Proceedings Paper:

Wray, T., Panagiotou, P. orcid.org/0000-0001-5889-4412, Masoud, M. orcid.org/0000-0001-8805-8888 et al. (4 more authors) (2024) A compact and modular remote access platform for enhanced practical education in power electronics, machines, and drives. In: IET Conference Proceedings. 13th International Conference on Power Electronics, Machines and Drives (PEMD 2024), 10-13 Jun 2024, Nottingham, United Kingdom. Institution of Engineering and Technology (IET) , pp. 646-652.

https://doi.org/10.1049/icp.2024.2223

A Compact and Modular Remote Access Platform for Enhanced Practical Education in Power Electronics, Machines, and Drives

Tom Wray[1], Panagiotis Panagiotou[2], Mahmoud Masoud[2], Henry O'Keeffe[2], Raja Toqeer[1], Antonio Griffo[2], Panagiotis Lazari[1]*

[1]*Department of Multidisciplinary Engineering Education, University of Sheffield, Sheffield, S1 3JD, UK*
[2]*Department of Electronic and Electrical Engineering, University of Sheffield, Sheffield, S1 3JD, UK*
**p.lazari@sheffield.ac.uk*

Keywords: electrical machines and drives, remote laboratories, online learning, and training systems

Abstract

This paper presents a novel, scalable, and cost-effective remote access platform that enhances practical Power Electronics, Machines, and Drives (PEMD) education. The proposed solution addresses the limitations of traditional PEMD training systems and the challenges posed by the COVID-19 pandemic, which has accelerated the need for accessible and effective remote learning tools. The platform enables learners to gain practical experience by providing access to physical PEMD hardware in real-time through a user-friendly and adaptable interface, offering a seamless and effective remote learning experience that closely replicates in-person, hands-on laboratory activities. The key innovations of the proposed platform include a scalable architecture that accommodates increasing numbers of users without compromising performance or incurring significant infrastructure costs, achieved through the use of serverless technologies and peer-to-peer communication between the user and the laboratory hardware. The latter is a feature currently not available in existing offerings for remote learning via online platforms. Additionally, the platform features a modular and compact hardware design that reduces the cost and space requirements of PEMD training systems, making them more accessible to a wider range of educational institutions and learners. Further, the platform's flexible software architecture allows for the customisation of communication protocols and user interfaces.

1. Introduction

The Power Electronics, Machines, and Drives (PEMD) sector is facing a significant skills gap, as evidenced by a series of surveys and reports that reveal an urgent need for reskilling, upskilling, and new-skilling across the industry workforce. This gap poses a considerable challenge for training providers and the industry at large, especially in light of the UK's commitment to achieving net-zero by 2050 and the rapid transition towards greener alternatives. These needs are imminent in several sectors across Industry 4.0 such as automotive, aerospace, renewables, etc., where a substantial portion of roles are undergoing significant changes [1]-[5]. The UK PEMD sector's contribution to the global market further emphasises the critical need for a skilled workforce to sustain innovation and growth.

Addressing this gap, UK Research and Innovation (UKRI) and other initiatives have been instrumental in developing a multifaceted approach to enhance the PEMD workforce. Significant investments in projects for immediate skills development, the creation of comprehensive online training platforms, and the establishment of skills hubs constitute efforts to create a robust pipeline of talent [6]. Innovate UK's "Driving the Electric Revolution" challenge and the development of the Power Electronics, Machines, and Drives Body of Knowledge (PEMDBoK), alongside industry and academic partners, are pivotal in unifying the sector's skills-language and understanding [7]. These approaches, aimed at fostering high-quality training and facilitating widespread engagement through platforms like the Electric Revolution Skills Hub (ERS Hub), are crucial for bridging the current skills gap and ensuring that the UK remains at the forefront of PEMD innovation and deployment [8]. This context sets a solid foundation for our proposed approach to addressing these challenges within the PEMD sector.

Practical training emerges as a cornerstone of PEMD engineering education, bridging theoretical knowledge with real-world applications. The challenges associated with existing practical training equipment, primarily cost and size, restrict the scalability and accessibility of practical learning in the PEMD sector. Traditional laboratory setups often involve expensive, bulky equipment that is not feasible for all educational institutions, especially for those with limited resources. This limitation not only affects the quality of education but also hinders the efforts to address the skills gap effectively [9]. As such, the introduction of compact and cost-effective alternatives offers a promising solution to these challenges, enabling a more inclusive and scalable approach to practical PEMD education.

