Erasmus+ - Key Action 2

Capacity Building within the Field of Higher Education

eACCESS Project

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EU-Asia Collaboration for aCcessible Education in Smart Power Systems

WP 4	**DEVELOPMENT**
TASK	**T4.6 Preparation of the final technical documentation and teacher and student instructions for laboratories**
LEAD PARTNER	**TUL**
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1 EXECUTIVE SUMMARY

This document outlines the completion of Task T4.6 under the Erasmus+ eACCESS Project, led by Lodz University of Technology (TUL), with participating partners from KEC, RUB, ATM, and SCU. The task involved preparing final technical documentation and instructions for teachers and students for newly developed laboratories in higher education concerning smart power systems. The eACCESS project aims to build capacity in EU-Asia collaboration for accessible education in intelligent power systems.

The document details teaching activities at five laboratories established across four partner universities, each focusing on power engineering and renewable energy. At KEC, Nepal, Industrial Automation and Power Electronics laboratories were developed. At RUB, Bhutan, a Switchgear and Protection laboratory was established. ATM, Indonesia, now features a PV laboratory, and SCU, Indonesia, has a new Microgrid and Power Electronics laboratory.

For each of these laboratories, corresponding laboratory exercises were created to integrate practical skills training into the academic curriculum. These exercises complement theoretical knowledge with hands-on experience working with relevant equipment, simulating scenarios, and solving real-world problems. These laboratories are innovation hubs for research and collaboration on projects of green energy and sustainable power systems. The document emphasises that through these laboratories, students can gain exposure to industry practices and participate in research projects, vital for producing industry-ready graduates.

The deliverable also provides detailed information on the laboratory manuals and annexes created for each partner university. These include student and teacher manuals, safety instructions, laboratory maintenance procedures, and additional reading materials. The manuals are designed to facilitate the smooth operation of the laboratory classes and to ensure that the objectives of each exercise are met.
Significant attention is given to the safety measures and procedures for conducting laboratory exercises safely. This includes instructing students and academic staff to prevent accidents and ensure adequate supervision. The manuals detail the technical specifications and functionality of the equipment used in the laboratories and the maintenance procedures to ensure the longevity and efficiency of the laboratory infrastructures.

The eACCESS project has successfully prepared over 47 laboratory experiments across the five laboratories, totalling over 600 pages, effectively utilising the Erasmus+ CBHE funds. The deliverable, consisting of several manuals and annexes, lays a solid foundation for future extensions of the scope of teaching, research activities, and industry collaboration. The laboratory manuals acknowledge the contribution of the eACCESS project and the support of the Erasmus+ CBHE programme.

The project's success in developing the laboratories and effectively and safely using the developed infrastructures during the teaching duties represents an essential step in fostering EU-Asia collaboration in higher education and driving the transition towards cleaner and more resilient power systems.

2 INTRODUCTION

Physical laboratories are pivotal in power engineering, especially when teaching and researching renewable energy sources (RES) and green transformation.
Laboratories provide students with practical experience that complements theoretical knowledge. In power engineering, students can work directly with equipment, simulate scenarios, and troubleshoot real-world problems. This hands-on approach fosters a deeper understanding of concepts and prepares students for industry challenges.

Renewable energy technologies are dynamic and diverse. Laboratories allow students to experiment with RES components, such as solar panels, wind turbines, and energy storage systems. They can validate theoretical models, analyse performance data, and optimise system designs. This empirical approach bridges the gap between theory and application.
Laboratories serve as hubs for innovation and research. Students and faculty can collaborate on projects for green energy, grid integration, and sustainable power systems. They explore novel solutions, develop prototypes, and contribute to advancements in RES technology, which drives the transition toward cleaner energy sources.

Laboratories offer sophisticated simulation tools to model complex power systems. Students can simulate scenarios like grid stability during high-RES penetration, energy management strategies, and microgrid operation. These simulations enhance problem-solving skills and encourage critical thinking.
Power engineering intersects with various disciplines, including electrical engineering, environmental science, economics, and policy. Laboratories facilitate interdisciplinary learning by bringing together students from different backgrounds. Collaborative projects encourage holistic approaches to energy challenges.

