Blockchain-based Peer-to-Peer Energy Markets to Incentivize Renewables and EVs

– A short course jointly organized by the School of Electrical and Electronic Engineering, NTU, FAU, Germany, iba-AG, Germany, and IEEE Singapore Section –

❖ Why Renewables and Electric Vehicles (EVs)?

- ✓ Modern power systems are undergoing a transition from conventional to renewable generation, which is considered an effective way to resolve the global energy crisis and reduce carbon emissions.
- ✓ Increasing penetration of renewable energy sources (RESs) in Singapore and Germany and elsewhere in the world requires owners of small/big renewable energy installations to have an opportunity to sell their electrical energy via a low-cost platform.
- ✓ Electricity at an affordable rate promotes EV deployment leading to a sustainable transportation system.

❖ Why Peer-to-Peer Energy Markets?

- ✓ A decentralized market platform allows all members of an electrical network to enter directly into the market and exchange energy with other prosumers without oversight from a centralized authority.
- ✓ The local trading of energy generated by distributed RESs between consumers, storage, and EVs maximize the exploitation of RES capacities and minimize the energy exchange with adjacent grids.

❖ Why Blockchain?

- ✓ A digital ledger technology that facilitates tracked, verifiable, and secure transactions between prosumers participated in peer-to-peer (P2P) energy trading.
- ✓ Blockchain enables self-executed energy market mechanisms and provides stronger guarantees against data mutation.

Learning Outcomes

In this short course, the attendees will learn about the following aspects.

- ✓ Energy system context of Singapore and Germany and their potential to adopt P2P energy trading.
- ✓ Blockchain fundamentals and designing a decentralized energy market framework.
- ✓ Algorithms and models to establish an ecosystem and business model for efficient participation in blockchain-based energy markets.
- ✓ Optimization and learning-based approaches for grid feasible energy trading.

An electronic Certificate of Attendance will be issued for participants upon request.

Visit NTU and FAU project websites for more information.

Course Outline

Following is a brief introduction to the topics that the short course is intended to cover.

1. P2P energy trading: Background and motivation

Singapore and Germany's energy systems differ significantly. While Singapore, as a city-state, has very few renewables and decentralized energy sources, they account for 40% of Germany's annual electricity demand. However, this energy is mainly transmitted through a large, old, and complex grid, which is difficult and costly to adapt. Singapore on the other hand boasts a relatively small grid and is very fast at adapting novel technologies. In this context, P2P energy trading provides a potential solution to maximize the utility of RESs while reducing the strain on the grid and offering new incentives to build RESs.

2. Blockchain applications in energy systems

Blockchain technology supports energy trading by storing the information of transactions in blocks, verifying the validity of transactions by all the nodes in the network, and ensuring the security and privacy of transactions by encrypting them. The design of assembled transactions and short-term balancing contracts based on smart contracts are necessary for energy trading via blockchain. The smart contract function is the most significant part of the implementation of blockchain in P2P energy trading. The pricing algorithm is written in smart contracts via Solidity language.

3. Blockchain ecosystem and business model for P2P energy trading

We suggest a blockchain-based local trading platform similar to the European and Singaporean energy exchanges. The market uses a double-auction market, which offers game-theoretically proven incentives to the participants. The market is realized as a Solidity Smart Contract and runs independently on the blockchain. The trading process is fully automated with a range of intelligent agents, including machine learning algorithms.

4. Optimal prosumer dispatch enabling grid-feasible P2P energy trading

The objective of power system operation and control is to ensure the operational feasibility of the network. Typical operational feasibility requires that when the energy transaction is executed, the system remains stable. The bus voltages and line currents lie within predefined acceptable ranges. As blockchain technology does not require third parties to validate the transactions before execution, P2P energy trading may introduce power injections which eventually lead to feasibility violations. Here, we introduce self-validation mechanisms for grid constraint satisfaction which omits the solving of non-linear power flow equations.

5. Voltage and frequency control

The intermittency and variability posed by distributed resources such as renewable energy sources, and flexible loads bring control issues in microgrid operation. This necessitates robust voltage and frequency control for the smooth operation of the system.