The transition to remote laboratories represents a pivotal evolution in engineering education, especially in the event of unprecedented circumstances, such as the COVID-19 pandemic and the increasing need for flexible learning environments. Remote labs facilitate practical training by allowing students to conduct experiments and access laboratory equipment over the Internet, breaking down geographical and logistical barriers to education [10]-[11].

Remote laboratories have significantly transformed engineering education, offering students the flexibility to engage in practical experiments beyond the traditional classroom and laboratory settings. The emergence of remote labs in the mid-nineties marked the beginning of a paradigm shift [12], [13], enabling asynchronous learning and addressing the constraints posed by geographical and temporal limitations [14]. The COVID-19 pandemic further accelerated this shift [15]-[21], indicating the importance of remote laboratories in ensuring continuity in engineering education amidst global disruptions [22]-[23].

Noteworthy contributions include Zhong et al.'s SYNDEM Smart Grid Research and Educational Kit, facilitating the transition from simulations to real experiments, and Van den Beemt et al.'s work on enhancing student engagement through remote lab assignments in systems and control courses [14],[22]. Additionally, Martínez et al. reviewed remote lab approaches, particularly highlighting a European network focused on renewable energies and underscoring a transdisciplinary move towards remote laboratory integration [25].

Despite the advancements of remote laboratories across various engineering disciplines, their application within the PEMD sector has been limited, suggesting an area ripe for development. The specialised nature of PEMD education, which requires a deep understanding of complex systems and the interaction between power electronics and electromechanical devices, poses unique challenges for remote laboratory implementation. The need for high-quality yet cost-effective and compact electrical machines and drives test sets coupled with the requirements for real-time control and feedback, demands innovative solutions that often go beyond the capabilities of traditional remote lab setups [23]-[25]. The limitations in replicating the dynamics of high-power systems in a remote environment, while ensuring real-time interaction and safety, have been significant barriers to achieving the depth of practical skills required by the industry [14], [22].

The discussed issues and challenges are exacerbated by the need for significant organisational and technical support, high initial costs, and the risk of system damage from remote experiment control [11]. Additionally, integrating these labs into educational frameworks requires extensive resources and poses challenges in maintaining engagement and interactivity [25]. Overcoming these hurdles is crucial for developing remote labs that are accessible, engaging, effective, and tailored to PEMD's unique needs, highlighting the demand for innovative solutions to bridge the gap between traditional and remote laboratory experiences.

Our approach focuses on remote hardware for PEMD education, bridging the theoretical-practical gap with compact, cost-effective electrical machines and drives test systems with EV emulation functionality. This strategy, supported by a remote labs platform, aims to make practical training more accessible and relevant, aligning with the demands of Industry 4.0 applications. The "*Practical PEMD for All*" project embodies this approach, offering a versatile, remotely accessible PEMD training system designed for large cohorts [23]-[29]. This paper details the development of this PEMD training system, addressing the limitations of current setups and introducing remote functionality. Following this introduction, the remainder of the paper is structured as follows: Section 2 describes the hardware development, Section 3 outlines the software architecture and the information and communications technology (ICT) infrastructure, Section 4 presents initial testing results, and Section 5 concludes the paper.

2. Proposed PEMD Training System Hardware

Fig. 1 illustrates a traditional PEMD training system used for teaching and learning purposes at the University of Sheffield. Traditional electrical machines and drives training systems, exemplified by the setup at the University of Sheffield, are indispensable for educating electrical engineers. These systems facilitate a comprehensive understanding of electrical machine characterisation, dynamics, variable loading conditions, and a broad spectrum of industry workflows. However, the inherent limitations of such traditional systems –predominantly their size, weight, and their static nature– restrict modularity and accessibility. Specifically, the system's design, largely encapsulated within the drive cabinet, limits direct learning opportunities regarding the electric drive system's construction and integration. Further, the operation at high voltages (415V) introduces health and safety concerns, restricting system reconfigurability.

Fig. 1: Existing industrial-scale PEMD training system.