Laboratories often collaborate with industry partners. Students gain exposure to industry practices, learn about cutting-edge technologies, and participate in joint research projects. Industry-sponsored labs provide valuable insights into market trends and foster industry-ready graduates.
In summary, laboratories serve as dynamic spaces where theory meets practice, fostering innovation, preparing future engineers, and driving the transition toward a greener, more resilient power system.
The eACCESS project has developed five laboratories at four partner universities. At KEC, Nepal, two laboratories, Industrial Automation and Power Electronics, have been designed and successfully implemented. Technical details of the new laboratory facilities at KEC are presented in deliverable D4.1, which deals with the laboratory design process, and in deliverable D4.2, which documents the process of the KEC laboratory building.

The Switchgear and Protection laboratory was designed, developed, and validated at RUB, Bhutan. Deliverables D4.1 and D4.3 include more information about the laboratory's technical specifications, equipment, and functionality.

The PV laboratory (renewable and dispersed electricity generation) was designed and implemented in the regular academic curriculum and used for professional courses run at ATM, Indonesia. Deliverables D4.1 and D4.5 provide more information about the technical specifications and functionalities of this new eACCESS laboratory infrastructure.

Finally, at SCU partner university, Indonesia, the Microgrid and Power Electronics laboratory has been designed, built, and validated in regular teaching and additional professional courses. Deliverables D4.1 and D4.4 provide more technical information about this laboratory facility.

The laboratories supported by the eACCESS project are primarily used for teaching practical skills at the core and elective course of the academic curriculum related to power engineering area, renewable energy, smart grids, and smart power systems.

This deliverable demonstrates the essential teaching activity held by project partners at the eACCESS laboratory facilities, describes laboratory maintenance procedures, and finally, outlines the safety measures and procedures established at the partner universities for the safe conduct of laboratory exercises by students and adequate supervision of exercises by academic and technical staff.

3 KEC - AUTOMATION AND POWER ELECTRONICS LABORATORY

3.1 Industrial Automation Laboratory

The KEC team, in collaboration with industrial partners and with EU partner universities, mainly TUL responsible for the implementation of Pillar Three of the eACCESS project, has prepared eleven laboratory exercises for the teaching of the primary and intermediate practical skills in the application of PLC controllers, which involve the design of the PLC-based automation systems and development of programming skills using ladder diagram programming method.
The initial set of laboratory exercises includes the following experiments:

1. **Study of Proximity Sensors**
2. **Operation of switch, relay, and contractor**
3. **Familiarisation with basic gate programming**
4. **Introduction to basic PLC wiring methods**
5. **Application of PLC controllers to induction motor start-delta start-up method**
6. **Application of PLC controllers to forward and reverse rotation control of induction motors.**
7. **Application of PLC controllers to standby dual pump control and monitoring**
8. **Application of PLC controllers to the monitoring and control of water reservoir and dam system**
9. **Application of PLC controllers to the control of the water level in water storage and irrigation systems**
10. **Application of PLC in elevator units**
11. **Application of PLC to control traffic lights.**

All the presented laboratory practical exercises are relevant and effective in teaching basic programming skills.

The student's instruction and teacher's manuals are provided for each laboratory exercise. They are included in **Annexe D4.6.1 KEC -1** (55 pp.) and **Annexe D4.6.1 KEC -2** (61 pp.). The instructions and manuals are of good quality and will help students, academics and technical staff smoothly run laboratory classes and achieve objectives established for each exercise. Each laboratory exercise plan involves a description of the equipment that will be used, instructions on how to operate devices, examples of ladder instructions that might be used for the exercise, and, optionally, tables for the measurement and other observations.

What needs to be stressed is that exercises 5 to 9 are of particular importance for the local energy sector and power plants in Nepal, which mainly use run-of-the-river electricity generation in small power plants, for farming and water supply systems critical for improving live and work conditions in remote, rural areas of Nepal. This is an excellent use of the eACCESS-supported laboratory facilities for developing local communities and the green transformation of the country's energy industry.

The necessary safety instructions have been prepared and included in the Student's and Teacher's Manual.

