MAKERERE UNIVERSITY

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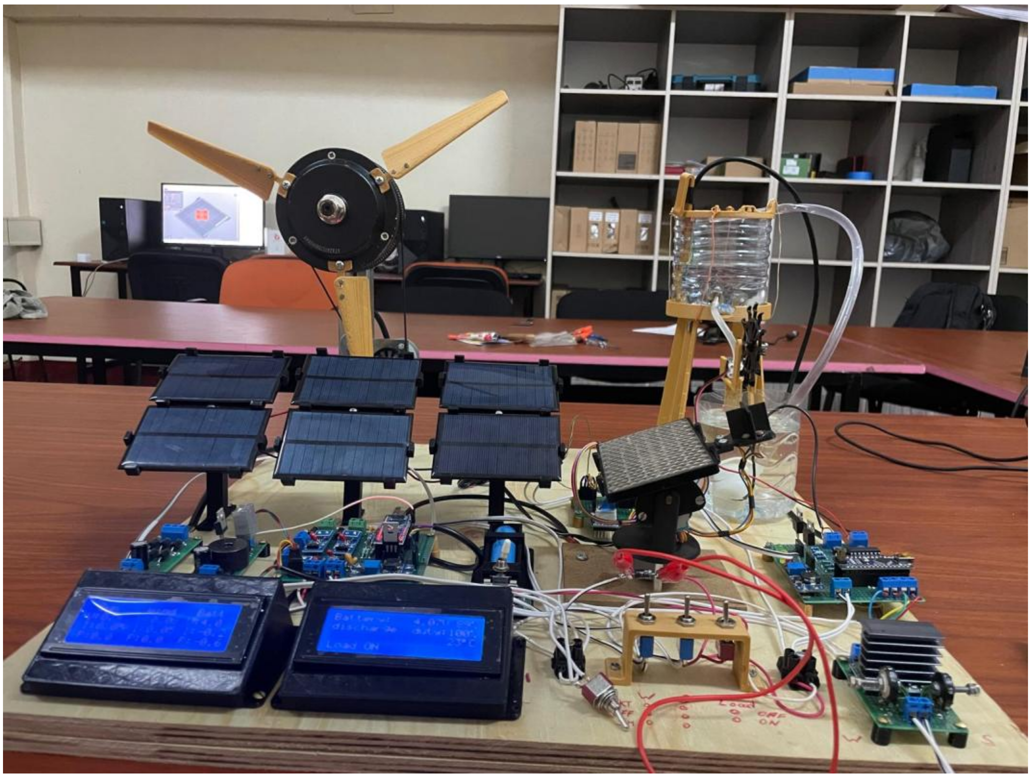
BOKU

PROMOTION OF HYBRID RENEWABLE ENERGY SYSTEMS TOWARDS ELECTRICITY ACCESS IN UGANDA (PHRE)

TRAINING REPORT

PART 3: MAKER MOVEMENT INSPIRED PRACTICAL COURSE: HYBRID ENERGY MODEL



February 2026

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List of Acronyms

CAD	Computer-Aided Design
CC	Constant Current
CV	Constant Voltage
DC	Direct Current
DS18B20	Digital Temperature Sensor
I^2C	Inter-Integrated Circuit
LED	Light Emitting Diode
Li-Ion	Lithium-Ion Battery
MPPT	Maximum Power Point Tracking
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistor
PHRE	Promotion of Hybrid Renewable Energy Systems Towards Electricity Access in Uganda
PV	Photovoltaic
PWM	Pulse Width Modulation
ToT	Training of Trainers

INTRODUCTION

The workshop formed part of the 3rd round of the maker-inspired training series. It emphasized hands-on development of a hybrid energy model integrating solar PV, wind, battery storage, and intelligent control systems. The previous Maker Movement Inspired Practical Course (February 2025) focused on building foundational competencies required for hybrid renewable energy systems, particularly in power electronics and battery management. Participants progressively developed skills in MOSFET-based current switching, voltage and current measurement using sensors and microcontrollers, PWM control techniques, OLED data display integration, and ultimately the design and prototyping of a basic battery charge controller. The most critical output of that training was the functional battery charge controller prototype, which integrated switching, sensing, and control logic. The most recent training built directly upon these outputs by scaling and integrating them into a complete hybrid energy model. Specifically, the charge controller concepts, measurement systems, and control logic developed in the earlier workshop were refined, embedded into a broader hybrid controller architecture, and combined with solar PV inputs, wind components, battery storage, CAD-designed structures, and 3D-printed mechanical parts. Thus, the latest training did not start from scratch but consolidated and expanded the previous practical tasks into a fully assembled and operational hybrid renewable energy model.