The system depicted in Fig. 1 consists of three different electrical machines, namely, a brushed DC machine (left), a 3-phase induction machine (middle), and a brushless permanent magnet AC machine (right). All machines are rated at ~2.2kW. At the very right of Fig. 1, the power electronics cabinet is shown, which houses the power electronics driving each of the machines. The system is supplied by a 3-phase 415V source. This lab apparatus has a size of 200cm x 125cm and a weight of 500kg.

Commercial PEMD training systems, designed for industrial motor testing, exemplify these limitations due to their size, power consumption, weight, and cost. Such systems, requiring dedicated high current power supplies and weighing hundreds of kilograms, confine practical PEMD education to small, in-person classes within specially equipped facilities. This traditional approach, although effective for small-scale instruction, proves costly and impractical for broader application, particularly in further education (FE), continuing professional development (CPD) outside specialised settings, or university-level education for large cohorts. Therefore, the need for innovative solutions that overcome these barriers while enhancing educational quality is evident.

To address these challenges and broaden the scope of PEMD education, it is imperative to develop training systems that not only replicate the functionality of industrial-scale PEMD setups but are also more compact, cost-effective and flexible/customisable. By scaling down these systems, we can maintain the essential practical learning experience while making PEMD teaching accessible to additional learners, including cohorts from other engineering disciplines, such as aerospace and mechanical engineering. This approach is particularly relevant given the rapid trend towards electrification across various industries, necessitating a workforce skilled in PEMD technologies. Complementing this with remote access functionality further contributes to scaling up practical PEMD training.

The proposed innovative PEMD training system is designed for enhanced safety, space efficiency, cost-effectiveness, and hands-on learning experiences within educational settings. Illustrated in Fig. 2 and Fig. 3, the system features a low-voltage power supply directly connected to the mains, which powers the drive beneath (or on the side of) the electrical machines. This configuration not only ensures user safety by operating at a bus voltage of 48V, aligning with health and safety standards, but also conservatively utilises lab space with the total system footprint being 50cm x 32cm and weighing less than 25kg. The integration of a low-cost reaction torque sensor and an encoder on the shaft, shown in Fig. 4, enables precise torque, speed, and rotor position measurements.

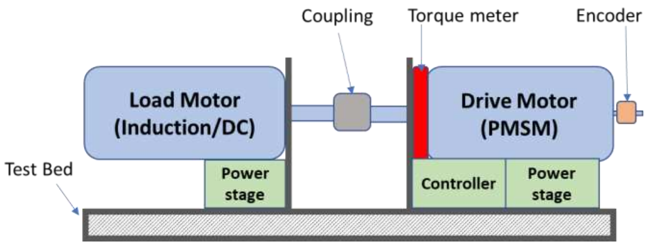


Fig. 2: Schematic of the proposed PEMD training system.

This compact, state-of-the-art system allows for an expansion of practical learning setups within a given space, increasing the number of test sets, and enabling two learners per bench for a more effective practical training experience. Further, by employing high-quality, commercially available components, our system can demonstrate a variety of key electrical machine types, ranging from approximately 300 W up to 1 kW. Despite its reduced size, the system does not compromise on performance compared to its larger-size counterparts. This approach makes PEMD teaching more accessible and safer and ensures that the quality of education is maintained across smaller, more manageable test systems.

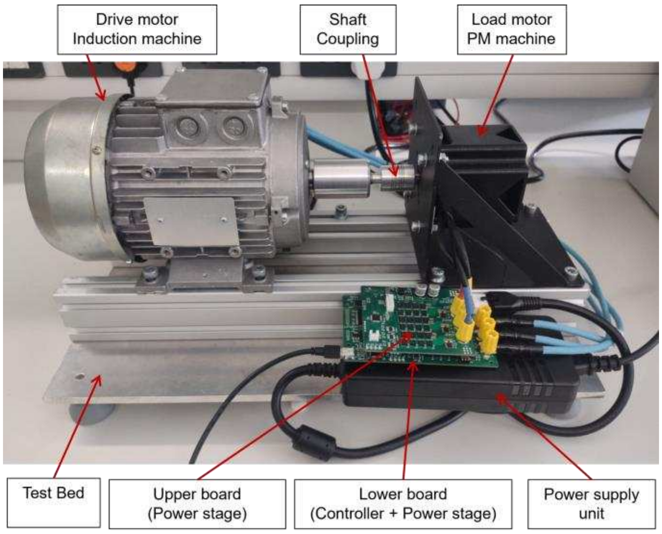
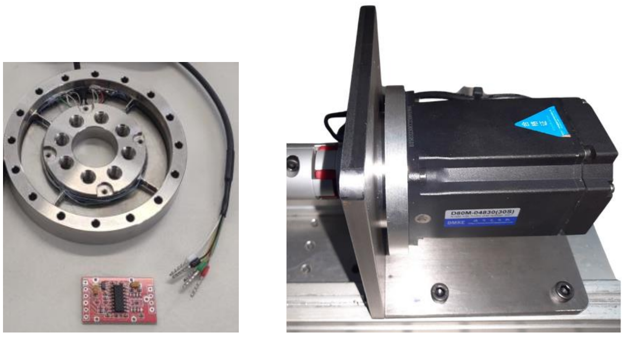