Now, laboratory classes focus on using digital inputs and outputs, as well as digital signal monitoring and visualisation. However, in the future, the developed laboratory infrastructure will allow full exploration of the PLC controller's capabilities, including analogue inputs and outputs, communication, and networking functionalities.

3.2 Power Electronics laboratory

Using the laboratory toolkits, the KEC academic staff, in collaboration with the TUL, has developed twelve laboratory exercises to familiarise students with the operation of the most popular power electronic circuits and devices.

This includes the following experiments:

1. **Study of SCR**
2. **Study of IGBT**
3. **Study of DIAC**
4. **Study of TRIAC**
5. **Study of SCR triggering using UJT**
6. **Single Phase Half wave-controlled rectifier with resistive load**
7. **Single Phase Full wave-controlled rectifier with resistive load**
8. **Single phase inverter**
9. **Series inverter**
10. **Step up chopper.**
11. **Step down chopper.**
12. **Single phase cycloconverter**

For each of these exercises, both student instructions (laboratory exercise plan) and teacher instructions (teacher's manual) have been prepared, and they are included in **Annexe D4.6.2 KEC—1** (50 pp.) and **Annexe D4.6.2 KEC—2** (56 pp.), respectively. These documents also address safety issues, with brief safety instructions given in the introduction.

The instructions and manuals are of good quality and will help students, academics, and technical staff smoothly run laboratory classes and achieve the objectives established for each exercise. Each laboratory exercise plan involves a description of the equipment used, instructions on how to set up the experiment, how to operate devices, tables for the measurement, and other observations that need to be recorded to draw the correct conclusions.

The presented laboratory exercise curriculum fully and efficiently explores laboratory facilities funded by the eACCESS project, and only minor improvement to the student's instructions is expected when the overall programme for this laboratory is maintained.

4 RUB - SWITCHGEAR AND PROTECTION LABORATORY

The SGPL (Switchgear and Protection Laboratory) is the country's first laboratory, as the laboratory equipment developed is aligned with the actual use of the digital relay units used in MV and HV substations and power plants.

The laboratory technical specification, which is presented with more details in deliverables **D4.1** and **D4.3**, includes five exercise stations:

1. **Generator protection relay**
2. **Bus bar protection**
3. **Power transformer differential protection**
4. **Transmission line protection relay**
5. **Feeder protection line**

These five stations are connected to Omicron 356 secondary test kit.

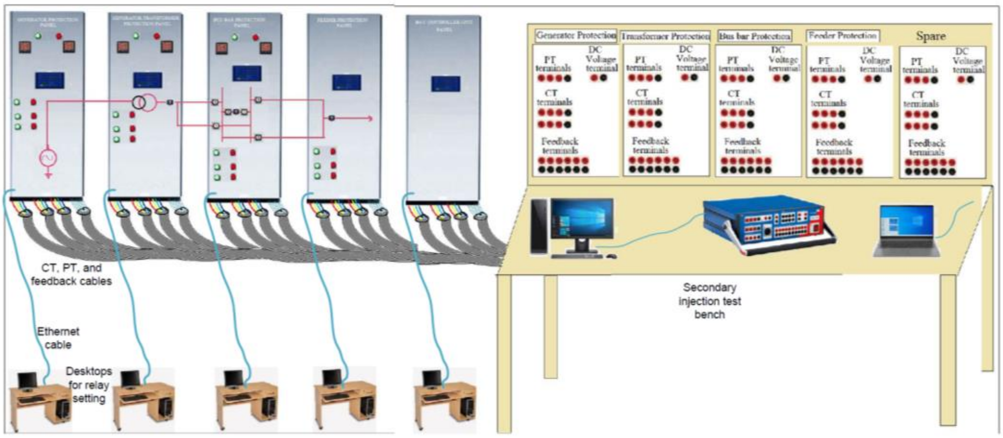

Figure 1 The configuration of the lab equipment.

