific research on SWMD has been ongoing for half a decade, resulting in over 20 IEEE journal publications and more than 30 granted patents in this field. The basic concept of SWMD has been awarded the "Gold Medal with Congratulations from the Jury" at the 47th Geneva Invention Expo. These pioneering research results have laid the foundation for the next generation of SWMD applications, though specific challenges remain in different use cases.

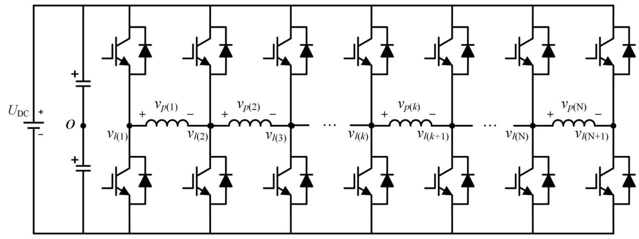

Fig. 4. Multi-phase SWMD —— N+1 inverter.

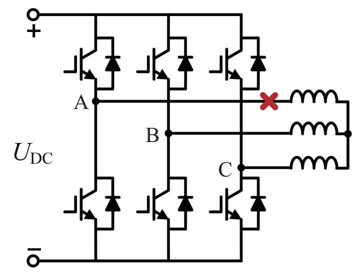

Fig. 5. Three-phase half-bridge topology.

Additionally, these fundamental research results offer a broad scope for talented and motivated students to explore. Leveraging student technical contests as a platform, this concept has been implemented in drones, electrical vehicles and magnetic bearings by students in these contests. The following three sections introduce three major examples.

IV. Case 1: Implementation in Drone

In recent years, drones have made significant strides in lightweight design and intelligent capabilities. With the rapid advancements in batteries, motors, and power electronic controllers focusing on high power density, drones have become highly promising solutions for agricultural crop protection, logistics delivery, and even manned flight. This suggests that drones are on track to become an indispensable part of daily life in the future.

Given their integral role in critical human activities, the reliability of drones has become a crucial metric for evaluating their performance. Reliability risks—primarily associated with switching devices and motor winding failures—directly impact drone performance. If a high-speed drone experiences a power interruption, it could damage valuable cargo or even pose a threat to human safety. Consequently, research aimed at improving the reliability of drone power systems is urgently needed.

The most common motor drive topology available is the three-phase half-bridge, which offers minimal switch numbers and high power density, as illustrated in Fig. 5. However, in the event of a switch or winding failure, the faulty phase may become uncontrollable. For instance, if an open-phase fault occurs on Phase-A, only currents flowing in opposite directions can pass through remaining Phase-B and C windings. In this scenario, the motor can only produce pulsating torque, which

Fig. 6. High-power drone platform.

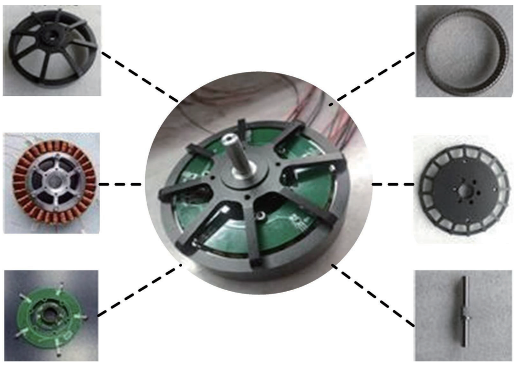

Fig. 7. Five-phase open-winding motor.

may not meet the power requirements for the drone. The SWMD discussed in this paper is expected to offer solutions to these problems.

It should be noted that the SWMD was only prototype-verified in the laboratory at the time, and its performance was tested using a generic platform with reconfigured windings. To enhance drone solutions, it is necessary to establish a dedicated drone testing platform where both the half-bridge and the SWMD can be compared.

Additionally, given the limited research on drone systems in our laboratory, we encourage students to use the contest timeline as key milestones for completing the prototype design. The contest will also serve as an opportunity to invite experts in various fields to provide feedback and suggestions on the research.

During prototype development, students are expected to face numerous challenges due to a lack of prior training on drones and the absence of a suitable platform. Therefore, a practical approach is to purchase a commercial drone platform, study its key components, and replace the circuit parts we aim to optimize based on this foundation. Consequently, we instructed the students to acquire a commercial drone platform, as shown in Fig. 6. This high-power drone, designed for agricultural crop protection, features four rotors, each driven by a three-phase motor and a corresponding inverter. Our task is to install the SWMD system we designed onto this drone platform and conduct testing.