Fig. 3: Prototype of the proposed PEMD training system, incorporating an induction machine (1kW), a brushed DC machine (1kW), and the modular power electronics board.

Acquisition of the torque measurement is enabled by the use of an ultra-low-cost reaction sensor made from either steel or aluminium. The design and effectiveness of this type of torque sensor is described in detail in [30]. Fig. 4 shows the torque transducers (reaction torque sensors), which are interposed between the motor and mounting bracket for sensing the torque. The lack of moving parts on this type of torque transducer increases reliability, ensures accurate sensing and maintains a small footprint. The cost of this torque sensing solution is substantially lower compared to typical rotating torque transducers.



(a) (b)

Fig. 4: (a) low-cost reaction torque sensor, and (b) implementation of sensing instrumentation: electric motor and reaction torque sensor integration.

Another aspect of size and cost optimisation of the proposed system concerns the power electronics implementation. Fig. 5 shows the current prototype power electronics boards for the electrical machines and drives test system, clearly illustrating the achievable reduction in size. The boards use MOSFETs and are capable of driving 50 A, 48 V three-phase induction machines, as well as brushless AC machines and DC brushed machines up to ~1 kW power rating. At the same time, an integrated FPGA captures real-time analogue data, allowing the current switching process to be captured and studied in detail. The implementation is based on the open-source project enabling oscilloscope functionality on-board, described in [31]. The power electronics boards have been designed in an effort to achieve a balance between functionality/features, size, safety, cost-effectiveness, and customisation.

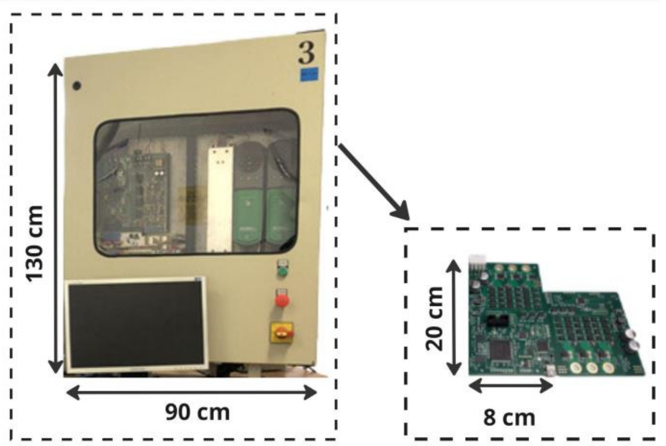


Fig. 5: Industrial drives cabinet (left) and the proposed stackable power electronic drives (right).

The architecture for the controller and power stage of the proposed electrical machines and drives training system, shown in Fig. 6, is designed to offer flexibility enabling the selection of the most suitable controller for the application. The controller has the capability of executing all the control strategies for the desired functionality, including:

- Soft-starting of the induction machine.
- Auto-phasing routine to ensure the PMSM is correctly phased for effective field-oriented control and field-weakening.
- Routine for reading and calibrating the encoder.
- Safety procedures to ensure the system is under control at all times, including appropriate shutdown processes.

The architecture tested in the presented PEMD training system has a large feature-set supported by MATLAB Simulink, allowing for the rapid development of advanced functionality, such as field-oriented control (FOC), four quadrant electrical machine control and field-weakening. This in turn enables the development of a comprehensive range of PEMD experiments.

The proposed PEMD training system is designed to achieve the core learning outcomes of traditional PEMD education, such as understanding the principles of operation, modelling, and control of various electrical machines (brushed DC, brushless AC PMSM, and 3-phase induction machines).