With this hardware configuration, the RUB team prepared eight laboratory exercises:

1. **Study the construction of protection equipment.**
2. **Study of the configuration and performance of the over-current protection relay.**
3. **Study of the configuration and performance of the transformer differential protection relay.**
4. **Study the configuration and performance of the transformer differential protection relay.**
5. **Study the configuration and performance of the generator unit protection relay.**
6. **Study the configuration and performance of the transmission line protection relay.**
7. **Study the configuration and performance of the feeder protection relay.**
8. **Study the configuration and performance of the busbar protection relay.**

For all these laboratory exercises, student instructions have been prepared by the RUB team, and they are of good quality. The document includes a presentation of applicable standards concerning general and specific requirements for digital protection relays, technical and functional specifications of each of the relay units, followed by a detailed description of the wiring of the unit and OMICRON test kit, procedures to configure the testing software (Easergy).

The laboratory instructions are included in **Annexe D4.6.3 RUB -1** (59 pp.).

The quality of the laboratory instructions is acceptable. However, the safety instructions for Industrial Automation have not yet been developed. Moreover, the student's instructions do not clarify how to collect and analyse the results generated during the tests. What is more, the laboratory maintenance manual is not provided.

The Switchgear and Protection Laboratory will require further improvements, which should be done after the finalisation of the eACCESS project.

5 ATM - PHOTOVOLTAGE LABORATORY

The PV laboratory established by the eACCESS project at the Atma Jaya Universitas Katolik Indonesia (ATM) is oriented towards the basic training of engineers and technicians, both at the regular academic undergraduate courses and at the occasional professional courses, concerning installation, commissioning, monitoring, and maintenance of simple, single-phase PV installations equipped with small local battery storage.
The PV Lab Manual for Students was created so that the users can use the laboratory facility optimally and safely, as well as the Engineering Faculty (ATM), as the owner, will be able to operate it while carrying out the objectives of this laboratory, to conduct the research also to conduct the training for industries. The ATM academic staff compiled a detailed manual and listed the types of practical work used in this PV lab. Also, it is hoped that students/other users can use this lab optimally for operating and maintenance purposes.

The skilled professionals are pivotal in advancing sustainable energy solutions and driving positive change in Indonesia.

Properly maintained PV installations are essential for safety and efficiency. These require regular inspections, cleaning, and component replacements to enhance system performance. Safety protocols during installation to prevent accidents and fires need to be respected. Finally, efficient PV systems maximise energy output, benefiting users and investors.

Indonesia is a vast archipelago with remote and rural regions with limited access to electricity. Trained Engineers and Technicians design and install PV systems tailored to local needs, ensuring a reliable energy supply. The system requires maintenance expertise to ensure uninterrupted power, benefiting schools, healthcare centres, and households. Consequently, the engineers and technicians empowering these areas with electricity enhance education, healthcare, and economic opportunities.

Finally, the work of trained engineers and technicians also has an educational aspect. They engage with local communities in their daily work, explaining PV advantages. Education fosters acceptance, dispels myths, and encourages adoption. Informed communities actively participate in the energy transition.
Training programs for engineers and technicians invest in Indonesia's sustainable future. By empowering local communities, reducing energy poverty, and promoting renewable energy, these skilled professionals contribute significantly to Indonesia's energy transformation.

The technical details of the developed PV Laboratory have been provided in deliverable D4.1, dealing with the technical design of the laboratory, and in deliverable D4.5, describing the construction and commissioning of the facility, both available on the project website.

Taking into consideration the focus of the laboratory and the available equipment, the ATM academic team, in collaboration with their technical partner SUP, prepared ten student laboratory experiments:

1. **Understanding how to measure the actual output of the solar array.**
2. **Measuring the light intensity of solar radiation and ambient temperature.**
3. **Measuring the input and output of the solar charger controller**
4. **Measuring the input and output of solar inverter (on grid inverter).**
5. **Measuring the input and output of a battery**
6. **Measuring the input and output of a battery inverter (bi-directional Inverter)**
7. **Measuring The Characteristics of The On-Grid System**
8. **Measuring The Characteristics of The Off-Grid System**
9. **Troubleshooting on the off-grid and on-grid systems**
10. **Design and installation overview of an on-grid and an off-grid system.**

Annexe D4.6.4 ATM -1 (76 pp.) describes these experiments well, with defined objectives for each exercise, a brief theoretical introduction, the actions to set up the experiment (equipment and measurement devices that should be used), and the main experiment procedure steps.
Each of the laboratory experiments includes some hints for the academic staff overseeing the experiments (questions) for students to verify whether they have not only correctly completed the experiment procedure, taken necessary measurements, proposed and implemented necessary maintenance and repair actions but also checked whether students have reached the overall objectives of the exercises.