A key component of the work involved designing a single-rotor test platform. As depicted in Figs. 7-8, we developed a five-phase permanent magnet synchronous motor, and a five-phase six-leg series-end winding motor controller. The five-phase motor is with 2 kW power rating and Halbach structure. The reliability of this setup was confirmed through experiments shown in Fig. 9.

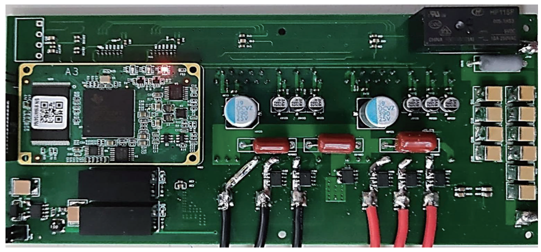

Fig. 8. Motor drive with five-phase SWMD.

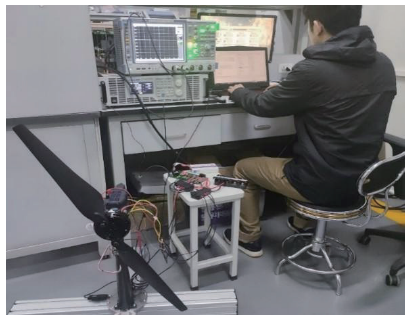

Fig. 9. The testing platform for single propeller power system.

During the contest, experts offered several suggestions, including optimizing transient responses, making the structure more compact, and reducing costs. These recommendations led to improvements in system performance. Throughout the process, students deepened their understanding of motor control topologies. More importantly, the contest provided comprehensive training, guiding students through problem identification, method proposal, method validation, and the precise and fluent presentation of their research findings.

V. Case 2: Implementation in Electrical Vehicle

Electrical vehicles (EVs) are a key focus in the field of transportation electrification. Currently, EVs often face challenges such as weak power output and high demagnetization losses during high-speed operation, which hinder development and affect long-distance user experience.

Recent research on the SWMD's inherent ability to efficiently utilize high DC voltage aligns well with the demands of high-speed operation in EVs. This capability can reduce demagnetization currents at high speeds, significantly improving operational efficiency. Fig. 10 illustrates the speed-efficiency test conducted on a SPMSM prototype by students in the laboratory at rated torque. At speeds over 1500 RPM, the efficiency of SWMD is more than 10% higher than that of half-bridge.

However, EV design cannot focus solely on high-speed performance for highways, and it must also optimize efficiency for urban driving. The SWMD introduces higher device losses due to the increased number of legs. Consequently, the half-bridge

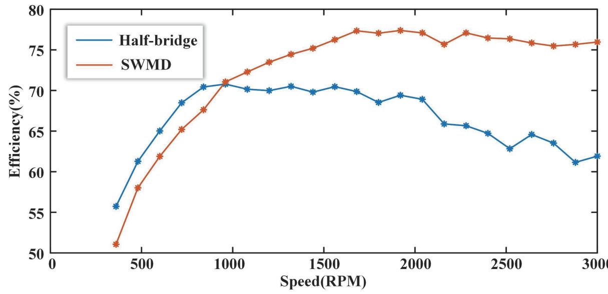

Fig. 10. Speed-efficiency comparison between half-bridge and SWMD [22].

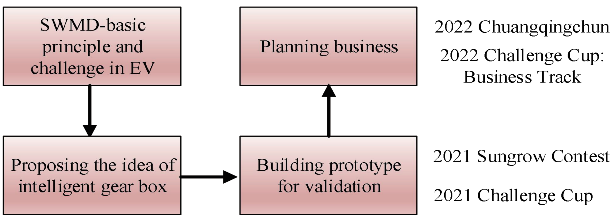

Fig. 11. Training progress of intelligent gear box and major milestones.

topology shows a greater efficiency advantage at low speed.

This issue has created an immediate barrier for the SWMD in EV applications but also presents an opportunity for students to overcome this challenge through research training. In 2020, We organized a team of students for EV applications. Over the next two years, this group has advanced significantly due to progress in technology and EV applications. The training process and major milestones are detailed in Fig. 11.