Training Objectives

- Review and consolidate knowledge from previous rounds.
- Focus specifically on Hybrid Energy Systems.
- Introduce 3D modelling and 3D printing.
- Plan and create a complete hybrid energy model.
- Apply electrical circuits and programming in a system-level setup.
- Participate in Science Week conference and present the developed model.

Participants

The training was structured as a ToT, and participant composition reflected both continuity and expansion. A significant proportion of attendees were returning participants from the previous cohorts, which strengthened cumulative learning and enabled the training to move from foundational skills to system-level integration. At the same time, the inclusion of new participants broadened the knowledge base and created peer-learning dynamics. The participants were mainly students and instructors from Makerere University

Gender participation showed clear improvement compared to previous rounds. Increased female representation not only enhanced diversity in technical discussions and group work but also strengthened the ToT objective of building a more gender-balanced pool of future trainers and practitioners in hybrid renewable energy systems.

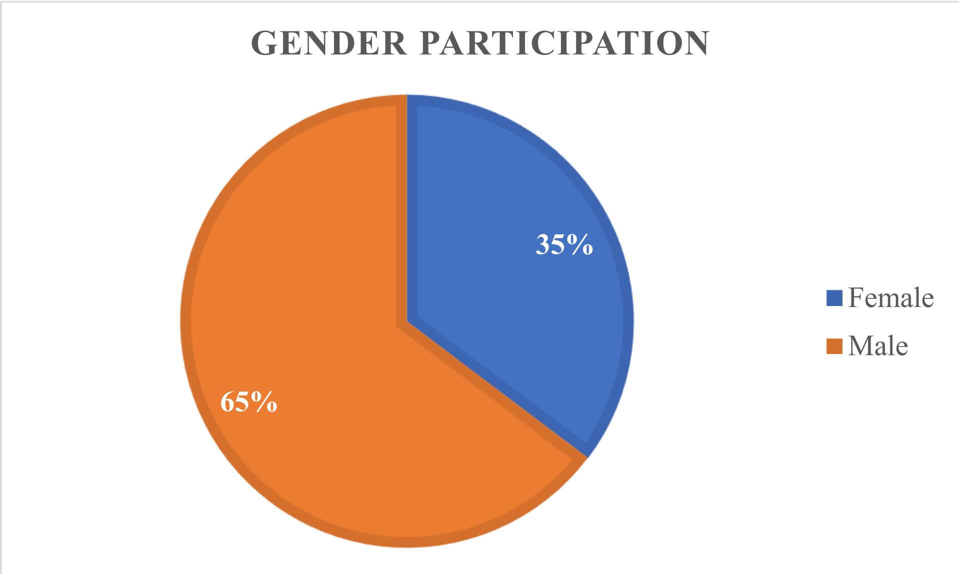

Figure 1: Female Vs Male participation

Training Activities

The training lasted for five days, and it commenced with a review of competencies previously acquired, including digital and analog inputs/outputs, voltage and current measurement, current switching, PWM and buck converter principles, battery charging algorithms, MPPT implementation, solar tracking, and sensor integration.

Work was structured through both group work approach with each team handling a unique task. Dedicated groups focused on developing the solar tracker, battery charger, water level sensor, and pump controller. In parallel, the entire team collaborated on constructing the wooden base model, assembling the wind turbine and rectifier, building water storage structures, fabricating component housings using 3D printing, installing loads (lamps), and completing full system wiring and integration.

Group work: Hands-on Activities

Task 1: Water Level Sensor / Pump and Valve control

Under this task, the groups focused on designing and implementing a pump and valve control system that could automatically regulate the water level in a container. The system was developed using an **Arduino Nano** as the main controller, together with supporting electronic components including two push buttons, LEDs, a pump, a valve, a water level sensor, a **ULN2003 Darlington transistor array**, **IRLZ44 N-channel MOSFETs**, resistors, and a breadboard with connecting wires.