The PV Lab student manual also includes an introduction to the laboratory's technical configuration, a specification of the critical components, and laboratory maintenance instructions.
Unfortunately, the student manual does not fully address the safety rules and procedures for the PV Laboratory.

6 SCU - MICROGRID LABORATORY

Photovoltaic (PV) installations and microgrids provide energy access to remote communities and small islands in Indonesia. Despite the country's high electrification ratio, the unique characteristics of remote areas pose significant challenges to implementing microgrids. These challenges include unclear land status, lack of social engagement, and technical knowledge gaps, further exacerbated by environmental conditions like humidity, high temperatures, and uncontrolled vegetation.

Due to the lack of grid connections, PV installations are essential for electricity provision, particularly in Maluku and North Maluku. Various stakeholders, including the Indonesian utility company PLN and international programs, support the deployment of PV microgrids in these areas. These initiatives aim to address issues of reliability and sustainability with advanced technologies such as online monitoring systems, battery lifetime estimation, and improved PV inverters.

Moreover, Indonesia's potential for renewable energy is vast, with untapped solar PV and wind resources that could provide clean and reliable energy to island communities. Various government and international entities support efforts to transition these communities to renewable energy, aiming to overcome the distribution challenges and improve access to electricity and clean cooking technologies. PV installations and microgrids are vital for Indonesia's remote and island communities. They offer a solution to the electrification challenges and pave the way for a sustainable, energy-secure future. These technologies' continued support and development are essential for Indonesia to harness its renewable energy potential and meet its energy goals.

The eACCESS project has designed, developed, and commissioned a cutting-edge physical microgrid laboratory at the Faculty of Engineering, Soegijapranata Catholic University. This laboratory will help educate new engineers and technicians in regular academic, core, and elective courses like Applied Photovoltaics, Introduction to Electric Power Distribution, and Electric Power Systems.
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In collaboration with the local industrial partner SYNTEK, the academic staff at the SCU prepared a basic set of laboratory exercises that helped enhance the student’s knowledge of practical aspects of PV-based microgrids and energy systems. The initial list of laboratory exercises at the SCU laboratory include:

1. **Study of the grid-connected system without battery mode for $P_{PV} < P_{Load}$**
2. **Study of the grid-connected system without battery mode for $P_{PV} > P_{Load}$**
3. **Study of the grid-connected system with battery mode for $P_{PV} < P_{Load}$**
4. **Study of the grid-connected system with battery mode for $P_{PV} > P_{Load}$**
5. **Study of the system islanding mode for $P_{PV} < P_{Load}$**
6. **Study of the system islanding mode for $P_{PV} > P_{Load}$**

The above experiments are of very good quality. The student and teacher manuals have been delivered. They are presented in **Annexe D4.6.5 SCU—1** and **Annexe D4.6.5 SCU -2**. The laboratory manuals adequately address safety rules, procedures, and administrative and management aspects.

The SCU supplemented these manuals with additional reading material for students and teachers taking care of laboratory classes, including the course book written in Bahasa by Prof. Slamet Riyadi, “Integrasi PV dan Sistem Kelistrikan melalui Sumber Arus Terkendali”, which deals with the integration of PV installations and microgrid systems within utility distribution systems. This book is included in **Annexe D4.6.5 - 3** (172 pages). Unfortunately, this manuscript does not acknowledge the support of the eACCESS project and Erasmus+ CBHE funding.

Regarding maintenance instructions for the Microgrid Laboratory, three manuals are prepared in collaboration with the laboratory's equipment supplier, developer, and system integrator, SYNTEK. They are included in **Annexe D4.6.5 SCU - 4** (43 pages, a general presentation of the laboratory facility and individual microgrid components), in **Annexe D4.6.5 SCU -5** (27 pages, in Bahasa, describing operational procedures for regular use and the maintenance of the laboratory), and in **Annexe D4.6.5 SCU -5** (8 pages, in Bahasa, additional hints for technicians for troubleshooting).