To leverage the advantages of both topologies while addressing their drawbacks, students proposed a topology transition method to achieve optimal performance at both low and high speeds. They designed a modular switching topology, named the "power electronics gearbox" to facilitate this transition. The "power electronics gearbox" is suitable for the current driving framework, and its framework and prototype are shown in Fig. 12. When K2 and K4 are on, the topology is equivalent to a half-bridge, and when K1 and K3 are on, the topology is equivalent to SWMD [22].

In 2021, this innovative hardware framework earned first prize in the Sungrow College Innovation Competition, with the judges highly praising it. However, the judges also raised a concern: frequent switching using relays could introduce potential instability issues to the system, such as overvoltage, switching safety risks, and motor torque fluctuations.

After the competition, the students explored whether they could achieve topology switching without affecting torque output and reducing stress on relays, as shown in Fig. 13. By fully utilizing the control freedom of the motor system, they discovered that the zero-axis current, which is generally not used, can indeed be utilized.

The students conducted research and found that injecting the appropriate zero-axis current, which has minimal impact on torque output, can reduce the current through the switches to zero. The operation speed range has been extended from 1500 rpm to 3000 rpm in the test.

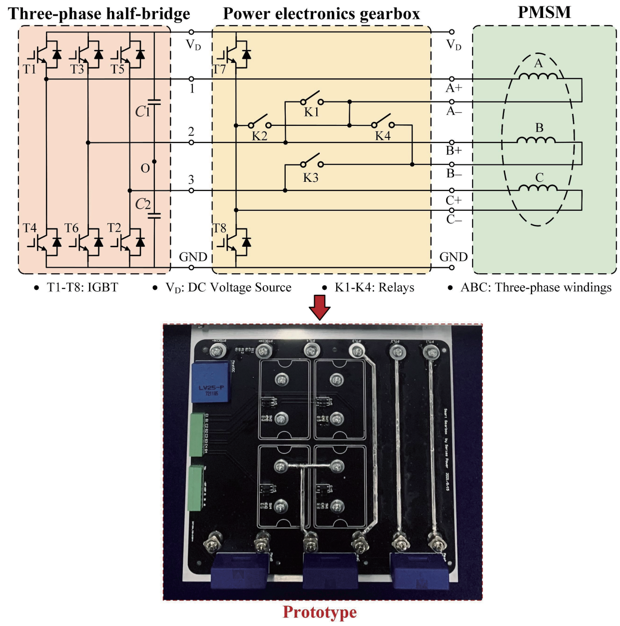

Fig. 12. Power electronics gearbox framework and prototype.

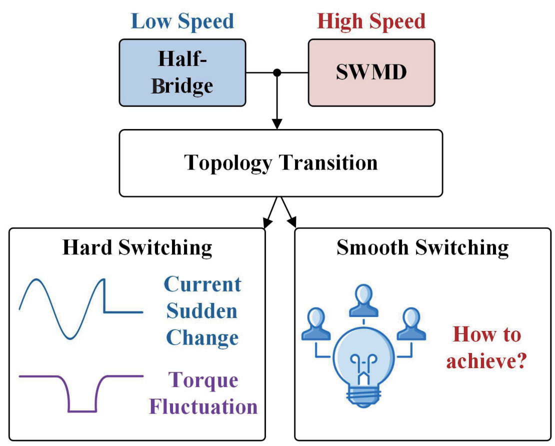

Fig. 13. Process of students' research.

The student team designed a comprehensive control framework and renamed it the "power electronics intelligent gearbox". This innovative solution won the top prize in the 2021 Challenge Cup.

Additionally, the students collaborated with EV companies to conduct performance tests. In 2022, the team participated in the Business Track of the Challenge Cup and the Chuangqingchun Contest, winning national bronze awards. They received high praise and attention. As shown in Table II, SWMD served as the foundation for their work, bridging theory and practical application. The students' expertise spanned from platform hardware design to the development of flexible switching algorithms integrated with motor control. Ultimately, they collaborated with EV companies to conduct system research.