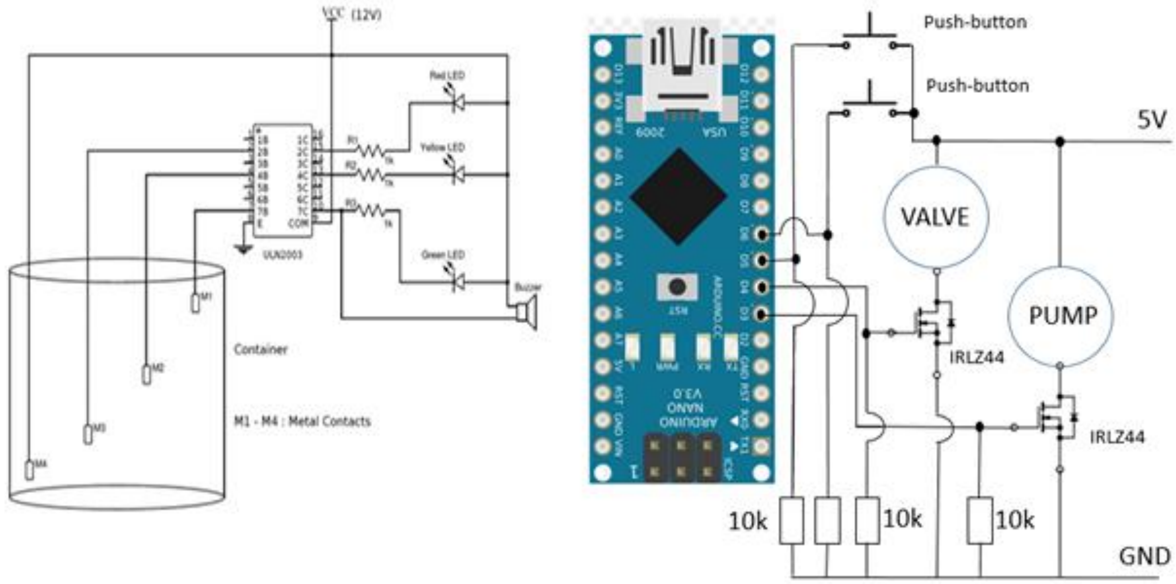

Figure 2: Reference water level sensor and pump control circuit

- The first stage of the task involved integrating the water level sensor, based on the principles established in the previous training. The level sensor signals were routed through the ULN2003 Darlington transistor array, which acted as an interface between the sensor and the Arduino. The ULN2003 allowed the sensor signals to be conditioned and safely processed by the Arduino's digital input pins. This configuration enabled the microcontroller to continuously monitor the water level status in the container and determine whether the tank was full or empty.
- Next, push-button controls were implemented following the digital input reading approach introduced previously. One push button was programmed to start the pump, initiating the fill process. The Arduino continuously monitored the signal from the water level sensor, and once the sensor indicated that the container had reached the full level, the controller

automatically stopped the pump to prevent overflow. The second push button was configured to open the valve, allowing water to be released from the container. Similarly, when the water level sensor detected that the container was empty, the Arduino automatically closed the valve to prevent unnecessary discharge.

- To control the pump and valve loads, the system utilized IRLZ44 N-channel MOSFETs, applying the switching method. Each load (the pump and the valve) was connected to its own MOSFET. The MOSFETs acted as electronic switches controlled by the Arduino's digital output pins, enabling the microcontroller to turn the pump and valve on or off as required.

Task 2: Charge controller for one Li-Ion Battery

This task involved the design and implementation of a custom DC–DC buck converter and battery charging system that could combine energy from both solar panels and a wind turbine while monitoring electrical parameters and protecting the battery. The system was controlled using an Arduino microcontroller and integrated several sensing, power electronics, and protection mechanisms.