Voltage control: Voltage management is achieved through optimal coordination and dispatching of set points to legacy voltage control devices such as capacitor banks, online tap changers, and line voltage regulators. However, slow actions and limited life cycles restrict the frequent operation of these devices. Nowadays, fast-acting devices such as inverter-based resources are getting attention because of their capability to perform voltage management functionality.
Frequency control: To regulate the frequency deviation produced by the power mismatch among generation and load demand, decentralized control is adopted. The conventional centralized control requires complex communication networks which reduce the system reliability, whereas, in decentralized control schemes, there is no communication among individual controllers.

6. Hardware-In-the-Loop (HIL) implementation for P2P energy trading

The HIL implementation is the standard procedure for developing and testing the most complex systems ahead of experimental validation. The P2P energy market involves the trading of energy generated by various prosumers from intermittent RESs. To emulate this scenario, a few prosumer models are developed using MATLAB/Simulink and energy trading is facilitated through HIL implementation using OPAL-RT/RT-Lab. The HIL implementation involves a collection of data from ibaLogic, communication through Raspberry Pi devices, and energy trading through a physical layer developed in OPAL-RT/RT-Lab simulation.

Hardware and Software Demonstration

The demonstration and the hardware validation of the developed blockchain-based P2P energy trading framework have been achieved through a three-phase, 400 V, 50 Hz microgrid system and via the real-time control HIL simulations in the OPAL-RT/RT-Lab simulator at Clean Energy Research Laboratory (CERL S2-B7c-05) of NTU. A network of Raspberry Pi devices is developed and interfaced with the above physical systems to emulate the P2P energy transactions. Communication between Raspberry Pi devices and the other physical assets is established using TCP/IP.

1. OPAL-RT Simulator

A part of the distribution feeder in the German distribution grid which includes 25 prosumers (one combined heat and power plant and 24 households) is modeled in the RT-Lab software module. Each household prosumer model features an electric vehicle, battery energy storage, a solar PV, and a flexible load. One of the three types of price prediction agents is modeled, and a local optimal dispatch algorithm is executed in each Raspberry Pi which automatically submits bids/asks representing each prosumer in the decentralized marketplace. Participants will have an opportunity to observe the communication between ibaLogic and Raspberry Pi devices, the status of the energy and price bids/asks, the trade history of the marketplace, and the real-time execution of the energy transactions in the OPAL-RT simulator display interface.

2. Microgrid System

The microgrid system mainly comprises a 13.5 kVA synchronous generator, 18 kVA programmable source, 13.5 kW programmable load, 55 kVA tap-changing transformers, OPAL-RT system with power amplifiers, 5 kWp solar PV system, 13.5 kW wind emulator system, 10 kWh energy storage system, 10 kW simulated industrial load, 6 kvar capacitor bank, and smart meters. Participants will be allowed to submit the bids/asks to the blockchain-based P2P energy marketplace and realize the acceptance of the cleared energy transactions physically taking place between the assets, such as the synchronous generator, energy storage system, and programmable load in the microgrid system. The layout of the designed blockchain-based P2P energy marketplace in the CERL microgrid system is depicted in Figure 1 below.