TABLE II
STUDENTS' PROGRESS IN EVs

Competition	Students' Progress
2021 Sungrow Contest	Proposed topology transition to adjust different speeds and designed prototype
2021 Challenge Cup	Proposed smooth switching method to optimize transient behavior
2022 Challenge Cup: Business Track	Collaborated with EVs companies for vehicle test

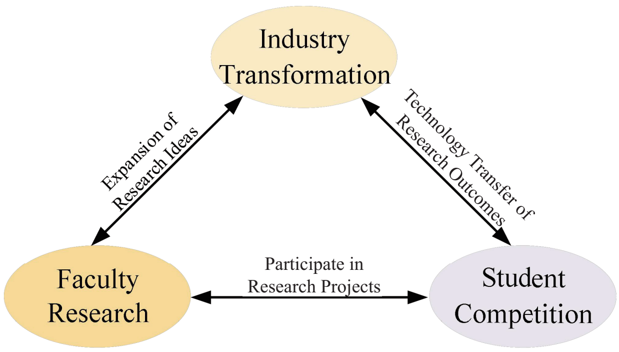

Fig. 14. Completely new interactive model.

VI. Case 3: Implementation in Magnetic Bearings

The final key case involved students using series-winding motor drive technology to overcome the limitations of traditional electric drives, achieving a novel application in the magnetic bearing drive system and realizing significant commercial value.

Unlike previous efforts, the team engaged in both technical and business-oriented competitions. Their goal was to explore a new interactive model of "Faculty Research, Student Competition, and Industry Transformation" as illustrated in Fig. 14. Early on, the project team proactively planned and integrated both horizontal and vertical research related to magnetic bearings, using these tasks to actively engage students in research projects. The team also simulated or engaged in real-world industrialization processes through business competitions, transitioning research outcomes into marketable products. This market-oriented approach enabled the team to evaluate the commercial potential of their research. Additionally, insights from market-driven activities informed and guided the faculty's scientific research, continuously opening new research fields and expanding ideas. This created a comprehensive loop from faculty research to student competition and industry transformation, forming a deeply integrated graduate education model that seamlessly connects academe, research, and industry.

This interactive model also established a new capability framework for engineering science graduate students in the modern era. It developed a multidimensional skill development system, as shown in Fig. 15, focusing on three aspects: research capability, innovation and entrepreneurship skills, and engineering application ability. This approach offers students practical motivation and platform support, fostering self-directed learning and practical skills. By breaking free from campus

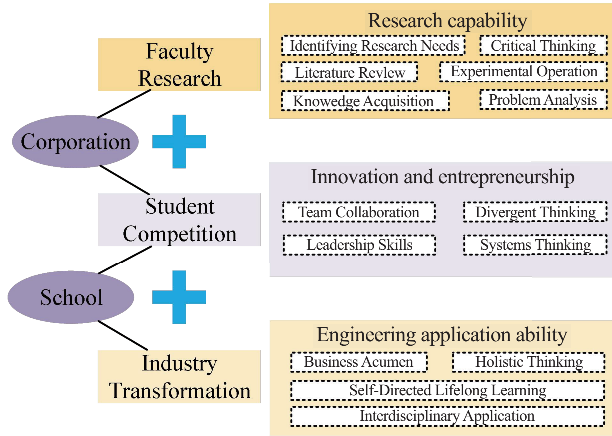

Fig. 15. Student comprehensive capability development system.

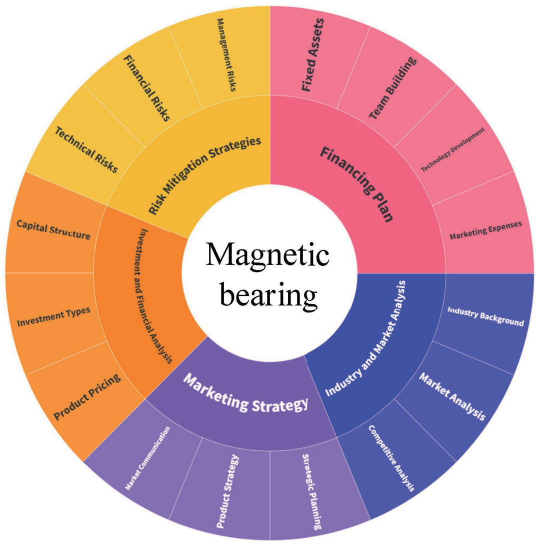

Fig. 16. Magnetic bearing industrialization analysis.

constraints and integrating resources both within and outside the university, the model allowed businesses and society to play roles in education. This encouraged students to continuously identify and solve problems, enhancing their research capabilities and practical innovation skills. The involvement of industry and society in the educational process proved beneficial for cultivating students' research quality and advancing their practical innovate abilities.