Learners can perform key experiments, including open-circuit and load tests, to characterise machine performance and relate it to equivalent circuit models. The system also enables learners to investigate the efficiency, control strategies, and servo drive characteristics of different machine types.

The modular and flexible architecture of the proposed system allows for the development of additional learning outcomes tailored to specific educational needs, such as exploring advanced control techniques, emulating real-world applications (e.g., electric vehicles), and examining the effects of system parameters on performance. This adaptability ensures that the system can evolve to meet the changing demands of PEMD education in the face of rapid technological advancements.

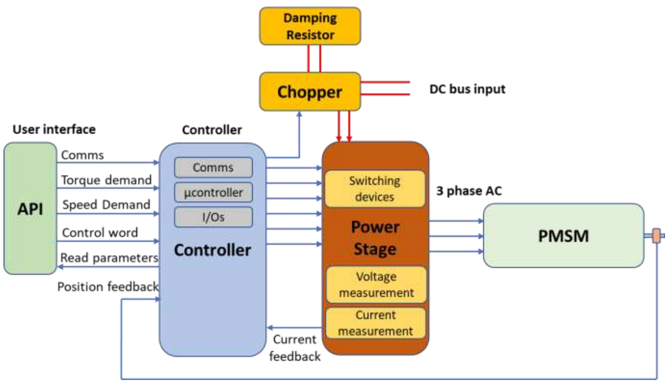


Fig. 6: Architecture of the proposed PEMD training system and remote platform connection.

3. Software Architecture & ICT Infrastructure

3.1 Platform ICT & Web-based Infrastructure

Fig. 7 shows the architecture of the web platform infrastructure, designed for scalability, cost-effectiveness, and flexibility. Using Amazon Web Services (AWS) and serverless technologies, the platform dynamically scales resource allocation based on usage, ensuring optimal resource utilisation and minimised costs. AWS also provides efficient methods for secure data storage and user authentication, increasing the platform's robustness and security.

An open source serverless content management system, enables efficient storage, access and management of lab materials and other content by leveraging the same serverless approach and its associated benefits. This integration provides scalability and flexibility in the breadth of lab content as well as an efficient learning management system (LMS). The same web-based platform is used whether the student is undertaking a lab activity within the physical lab or remotely. The controls and data visualisation will look the same to the user in either scenario, providing a consistent unified experience.

Fig. 7 illustrates the essential data flow between the remote users, the laboratory computers, and the hardware. Importantly, data transferred at each stage are controlled by configurations set within the content management sections of the platform. This ensures both efficiency and flexibility, as only necessary data travels through the system. For in-lab experiments, the infrastructure remains largely similar, with the key distinction being the absence of remote users and the associated communication pathway (the control GUI is instead presented on the local browser).

The proposed system employs WebRTC, a peer-to-peer real-time communication (RTC) technology, to enable real-time video, audio, and data transmission between the users and the laboratory equipment. WebRTC establishes direct connections compared to existing approaches which often deploy traditional methods relying on relay servers between the user and their destination [32]-[33]. This approach minimises the need for servers, resulting in a cost-efficient and seamless remote access experience for users, even at peak usage periods [25], [33], as well as keeping latency to a minimum. By establishing direct connections, WebRTC fosters inherent scalability, allowing the system to effectively handle increasing numbers of concurrent users without compromising performance or incurring significant infrastructure costs. The video and audio stream are provided by a camera connected to the local browser via USB.