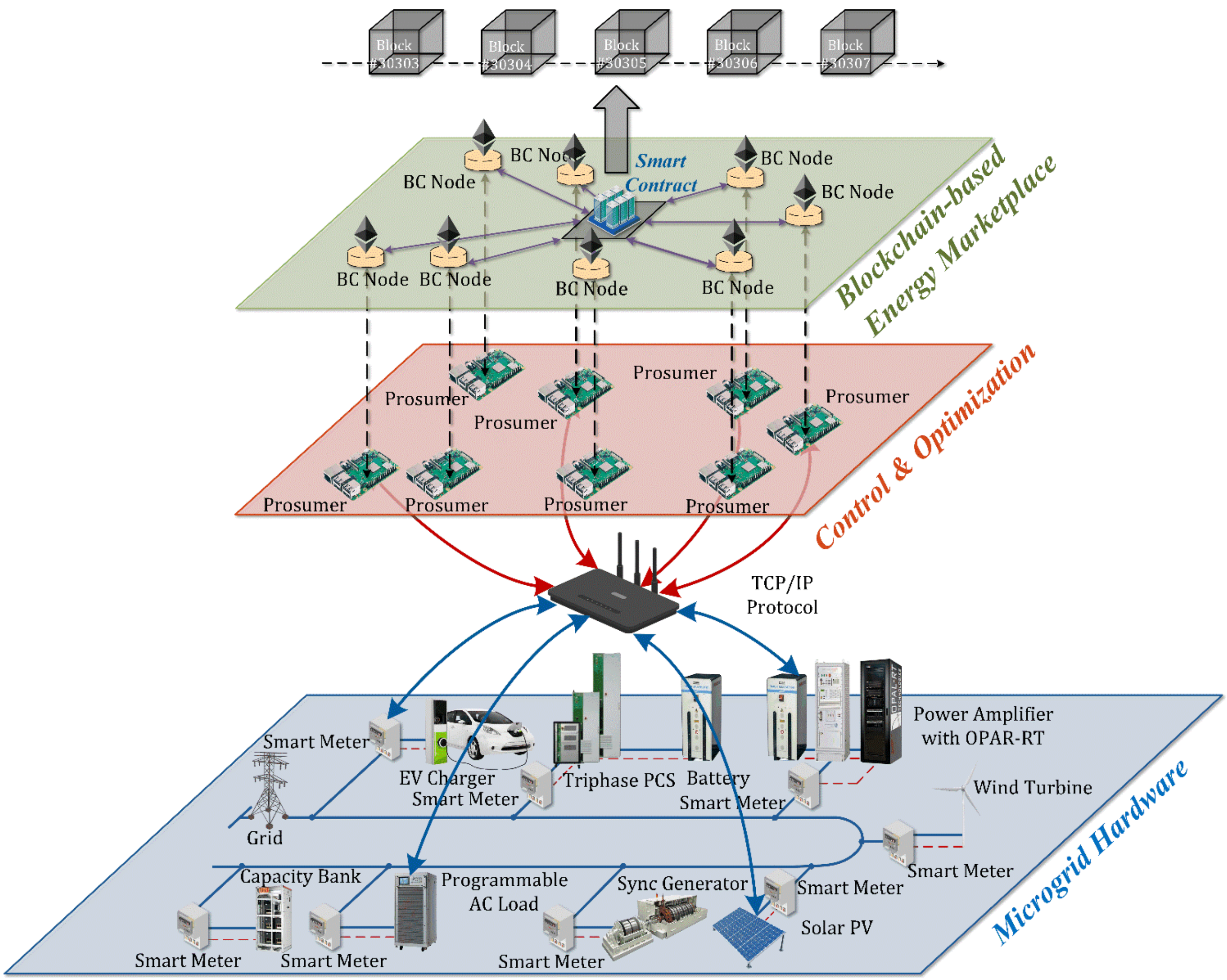

Figure 1: The layout of the Blockchain-based P2P energy marketplace.

Course Schedule

Time	Activities
8:30-9:00	Registration **(Executive Seminar Room S2.2-B2-53)**
9:00-10:15	Lectures delivered by Prof Hoay Beng Gooi and Mr. Felix Funk. Topic: **P2P energy trading: background and motivation.** 1. Energy systems – grid and market. 2. Ancillary services and grid management. 3. Potential for P2P Energy Trading.
10:15-10:45	Tea break **(Staff Lounge, S2.2-B4-06)**
10:45-11:45	Lectures delivered by Mr. Jiawei Yang. Topic: **Blockchain applications in energy systems.** 1. Blockchain fundamentals: Consensus protocol types, security, and privacy. 2. Smart contract design for P2P energy trading.
11:45-12:45	Lunch **(Staff Lounge, S2.2-B4-06)**
12:45-13:30	Lectures delivered by Mr. Felix Funk Topic: **Blockchain ecosystem and business model for P2P energy trading.** 1. System overview: market design and incentives. 2. Automated agent designs and comparisons. 3. Blockchain integration and evaluation.
13:30-14:15	Lectures delivered by Prof Hung D. Nguyen and Dr. L. P. M. I. Sampath. Topic: **Network feasible P2P energy trading: Self-validation and optimal dispatch.** 1. Self-validation of grid constraints. 2. Grid-constrained P2P energy market design. 3. Decentralized market clearing mechanisms.
14:15-15:00	Lectures delivered by Dr. Shailendra Singh, and Dr. V. Veerapandiyan. Topic: **Voltage and frequency control.** 1. Optimal power flow considering Volt/Var optimization devices. 2. Droop-based real-time voltage control. 3. Decentralized frequency control using recurrent neural network. 4. Blockchain-based primary and secondary frequency control.
15:00-15:30	Tea Break **(Executive Seminar Room S2.2-B2-53)**
15:30-16:00	Lectures delivered by Dr. Eddy. Y. S. Foo and Dr. Shadab Murshid. Topic: **HIL implementation for P2P energy trading.** 1. Introduction to HIL implementation. 2. Prosumer modeling and control for P2P energy trading.
16:00-18:00	Hardware Demonstration: **Clean Energy Research Laboratory (CERL S2-B7c-05)**.