During the Graduate Electronic Design Contest—Business Plan Competition, the student team utilized university and college resources while leveraging the benefits of school-enterprise collaboration. They worked directly with SYiTech Co., Ltd., a startup specializing in magnetic bearings, to gain an in-depth understanding of transitioning magnetic bearing technology from research to industrialization. During the business competition, the student team conducted targeted research on every aspect of the entrepreneurial process, including industry and market analysis, marketing strategies, financing plans, investment and financial analysis, and risk mitigation strategies, as shown in Fig. 16. Through their participation, students in-

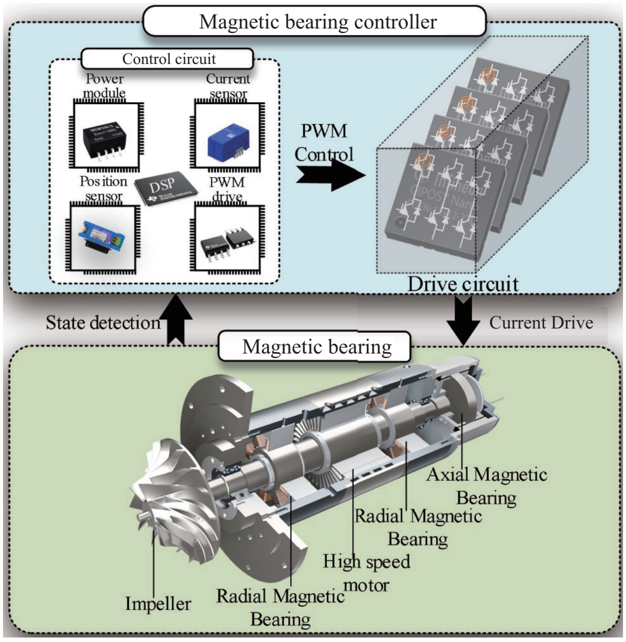

Fig. 17. Magnetic bearing system.

sights into the entire process, from developing magnetic bearing controller products to factory production and sales. This experience transcended the traditional, technology-focused constraints of conventional school-based education, broadening their perspectives and expanding their thinking.

By incorporating market factors into product development, the team established higher standards for the industrialization of the technology. Specifically, active magnetic bearings require electromagnetic force control in five degrees of freedom, including two radial magnetic bearings and one axial magnetic bearing, as shown in Fig. 17. This involves controlling 10 sets of winding currents, necessitating more switching devices compared to traditional motors. For a conventional half-bridge circuit, 4N switching transistors and 4N diodes are needed, where N represents the number of degrees of freedom for the magnetic bearings. This significantly increases the cost and risk of failure for the magnetic bearing controller.

Additionally, the magnetic bearing system depends on the magnetic bearing controller to manage the magnetic bearing motor. The magnetic bearing controller consists of power modules, current sampling, position sampling, PWM drive circuits, and power electronics topology. The entire system integrates mechanical and electrical components, resulting in a high level of complexity.

Through research conducted within the company and market, the student team identified stability and reliability as key factors limiting the large-scale application of magnetic bearings. Building on the university's scientific research, the team integrated a series-winding topology with a magnetic bearing driver to develop a high-performance magnetic bearing controller, as shown in Fig. 18. This controller offers several advantages:

1. Series-Winding Topology: By employing a series-winding topology, the number of power switching devices in the magnetic bearing is reduced by nearly half, significantly lowering the likelihood of failures. The current control bandwidth can be with the same level of H-bridge based controller.

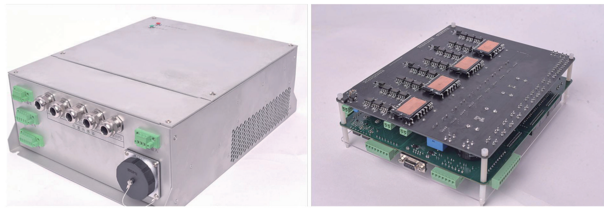

Fig. 18. High-reliability magnetic bearing controller.

2. Fault-Tolerant Design: The team developed a fault-tolerant scheme at the power electronics level for the series-winding topology, ensuring the stable suspension of the bearings even under fault conditions. The ride-through of device open circuit failure is within maximum position error of less than 100 μm.