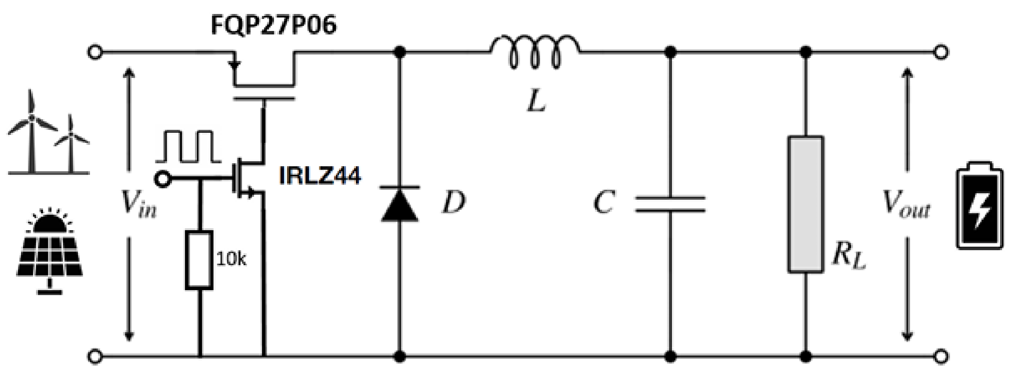

Figure 3: Reference circuit for a charge controller

- The first step was constructing the buck converter circuit, with a custom-built solution. Because the system operated at relatively low voltages and currents, a P-channel MOSFET (FQP27P06) was used for high-side switching in the converter. To properly drive the gate of this P-channel MOSFET, an IRLZ44 N-channel MOSFET was used as the gate driver. This configuration allowed the Arduino to control the switching process efficiently and regulate the converter's output voltage.

- The system incorporated two power sources; the output from the solar panels and the rectified output from the wind turbine. To prevent reverse current flow between the two sources, Schottky diodes were installed on each input line. These diodes ensured that energy from one source could not flow back into the other source, thereby protecting the components and maintaining stable operation.
- To monitor system performance, several electrical measurements were implemented. Three voltage dividers, were used to measure the rectified wind turbine voltage, the solar panel voltage, and the output voltage of the buck converter. The resistor values were selected such that voltages up to 20V could be safely measured by the Arduino's analog inputs. In addition, three ACS712 current sensors were installed to measure the solar input current, wind input current, and the output current of the converter. These sensors allowed the system to track energy flow through the converter in real time.
- An Arduino script was then written to continuously read all voltage and current values from the sensors. The measured data was displayed using i2c-displays, to allow participants to visualize the system's electrical parameters in real time, including input voltages, output voltage, and current levels.
- For energy storage, the system used a single Li-Ion battery cell (Samsung INR18650-29E). Based on the battery's specifications, a charging algorithm was incorporated into the Arduino program to ensure proper battery charging using the constant-current/constant-voltage (CC–CV) method. This algorithm regulated the charging process to maintain safe voltage and current limits according to the battery manufacturer's specifications.

Teamwork: Building the Hybrid-Energy-Model on the wooden board

After completing the individual subsystem tasks, the participant groups combined their work to construct a complete hybrid energy model. This model integrated several components of renewable energy generation, storage, and control into a single demonstrative system. The hybrid energy model consisted of solar panels with a solar tracker, a wind turbine, rectifiers, battery storage, battery chargers, water reservoirs, a hydro power generator, a water pump, and electrical loads representing both consumer loads and dump loads. The objective was to demonstrate how multiple renewable energy sources can be integrated into a hybrid system capable of generating, storing, and utilizing energy while managing excess power.