The details of the finalized course schedule will be available from the Short Course sub-menu on the NTU project website a couple of weeks before the scheduled course date.

Instructors

Hoay Beng Gooi received the Ph.D. degree from Ohio State University, Columbus, OH in 1983. He worked as Assistant Professor at Lafayette College, Easton, PA during 1983-85, and Senior Engineer at Control Data – Energy Management System Division, Plymouth, MN for about six years before joining Nanyang Technological University (NTU), Singapore in 1991. He is an Associate Professor with the School of Electrical and Electronic Engineering. He has served as Co-Director of SP Group-NTU Joint Lab since 2020 and Chairman, LMAG, IEEE Singapore since 2021. In July 2021, he won the Outstanding Associate Editor Award IEEE Transactions on Power Systems. His current research interests include microgrid energy management systems dealing with energy storage, condition monitoring, electricity market, and spinning reserve.

Hung Dinh Nguyen received the Ph.D. degree in electric power engineering from the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA, in 2017. He is a 2017 Siebel Scholar in energy science. Currently, he is an Assistant Professor in Electrical and Electronic Engineering at Nanyang Technological University, Singapore. His research interests include power system operation and control with machine learning, the nonlinearity, dynamics, and stability of large-scale power systems; dynamic security assessment (DSA)/energy management system (EMS), and smart grids.

Eddy Y. S. Foo received the B.Eng. and Ph.D. degrees in electrical and electronic engineering from Nanyang Technological University, Singapore, in 2009 and 2016, respectively. From 2014 to 2016, he was a Research Engineer with the Cambridge Centre for Advanced Research and Education in Singapore Ltd., an entity under the National Research Foundation's Campus for Research Excellence and Technological Enterprise Program. Since 2016, he has been a Lecturer with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. His research interests include multiagent systems, microgrid energy management systems, electricity markets, and renewable energy resources.

Felix Funk is a Researcher and PhD student for the Institute of Factory Automation and Production Systems at University of Erlangen-Nuremberg, Germany. His research focuses on novel business models and concepts for the German energy and mobility sectors as well as Blockchain technology, having developed smart contract applications since 2019. Prior to his PhD study, Mr. Funk has worked at Siemens Energy and various Smart Metering firms.

L. P. Mohasha Isuru Sampath received the Hons. Degree of B.Sc. Eng. in Electrical Engineering from the University of Moratuwa, Sri Lanka, in 2014. He was working as an electrical engineer in Sri Lanka Ports Authority in 2015. He received the Ph.D. degree from Interdisciplinary Graduate School, Nanyang Technological University (NTU), Singapore, in 2020. Currently, he is a Research Fellow and the Team Leader in the Blockchain-based Decentralized Peer-to-Peer Energy Trading project at the Centre for System Intelligence and Efficiency, NTU, Singapore. His research interests include convex optimization, distributed energy trading, modeling and optimization under renewable energy-based uncertainties, and optimal power flow.

Shadab Murshid is a Research Fellow at the Centre for System Intelligence and Efficiency, Nanyang Technological University, Singapore. He received his B. E (Electrical) from AMU, Aligarh, India, in 2013. He joined Electrical Engineering Department, IIT Delhi, India, for M.Tech in 2013. He received his doctoral degree in Electrical Engineering from IIT Delhi in 2020. His research interests mainly focus on power electronics, electric drives, microgrids, power quality, and PV water pumping systems.