3. Sensorless Vibration Suppression Strategy: The team developed a strategy to suppress vibrations without relying on speed sensors, thereby addressing sensor failure risks, further reducing system costs, and significantly enhancing the system's resistance to disturbances. The rotational trajectory is with less than 10% of the regular case without vibration suppression strategy.

Unlike technical competitions, business competitions greater emphasis on market adoption challenges. Students prioritize safety, reliability, and long-term operational stability as ultimate technical goals, integrating factors such as material costs, assembly costs, and testing expenses into their evaluation of technical merits, directly linking these factors to product benefits. This approach contrasts sharply with the isolated technical indicators typically found in academic research. In this competition, market needs were incorporated into the research process, integrating reliability and safety considerations into both faculty and student research activities. The research focus expanded to encompass the reliability of power electronics in magnetic bearing systems, including in-depth studies on active fault-tolerant control strategies for device short circuits and open circuits. This research was further extended to explore alternative topologies beyond the series-winding configuration [23]–[26].

The student team participated in both the China Graduate Electronics Design Contest and the Business Plan Competition, where they designed a high-performance magnetic bearing controller. This controller was used in various fields, including magnetic bearing blowers, compressors, and energy storage motors, and won first prize. Later, in 2024, the team competed in the China International College Student Innovation Competition, where they applied the magnetic bearing controller to Organic Rankine Cycle (ORC) generators and won a provincial gold medal. During the competition, they engaged extensively with the market and businesses, collaborating with multiple companies on various magnetic bearing application scenarios. This establishment led to the creation of a school-enterprise communication platform, facilitating the integrated development of industry, academia, and research.

VII. Conclusions

This paper presents a systematic study of transferring cutting-edge research to education, particularly focusing on hardware-based research for talented students in the power electronics field. The primary barrier between research and education in the field of power electronics is the development of hardware prototypes for high-performance testing. For talented young students with the right motivation and skills, training can be provided through suitable platforms, such as contest. The Google Little Box Challenge as an excellent example. The Virginia Tech FEEC team's example shows that the frontier research contribution can be a solid foundation for students to develop prototypes for certain target and to train students with many important capabilities.

The Chinese education system is characterized by a series of scientific competitions designed for university students, which afford copious opportunities to put cutting-edge research findings to use in a wide array of applications, spanning both technical and business arenas. This paper takes the recent advancements in series-end winding motor drives as an exemplar and delves into diverse instances of student applications within contests across three distinct domains..

Case 1 illustrates the initial attempt to train students on SWMD, focusing on drone applications. This example demonstrates students' ability to transfer complex technology to transportation elements.

Case 2 showcases the implementation of SWMD in the mass production of EV. This example highlights students' breakthroughs in overcoming application barriers and planning business strategies based on technical progress.

Case 3 demonstrates the application of SWMD in the specific area of magnetic bearing drives, illustrating how students are trained to innovate and develop business plans beyond traditional areas.

In these three examples, the frontier research achievement of SWMD is a solid source of innovation. Then, the students can organize the teams for different targets and develop prototypes for different applications. During this process, the students will be highly motivated for a purpose, much more than just doing a research project, but for leadership, teamwork, real problem solving and business model.

These three cases exemplify significant success in education, not only through nationwide contest medals but also in training a group of talent students. Contest participants have a winning rate for national scholarships in China that is five times higher than that of regular students. Two of the contest team members have won the highest award of the university, which is less than 0.1% of the whole group of graduate school. Graduates with this type of training have taken on leadership roles as faculty members and co-founders of start-up companies.

References

[1] R. W. Sorensen, "The relation between engineering education and research, with particular reference to the California Institute of technology plan," in *Journal of the A.I.E.E.*, vol. 44, no. 12, pp. 1288–1290, Dec. 1925.

[2] J. Sonnenberg-Klein and E. J. Coyle, "Leadership growth over multiple semesters in project-based student teams embedded in faculty research (vertically integrated projects)," in *IEEE Transactions on Education*, vol. 67, no. 3, pp. 443–452, Jun. 2024.

[3] R. Nelson, V. Marone, S. A. Garcia, T. T. Yuen, E. P. Bonner, and J. Browning, "Transformative practices in engineering education: The embedded expert model," in *IEEE Transactions on Education*, vol. 64, no. 2, pp. 187–194, May 2021.