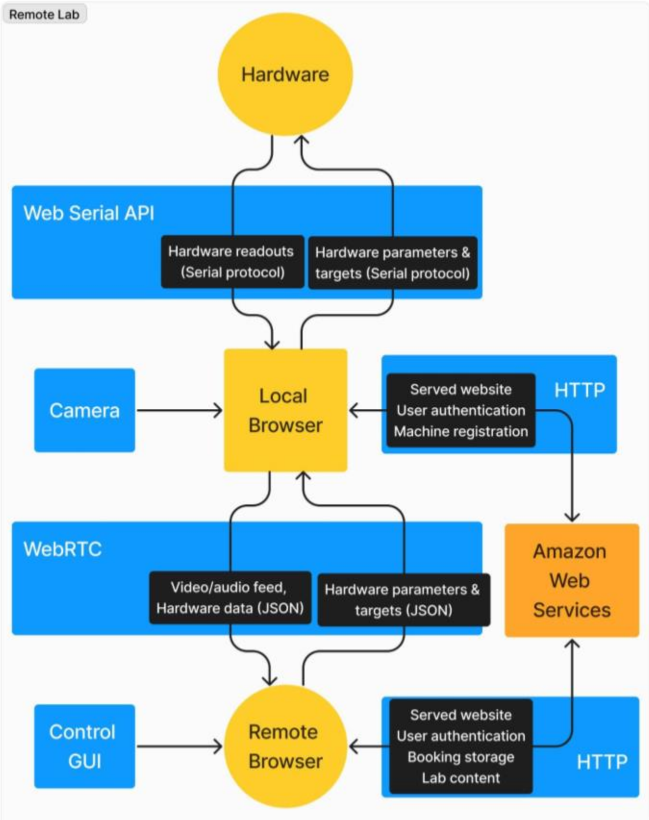


Fig. 7: Architecture and ICT of the proposed remote lab infrastructure.

The platform interacts with laboratory hardware through a simple serial communication protocol. The PEMD training system of Fig. 3 employs a straightforward serial protocol for data exchange. The simplicity of the serial protocol keeps the communication overhead low, allowing for high performance to minimise latency issues. This design approach also empowers the web platform to readily adapt and expand its hardware compatibility by adjusting or extending upon the protocol. This flexibility grants the platform wider capability and future-proofs its functionality, providing a foundation for a variety of lab hardware to become remotely accessible with a standardised approach. Furthermore, when required, communication with specific hardware can be customised. For situations where communication with the serial protocol isn't feasible, a dedicated middleware, such as one using UDP communication, can be created to bridge the gap.

Integrated directly into the platform, a booking system streamlines hardware access through automation. This efficient allocation ensures user accessibility and a seamless experience. It also provides security through web tokens, granting permitted users exclusive access during their allocated timeframes.

3.2 User Interface

Prioritising usability and intuitive interactions is key to enhancing positive user experience and engagement in remote lab frameworks [10], [14]. The proposed platform provides administrators with dedicated sections for comprehensive lab management. They can add hardware types, integrate them into the booking system via rig registration, and define labs and their corresponding learning activities, offering granular control and organisation with minimal friction. The LMS also includes modification of basic lab details such as title, lab duration and hardware employed, generation of lab scripts, selection of the readable and writable parameters on a per-activity basis, etc.

The user interface adheres to responsive design principles, ensuring accessibility across various devices. Customisable layout and data visualisation options enable users to personalise their experience and focus on relevant parameters. This results in an uncluttered and intuitive learning environment tailored to their specific experimental requirements. It also aligns with the previously described lab setup, where user access to parameters is restricted to those related to their assigned experiment; thus, further minimising interface complexity, while also preventing equipment accidental damage.

As shown in Fig. 10, the platform offers various data visualisation tools, including parameter value displays, user-selectable real-time data plots, and the ability to integrate mathematically processed data points into tables with synchronised plot updates. This setup allows effective data analysis and evaluation during any lab activity. The user can also download the collected data for offline post-processing and analysis using other numerical analysis software packages and tools.

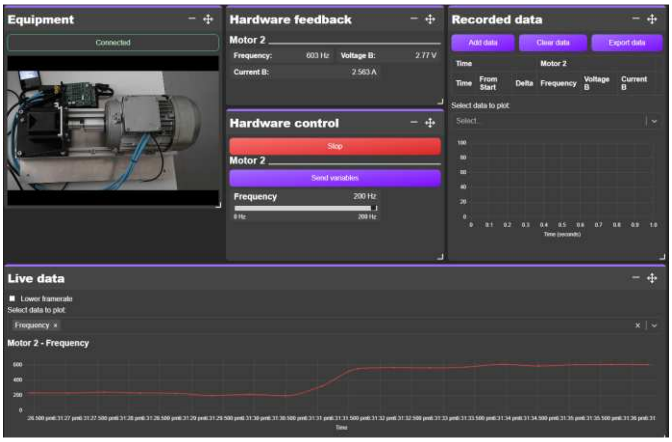


Fig. 10: User interface illustration of a lab activity page showing the controls and data visualisations.