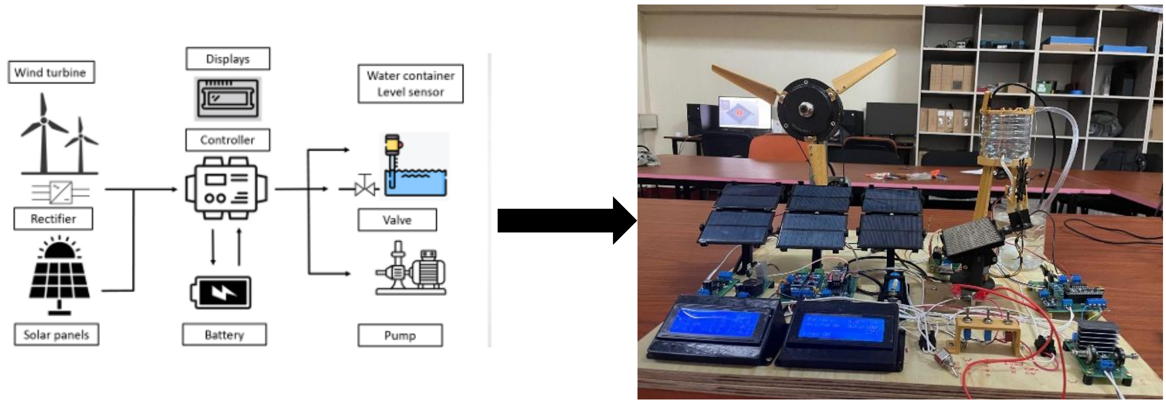

Figure 4: The Hybrid Energy System Model

CAD Modelling and 3D Printing

The first stage of the process involved the mechanical design and fabrication of structural components. Several physical parts required for the model such as component housings, support structures, and mounting elements, were modelled using computer-aided design (CAD) software and then produced using a 3D desktop printer. This enabled participants to create customized components that securely held electrical devices and demonstrated the physical layout of a hybrid renewable energy system.

The mechanical components of the hybrid energy model were designed using two 3D CAD software, Autodesk Inventor Professional and Solid Works which were installed on two desktops.

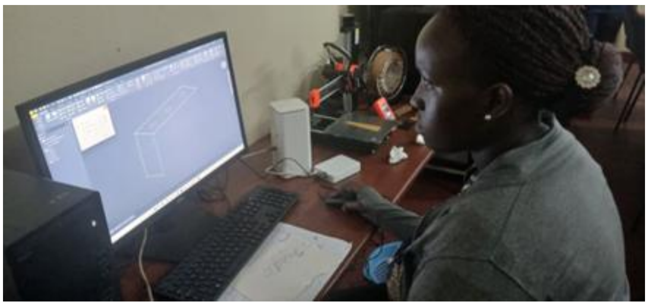

Figure 5: A female student modelling one of the mechanical components using Autodesk Inventor software

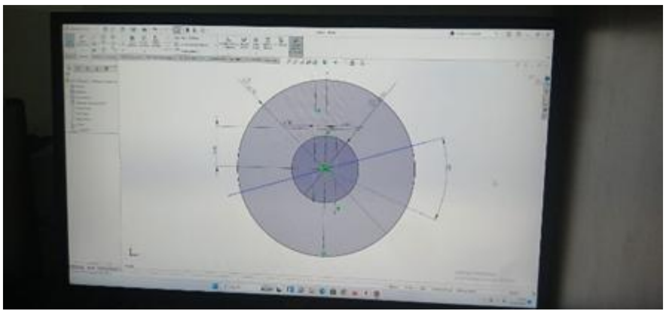

Figure 6: The base of the water tank, which was modelled using SolidWorks

Following the fabrication of the mechanical parts, participants began the assembly of the electrical subsystems. Some components, such as the solar tracker, had already been prototyped earlier during the training on breadboards, where the control logic and electronic circuits had been tested. For the hybrid energy model, these previously tested circuits were refined, permanently assembled, and integrated into the physical model structure. The solar tracker mechanism was then mounted alongside the miniature solar panels so that the panels could simulate tracking the sun for improved energy capture.

Next, the wind energy subsystem was integrated. A small wind turbine was connected to a rectifier circuit to convert the alternating current produced by the turbine into direct current suitable for battery charging. Both the solar and wind subsystems were connected to the battery charging circuits developed earlier in the training.

Figure 7: The instructors are engaging with the trainees during the training session

Figure 8: The 3D Desktop printer

Figure 9: A team soldering the circuit board for the solar tracker

Figure 10: Groups working on their unique tasks

A VISIT TO BUNJAKO ISLAND BY BOKU UNIVERSITY

As part of the training activities, the BOKU instructors conducted a field visit to Bunjako Island to observe operational mini-grids developed and implemented by Winch Energy. These mini-grids provide electricity to the island community for both household consumption and productive use of energy, including small businesses and income-generating activities.