[4] I. G. Guardiola, C. Dagli, and S. Corns, "Using university-funded research projects to teach system design processes and tools," in *IEEE Transactions on Education*, vol. 56, no. 4, pp. 377–384, Nov. 2013.

[5] T. K. F. Chiu, H. Meng, C. -S. Chai, I. King, S. Wong, and Y. Yam, "Creation and evaluation of a pretertiary artificial intelligence (AI) curriculum," in *IEEE Transactions on Education*, vol. 65, no. 1, pp. 30–39, Feb. 2022.

[6] D. Roldán-Álvarez and F. J. Mesa, "Intelligent deep-learning tutoring system to assist instructors in programming courses," in *IEEE Transactions on Education*, vol. 67, no. 1, pp. 153–161, Feb. 2024.

[7] C. W. Halsted and M. D. Manjrekar, "A critique of little box challenge inverter designs: Breaking from traditional design tradeoffs," in *IEEE Power Electronics Magazine*, vol. 5, no. 4, pp. 52–60, Dec. 2018.

[8] D. Neumayr, D. Bortis, and J. W. Kolar, "The essence of the little box challenge-part A: Key design challenges & solutions," in *CPSS Transactions on Power Electronics and Applications*, vol. 5, no. 2, pp. 158–179, Jun. 2020.

[9] D. Neumayr, D. Bortis, and J. W. Kolar, "The essence of the little box challenge-part B: Hardware demonstrators & comparative evaluations," in *CPSS Transactions on Power Electronics and Applications*, vol. 5, no. 3, pp. 251–272, Sept. 2020.

[10] K. A. Kim, Y. -C. Liu, M. -C. Chen, and H. -J. Chiu, "Opening the box: Survey of high power density inverter techniques from the little box challenge," in *CPSS Transactions on Power Electronics and Applications*, vol. 2, no. 2, pp. 131–139, 2017.

[11] R. Wang, F. Wang, D. Boroyevich, R. Borgos, R. Lai, P. Ning, and K. Rajashekara, "A high power density single-phase PWM rectifier with active ripple energy storage," in *IEEE Transactions on Power Electronics*, vol. 26, no. 5, pp. 1430–1443, May 2011.

[12] L. Zhang, R. Born, X. Zhao, and J. -S. Lai, "A high efficiency inverter design for Google little box challenge," in *2015 IEEE 3rd Workshop on Wide Bandgap Power Devices and Applications (WiPDA)*, Blacksburg, VA, USA, 2015, pp. 319–322.

[13] A. S. Morsy and P. N. Enjeti, "Comparison of active power decoupling methods for high-power-density single-phase inverters using wide-bandgap FETs for Google little box challenge," in *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 4, no. 3, pp. 790–798, Sept. 2016.

[14] C. Zhao, B. Trento, L. Jiang, E. A. Jones, B. Liu, Z. Zhang, D. Costinett, F. F. Wang, L. M. Tolbert, J. F. Jansen et al., "Design and implementation of a GaN-based, 100-kHz, 102-W/in3 single-phase inverter," in *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 4, no. 3, pp. 824–840, Sept. 2016.

[15] D. Neumayr, D. Bortis, and J. W. Kolar, "Ultra-compact power pulsation buffer for single-phase DC/AC converter systems," in *2016 IEEE 8th International Power Electronics and Motion Control Conference (IPEMC-ECCE Asia)*, Hefei, China, 2016, pp. 2732–2741.

[16] Y. Lei, C. Barth, S. Qin, W. -C. Liu, I. Moon, A. Stillwell, D. Chou, T. Foulkes, Z. Ye, Z. Liao et al., "A 2-kW single-phase seven-level flying capacitor multilevel inverter with an active energy buffer," in *IEEE Transactions on Power Electronics*, vol. 32, no. 11, pp. 8570–8581, Nov. 2017.

[17] D. Jiang, X. Sun, A. Li, Z. Liu, and R. Qu, "Series-end winding power electronics converter: principles and applications," in *IEEE Industrial Electronics Magazine*, vol. 18, no. 1, pp. 58–73, Mar. 2024.

[18] X. Sun, Z. Liu, A. Li, Z. Wang, D. Jiang, and R. Qu, "Self-adaptive fault-tolerant control of three-phase series-end winding motor drive," in *IEEE Transactions on Power Electronics*, vol. 37, no. 9, pp. 10939–10950, Sept. 2022.