4. Conclusion

This paper presented a novel, flexible, and scalable training system that offers both in-person and remote access to practical labs for Power Electronics, Machines, and Drives (PEMD) education. The proposed solution addresses the critical need for accessible, cost-effective, and engaging practical training in the rapidly evolving landscape of electrification.

The key advantages of this system include:

- Increased accessibility through compact, modular, cost-effective, and customisable hardware, coupled with remote access functionality.
- Scalability via a web-based platform that accommodates a growing number of users without compromising performance or cost.
- Flexibility in integrating various PEMD applications and supporting different hardware and experiments.
- A user-friendly interface that enhances the learning experience consistently across in-person and remote environments.
- Effective learning outcomes that bridge the gap between theory and practice, enabling students to acquire essential PEMD skills.

By addressing the limitations of traditional PEMD training systems and leveraging remote access technologies, this innovative solution paves the way for a more inclusive, efficient, and industry-relevant approach to practical PEMD education. The combination of modular, compact, and cost-effective hardware with remote accessibility significantly increases the reach of practical PEMD training, ensuring that a wider range of learners can benefit from these essential learning outcomes. As the demand for skilled professionals in the electrification sector continues to grow, the proposed training system offers a timely and effective means to train the workforce of the future, both in-person and remotely.

The proposed PEMD training system is currently in the final stages of development, with ongoing work focused on optimisation and comprehensive testing to validate its performance and functionality. Future efforts will involve the development and implementation of new learning experiments, leveraging the system's flexibility and customisability to address emerging trends in PEMD education. The system will be deployed in various educational settings to gather feedback for continuous improvement.

5. Acknowledgements

This work was supported by Innovate UK & UK Research and Innovation (UKRI) under the “Driving the Electric Revolution - Building Talent for the Future 2” challenge, via the project “Practical PEMD For All” (Project 10033254). The authors would also like to thank Magnokinetics Ltd for their support in the development of the EV emulator system.

6. References

[1] 'Power Electronics: A strategy for success' BIS, 2011.

[2] 'Educational pathways into engineering', Engineering UK, 2020.

[3] 'The Opportunity for a National Electrification Skills Framework and Forum', HV Catapult, 2021.

[4] 'Driving Innovation in Power Electronics across the UK Community', Powerelectronics UK, 2017.

[5] 'Working Future demand forecast 2014-24', Engineering UK, 2022

[6] ‘Innovate UK & UK Research and Innovation (UKRI)’, https://www.ukri.org/what-we-do/browse-our-areas-of-investment-and-support/driving-the-electric-revolution/

[7] ‘UK PEMD Body of Knowledge of the ERS Hub’, https://ershub.co.uk/body-of-knowledge

[8] ‘Electric Revolution Skills Hub, Coventry University, UK’, https://www.electricrevolutionskillshub.co.uk/

[9] S. Raju, L. N., Srivatchan, & N. Mohan, “An End-to-End Modeling and Prototyping Platform for Power Electronics and Electric Drives”. IEEE Journal of Emerging and Selected Topics in Power Electronics, 10(2), 1395-1408. 2021.

[10] J. Haase, “Teaching Engineering Students Practical Skills By Means of Remote Laboratories”. In 2022 IEEE 10th Region 10 Humanitarian Technology Conference (R10-HTC), pp. 419-424, IEEE. September 2022.

[11] I. V. Kovalenko, T. I. Tankovich, A. S. Amuzade, and V. V. Shevchenko, “Virtual distance laboratories for training bachelors with major electric power and electrical engineering”. In AIP Conference Proceedings, Vol. 2647, No. 1, AIP Publishing. November 2022.

[12] Haque, Emranul, Tahsin Ferdous Ara Nayna, and Feroz Ahmed. "A pragmatic approach for quality enhancement in classroom teaching of engineering education in developing countries: A case study on power electronics." In 2016 Future Technologies Conference (FTC), pp. 349-354. IEEE, 2016.

[13] Aktan, B., Bohus C.A., Crowl, L.A. & Shor, M.H., "Distance Learning Applied to Control Engineering Laboratories", IEEE Transactions on Education, Vol.39, No. 3, 1996, pp320-326.

[14] Van den Beemt, A., Groothuijsen, S., Ozkan, L., & Hendrix, W. (2023). Remote labs in higher engineering education: engaging students with active learning pedagogy. Journal of Computing in Higher Education, 35(2), 320-340.