The purpose of the visit was to gain practical insights into the technical, operational, and economic realities of deploying and sustaining mini-grid systems in remote communities. During the visit, the team examined system configuration, generation capacity, storage integration, distribution layout, and customer connections. Particular attention was given to understanding the business model and the factors that contribute to financial viability. A key lesson from the visit was that technical design alone does not guarantee sustainability. One of the most critical aspects of mini-grid success is long-term community sensitization and engagement. The team learned that building demand, encouraging productive use of electricity, and fostering community trust require sustained awareness campaigns over an extended period. Sensitization ensures that households and businesses understand the value of electricity, adopt energy-efficient appliances, and use power in ways that improve incomes and livelihoods. This demand stimulation is essential for revenue generation and long-term financial sustainability of mini-grid projects.

Figure 11: The8KWp Mini grid by Winch Energy on Bunjako Island

Figure 12: Inside The Power House with the Mini grid operator

Meeting with PhD students

During the Science Week, the two PhD candidates, Aida Namagambe and Sunday Asasio, presented their research progress and future plans to the project team. Sunday's study, titled "Assessment of Renewable Energy Resource Potential for Hybrid Electrification: A Case Study of Kasenyi Fish Landing Site, Kasese District, Uganda", focuses on quantifying solar, wind, and biomass resources and identifying suitable sites for hybrid system deployment. Aidaa's research, "Renewable Energy Resource Potential for a Sustainable Hybrid Energy System: A Case Study of the Bidibidi Refugee Settlement, Uganda", maps renewable resources and evaluates biomass–solar integration potential. Both highlighted completed resource assessments and spatial analyses, ongoing system optimization work, and next steps involving technology selection and economic feasibility.

Figure 13: The project team members meeting with the PhD students

CONCLUSION AND RECOMMENDATIONS

The training demonstrated the effectiveness of the maker movement approach in building practical, system-level competencies. The hands-on integration of electrical circuits, embedded programming, CAD design, and 3D printing reinforced both technical depth and collaborative problem-solving skills. To further enhance the program's impact and contribute meaningfully to building local expertise in hybrid renewable energy systems, the following improvements ought to be considered;

1. **Extend System Testing:** Future trainings should allocate more time, for example, six months for performance testing, fault simulation, and system optimization under varying load and generation conditions.
2. **Integrate Data Logging & Analytics:** Incorporate structured data acquisition and analysis to enhance understanding of system efficiency, battery health, and MPPT performance.
3. **Strengthen Industry Linkages:** Engage mini-grid developers and renewable energy companies to align prototype work with field realities and market needs.
4. **Sustain the ToT Model:** Continue mentoring returning participants to become co-facilitators in subsequent cohorts, strengthening long-term institutional capacity.

Appendix I: Pictures from Science Week Conference

Figure 14: A detour of the Makerspace

Figure 15: Opening speech by Prof. Barnabas Nawangwe - Vice-Chancellor of Makerere University

Figure 16: A photo moment after the opening ceremony

Figure 17: Makerere Staff members and project team

Figure 18: Award of certificates to the trainees from the Makerspace training

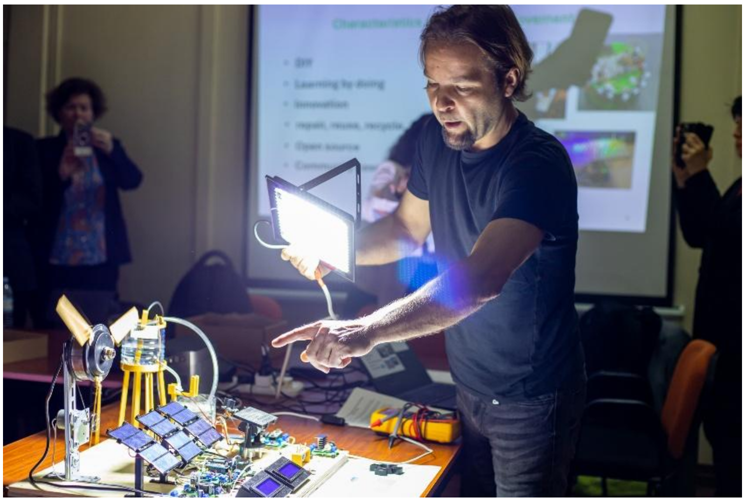

Figure 19: A demonstration of how the model works