Veerapandiyan Veerasamy received the B.E. degree in Electrical and Electronic Engineering from Anna University, India in 2013. He received his Ph.D. degree from University Putra Malaysia, Malaysia in 2022. He is currently working as a Research Fellow at the Centre for System Intelligence and Efficiency, NTU, Singapore. His research interests include robust controllers, recurrent neural networks, and power flow analysis.

Shailendra Singh received the M.Tech. degree in Electrical Engineering with specialization in power systems from the National Institute of Technology, Kurukshetra, India, in 2012. He received his Ph.D. degree in Electrical Engineering (Power Systems) at the Indian Institute of Technology (Banaras Hindu University), Varanasi, India, in 2019. He was a Visiting Scholar with the Power Systems Engineering Center, National Renewable Energy Laboratory (NREL), Golden, CO, USA, from April 2018 to October 2018. Currently, he is working as a Research Fellow at the Centre for System Intelligence and Efficiency, NTU, Singapore. His research interests include grid operation and control, smart energy distribution systems, microgrid control, and distributed energy resources management.

Jiawei Yang received the B.E. degree in electrical engineering and automation from Wuhan University, China in 2018 and the M.E. degree in electrical and electronic engineering from Nanyang Technological University, Singapore in 2020. He is currently a Ph.D. candidate in electrical engineering at Nanyang Technological University, Singapore. His current research interest includes peer-to-peer energy trading and blockchain applications in power systems.

Manuel König is a product manager at iba AG, Germany, and has a background in electrical engineering. He has been working for iba AG in various departments since 2005 and is responsible for the security of iba products in addition to his work as product manager.

Christian Heider is an embedded software developer at iba AG, Germany. He received his M. Eng. degree in Electronic and Mechatronic Systems from the Technische Hochschule Nürnberg in 2019 and has since been working as a fulltime employee at iba AG. His main tasks are Linux driver development (e.g. network drivers) and implementing and maintaining security features for the current iba hardware development projects.

Oliver Soukup is Head of Development at iba AG, Germany. He received his diploma in electrical engineering from the Technical University of Regensburg in 1993 and has been working at iba AG since 2008. He is also responsible for development-related research projects at iba AG and has supervised 6 research projects in recent years.

In addition to the abovementioned resource personnel, a team of research students from NTU, Singapore supports the hardware demonstration.

Who Should Attend?

This course is useful to engineers and managers working in renewable energy, decentralized energy markets and operation of smart grids, microgrids and intelligent energy systems. It is beneficial to anyone who wishes to know more about their development in Singapore. The course will be structured towards experience sharing and knowledge transfer.

Course Information	
Date:	June 23, 2022 (Thursday)
Time:	8:30 to 18:00
Lecture Venue:	Executive Seminar Room (S2.2-B2-53), Block S2.2, Level B2, Room 53, School of Electrical & Electronic Engineering (EEE), NTU
Demo Venue:	Clean Energy Research Laboratory (S2-B7c-05), School of EEE, NTU
CPD Programme:	This course is qualified for 7 PDUs by Professional Engineers Board (PEB), Singapore. Course ID: COA39117. Please visit https://www.peb.gov.sg/course_calendar.aspx
Fee (net amount): *Fees include refreshments, lunch and course notes*	S$700 or on-site S$800 (subject to space availability) Early Bird Registration: S$650 by 8 June 2022 Group Registration (3 or more from the same organization registered at the same time): S$600 by 15 June 2022 IEEE/IES Member: S$600 by 15 June 2022

Registration: Please register at this link: https://forms.office.com/r/UVzHTR4wtt

Payment is to be made payable to **IEEE Singapore Section** via a Singapore cheque or bank transfer in Singapore dollars. The details are in the registration link.

Please contact Mrs Jasmine Leong (Email: sec.singapore@ieee.org, Tel: +65 6743 2523) if you have any queries.

Accommodation is available at Genting Hotel Jurong on a first-come, first-served basis. Details are available at https://www.rwsentosa.com/en/hotels/genting-hotel-jurong

The proposed course contents may be modified where practical and the course is subjected to a minimum participation before commencement.