7 FINAL REMARKS

In task T4.6, Preparation of the final technical documentation and teacher and student instructions for laboratories resulting in the deliverable D4.6 accompanied by 12 Annexes, the Asian partners, in collaboration with the TUL project coordinator and their local industrial partners, have prepared 47 laboratory experiments for five eACCESS laboratories. The laboratory exercises, well linked to several of the eACCESS modernised and developed course units (Power Electronics at KEC, Switchgear and Protection, Advanced Power System Protection at RUB, Renewable Energy, Introduction to Electric Power Distribution at ATM, Applied Photovoltaic, Electric Power System, Electric Power Supply at SCU), effectively use the new laboratory infrastructures supported by Erasmus+ CBHE funds and will have a significant positive impact on the quality of teaching, the level of practical skills of graduates of the four Asian partner universities. This is an excellent result for the beginning of the exploitation of the new laboratories and a perfect starting point for the future extension of the scope of teaching practical skills, possible use of the laboratories by the academic staff and students in their research activities, including implementation of the final projects, collaboration with industry.

These basic 47 laboratory experiments are well described in the prepared student’s laboratory manuals (5 manuals, total of 279 pp.)

Two project partners, KEC and SCU, have developed separate teacher’s laboratory manuals (3 manuals totalling 135pp.).

All partners, except for RUB, have fully (KEC and SCU) or partially (ATM) addressed security issues with dedicated sections or annexes. Similarly, three partner universities, KEC, ATM and SCU, adequately addressed laboratory maintenance procedures developed in close collaboration with their local industrial partners, laboratory infrastructure developers or equipment suppliers. In this context, particular words of appreciation are due to colleagues from SCU, who prepared a very comprehensive laboratory manual with (3 annexes, a total of 78pp.).

All the manuals and annexes (except for the SCU PV course book for additional reading) acknowledge the eACCESS project's contribution and the support of the Erasmus+ CBHE programme.
As the bottom line, twelve good, very good, or excellent-quality laboratory manuals and additional reading materials (more than 600 pp.) have been prepared by project partners in this deliverable, which makes an excellent starting point for the efficient and safe exploitation of the eACCESS developed laboratory infrastructures as the part of the regular academic courses at the Asian partner universities.

8 LIST OF ANNEXES

Annexe D4.6.1 KEC-1 - The student's laboratory manual for Industrial Automation (eACCESS-APEL) at KEC.
Annexe D4.6.1 KEC-2 - The teacher's laboratory manual for Industrial Automation (eACCESS-APEL) at KEC.
Annexe D4.6.2 KEC-1 - The student's laboratory manual for Power Electronics Laboratory (eACCESS-APEL) at KEC.
Annexe D4.6.2 KEC-2 - The teacher's laboratory manual for Power Electronics Laboratory (eACCESS-APEL) at KEC.
Annexe D4.6.3 RUB-1 - The student's laboratory manual for the Switchgear and Protection Laboratory (eACCESS-SGPL) at RUB.
Annexe D4.6.4 ATM-1 - The student's laboratory manual for Photovoltage Laboratory (eACCESS-PVL) at ATM.
Annexe D4.6.5 SCU-1 - The student's laboratory manual for Microgrid Laboratory (eACCESS-MGL) at SCU.
Annexe D4.6.5 SCU-2 - The teacher's laboratory manual for Microgrid Laboratory (eACCESS-MGL) at SCU.
Annexe D4.6.5 SCU-3 - The additional reading material (course book) for Microgrid Laboratory (eACCESS-MGL) at SCU.
Annexe D4.6.5 SCU-4 - The laboratory maintenance manual for Microgrid Laboratory (eACCESS-MGL) at SCU, part I.
Annexe D4.6.5 SCU-5 - The laboratory maintenance manual for Microgrid Laboratory (eACCESS-MGL) at SCU, part II.
Annexe D4.6.5 SCU-6 - The laboratory maintenance manual for Microgrid Laboratory (eACCESS-MGL) at SCU, part III.