[15] Cooper, M., & Ferreira, J. M. (2009). Remote laboratories extending access to science and engineering curricula. IEEE Transactions on learning technologies, 2(4), 342-353.

[16] Taylor, K., & Trevelyan, J. (1995, October). Australia's telerobot on the web. In Proceedings of the International Symposium on Industrial Robots (Vol. 26, pp. 39-44). INTERNATIONAL FEDERATION OF ROBOTICS, & ROBOTIC INDUSTRIES.

[17] Trevelyan, J. (2004, June). Lessons learned from 10 years experience with remote laboratories. In International Conference on Engineering Education and Research (Vol. 11, p. 2007).

[18] Bayhan, S. (2014). Labview-based remote laboratory experiments for a multi-mode single-leg converter. Journal of Power Electronics, 14(5).

[19] Wang, S. C., Liu, Y. H., Chen, Y. C., Su, J. H., & Liaw, W. S. (2008, October). Web-based software programmable e-learning platform for power electronics courses. In 2008 38th Annual Frontiers in Education Conference (pp. T2B-9). IEEE.

[20] Hurley, W. G., & Lee, C. K. (2005). Development, implementation, and assessment of a web-based power electronics laboratory. IEEE Transactions on Education, 48(4), 567-573.

[21] Sousa, N., Alves, G. R., & Gericota, M. G. (2010). An integrated reusable remote laboratory to complement electronics teaching. IEEE Transactions on learning technologies, 3(3), 265-271.

[22] Zhong, Q. C., Wang, Y., Dong, Y., Ren, B., & Amin, M. (2020). Go real: Power electronics from simulations to experiments in hours: Versatile experimental tool for next generation engineers. IEEE Power Electronics Magazine, 7(3), 52-61.

[23] van Duijsen, P. J., & Zuidervliet, D. C. (2021, September). Power electronics and drives laboratory learning environment for electric vehicles. In 2021 44th International Convention on Information, Communication and Electronic Technology (MIPRO) (pp. 1581-1586). IEEE.

[24] Issa, W. (2023). Guidance Report on Power Electronic Curriculum Development. Authorea Preprints.

[25] Martínez, M., Segura, F., & Andújar, J. M. (2023). The Challenge of Digital Transition in Engineering. A Solution Made from a European Collaborative Network of Remote Laboratories Based on Renewable Energies Technology. Applied System Innovation, 6(2), 52.

[26] Masoud, Mahmoud I., and Walid Issa. 'Road map of power electronics knowledge and skills for enhancing engineering graduates' employability', International Conference of Electrical Machines and Drives PEMD'23, IET, October 2023.

[27] Issa, W., Al-Naemi, F., Al-Greer, M. and Bashir, I., 2023, August. Review on power electronics curriculums in academia and framework development. In 2023 58th International Universities Power Engineering Conference (UPEC) (pp. 1-4). IEEE.

[28] Borodenko, Y., Arhun, S., Hnatov, A., Hnatova, H., Kunicina, N. and Patlins, A., 2022, October. Features of training an electrical engineer in the context of distance learning. In 2022 IEEE 63th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON) (pp. 1-6). IEEE.

[29] Rojko, A. and Bauer, P., 2014, September. Education in power electronics based on remote resources: Three approaches and lessons learned. In 2014 16th International Power Electronics and Motion Control Conference and Exposition (pp. 839-844). IEEE.

[30] Ubeda, R. P., Gutiérrez Rubert, S. C., Zotovic Stanisic, R., & Perles Ivars, Á. (2018). Design and manufacturing of an ultra-low-cost custom torque sensor for robotics. Sensors, 18(6), 1786.

[31] GitHub - drandyhaas/Haasoscope: Docs, design, firmware, and software for the Haasoscope https://github.com/drandyhaas/Haasoscope

[32] Drysdale, T. D., & Braithwaite, N. S. J. (2017, June). An internet of laboratory things. In 2017 4th Experiment@ International Conference (exp. at'17) (pp. 236-240). IEEE.

[33] Reid, D. P., Burridge, J., Lowe, D. B., & Drysdale, T. D. (2022). Open-source remote laboratory experiments for controls engineering education. International Journal of Mechanical Engineering Education, 50(4), 828-848.