[19] A. Li, D. Jiang, Z. Liu, X. Sun, and W. Kong, "Unified analysis of winding connection sequence in series-end winding topology," in *IEEE Transactions on Industry Applications*, vol. 57, no. 1, pp. 516–527, Jan.-Feb. 2021.

[20] A. Li, D. Jiang, Z. Liu, and X. Sun, "Generalized PWM method for series-end winding motor drive," in *IEEE Transactions on Power Electronics*, vol. 36, no. 4, pp. 4452–4462, Apr. 2021.
[21] J. Yang, D. Jiang, H. Sun, A. Li, and Z. Liu, "Series-winding topology converter for active magnetic bearing drive," in *IEEE Transactions on Industrial Electronics*, vol. 68, no. 12, pp. 11772–11782, Dec. 2021.
[22] A. Li, D. Jiang, X. Sun, and Z. Liu, "Online drive topology conversion technology for PMSM speed range extension," in *IEEE Transactions on Power Electronics*, vol. 37, no. 6, pp. 7113–7121, Jun. 2022.
[23] J. Yang, D. Jiang, H. Sun, J. Ding, A. Li, and Z. Liu, "A series-winding topology converter with capability of fault-tolerant operation for active magnetic bearing drive," in *IEEE Transactions on Industrial Electronics*, vol. 69, no. 7, pp. 6678–6687, Jul. 2022.
[24] J. Ding, H. Sun, D. Jiang, J. Yang, and Z. Liu, "Open-circuit fault-tolerant control and topology switching strategy of active magnetic bearing power electronics controller," in *IEEE Transactions on Power Electronics*, vol. 37, no. 9, pp. 10928–10938, Sept. 2022.
[25] Y. Shuai, D. Jiang, and Z. Liu, "An improved transient control strategy for active magnetic bearing open-circuit fault-tolerant," in *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 12, no. 1, pp. 827–837, Feb. 2024.
[26] Y. Shuai, D. Jiang, F. Hu, M. Zhou, and Z. Liu, "General switch short-circuit fault-tolerant strategy of active magnetic bearing power electronics drive," in *IEEE Transactions on Power Electronics*, vol. 38, no. 11, pp. 14504–14515, Nov. 2023.

Dong Jiang received the B.S. and M.S. degrees in Electrical Engineering from Tsinghua University, China, and Ph.D degree from University of Tennessee, Knoxville, USA. He has been with the Huazhong University of Science and Technology, Wuhan, China, as a Professor, since July 2015. His main research interests include power electronics and motor drives.

Zicheng Liu received the B.S. degree from Huazhong University of Science and Technology (HUST), Wuhan, China, in 2011, and the Ph.D. degree from Tsinghua University, Beijing, China, in 2016. He is currently a Professor at HUST. His research interests include multiphase motor control systems and transportation electrification.

Min Zhou is an associate Professor in the School of Electrical and Electronic Engineering, Huazhong University of Science and Technology (HUST). She received her PhD from Wuhan University in China in 2014. Her research is focused on the investigation of advanced energy storage materials and novel energy storage devices for large-scale energy storage applications.

Lanhua Zhang received his B.S. and M.S. degrees in Electrical Engineering from Shandong University, China, in 2009 and 2012, respectively. He earned his Ph.D. degree from Virginia Tech in 2016. He is currently a Senior Hardware Engineer at Apple Inc. Dr. Zhang has published more than 40 conference and journal papers. In 2015, he led the FEEC team to achieve a top-three ranking in Google's $1 Million Little Box Challenge.

Wei Sun received the B.S. degree from Beijing Jiaotong University, and the M.S. and Ph.D. from Harbin Institute of Technology, all in electrical engineering. He is now an associate Professor in Huazhong University of Science and Technology, Wuhan. His main field of interest is AC motor drive, control theory application in power electronics system.

Wenli Xu received her B.S. degree from Huazhong University of Science and Technology (HUST), China, and the M.S. degree from the University of Michigan–Dearborn, USA, both in Electrical Engineering. She is currently serving at the School of Electrical and Electronic Engineering, HUST, where she has successively held positions as Graduate Counselor, Student Affairs Officer, and Deputy Director of the Student Education and Management Center.