Research Assessment Exercise 2020
Impact Case Study 2

University: City University of Hong Kong
Unit of Assessment (UoA): 12 - Electrical & Electronic Engineering
Title of case study: Emerging Technologies for Energy Conversion and Utilization

(1) Summary of the impact

The team on Smart Energy Conversion and Utilization Research at CityU EE has made significant contributions to emerging technologies for energy conversion and utilization, as well as system diagnostics, through developing various machine learning techniques to the design, control and diagnosis of power electronics systems. The team has established extensive research collaborations with local and global leaders in power electronics industry and government departments. The impact of the team's research and development includes:

- Development of advanced **machine learning algorithms for diagnosing power electronics** equipment, leading to significant resource saving in site inspection and reduction in electronic waste.
- Development of large-scale energy management systems for indoor and outdoor lighting equipment used in residential estates and roads, achieving an **energy saving of 20% to 40%**.
- Supporting a spin-off company, [redacted] Ltd., to produce energy-saving devices and smart thermostats for central air-conditioning systems that allow an average **energy saving of 25%** without sacrificing thermal comfort.
- Development of a cost-effective energy recycling technology for a power supply manufacturer, [redacted] Ltd., for reducing energy loss in power supply burn-in systems, amounting to **an annual saving of HK$5M**, and with a short payback time of less than 9 months. Such technology has led to advanced inverter technologies for distributed power generation systems.

(2) Underpinning research

Since 1998, the team on Smart Energy Conversion and Utilization Research under the leadership of **Prof. Henry Chung** has developed various **machine learning algorithms to design and control power electronics systems**. Among the highly successfully developed algorithms are an ant colony optimization (ACO) algorithm utilized in power electronic circuits [R1] and an adaptive particle swarm optimization (APSO) technique applicable to design and management problems [R2]. Further development has been carried out to incorporate recent optimization algorithms developed by **Prof. Ron Chen**, **Member of the Academy of Europe and Fellow of The World Academy of Sciences**, to provide new features for tackling a wider class of problems, such as a hybrid event-time driven scheme, convex optimization using tools from non-smooth analysis, and adaptive multi-output conversion [R3]. With the support of the Innovation and Technology Commission (ITC) of the HK Government, the team has also extended its research directions to include intrinsic parameter extraction of devices and renewable energy resources, with a particular focus on condition monitoring for solar panels and batteries [R4]. Together with his former Ph.D. student, Prof. Chung received a **Natural Science Award** (**First Class Prize**) presented by the **Ministry of Education of China** in 2010 for the research project entitled "Ant Colony System for Optimization of Power Electronics Circuits".

(2a) Energy Management Technologies for Lighting and Air-Conditioning Systems The research team has developed an energy-efficient central energy-saving technology that has the capability of changing the supply voltage to a large-scale lighting network in order to manage its overall energy consumption profile [R5]. This central system offers operators the flexibility of adjusting lighting energy at any location and time, and to any desired level of brightness. In order to minimize power dissipation, the central energy management system manages the reactive power to control the magnitude of the voltage supplied to the lighting networks and does not process any real power. Thus, its power rating is significantly smaller than the necessary power flow to the lighting networks, resulting in high energy efficiency and power density. Such energy management technology was successfully extended to control fan coil units in air-conditioning systems. It can instantly convert a

conventional fan coil unit with only three controlled speeds into a continuous speed control unit, thereby raising the thermal comfort of consumers and reducing energy consumption.

(2b) Energy-Saving Technologies for Power Supply Manufacturers With a support of HK$0.9M from ITC, a green burn-in system was successfully developed by the team with a power supply manufacturer, [redacted] Ltd., which was later acquired by [redacted] Ltd.. In order to detect early failures in a large number of power supplies, each power supply produced must undergo burn-in testing. Conventional burn-in systems connect the outputs of the power supplies to the loads, such as resistors and computers, resulting in inevitable waste of energy. The green burn-in system, however, regenerates energy from the power supplies under test and delivers it back to the AC grid. The system works over a wide voltage and frequency range. The required power for the entire burn-in process is only the power loss of the system. Such an innovative technology for energy-efficient power inversion with a swift power flow mechanism for the inverter was disclosed via a patent [R6]. The system increases the energy efficiency, reduces the physical size, and establishes strict operating conditions to test the dynamic performance of the power supplies. Such AC grid connection technology has led to advanced inverter technologies for distributed power generation systems. The team was awarded the **Natural Science Prize of Shanghai** by the Shanghai Municipal People's Government for the contribution of "Research into Advanced Inverter Topologies for Renewable Energy Generation and Energy Storage Integration into AC Grid" in January 2019.

(3) References to the research

[R1] J Zhang, H Chung, WL Lo, and T Huang, "Extended Ant Colony Optimization Algorithm for Power Electronic Circuit Design," *IEEE Trans. Power Electron.*, vol. 24, pp. 147-162 (2009).

[R2] Z Zhan, J Zhang, Y Li, and H Chung, "Adaptive Particle Swarm Optimization," *IEEE Trans. Systems, Man, and Cybernetics: Part B: Cybernetics*, vol. 39, pp. 1362-1381 (2009).

[R3] YN Zhu, WW Yu, GH Wen, GR Chen, and W Ren, "Continuous-Time Distributed Subgradient Algorithm for Convex Optimization with General Constraints," *IEEE Trans. Automatic Control*, vol. 64, pp. 1694-1701 (2019).

[R4] W Wang, H Chung, and J Zhang, "Near-Real-Time Parameter Estimation of an Electrical Battery Model with Multiple Time Constants and SOC-Dependent Capacitance," *IEEE Trans. Power Electron.*, vol. 29, pp. 5905-5920 (2014).

[R5] U.S. Patent 7,411,359 B2: H Chung, NM Ho, and SY Hiu, "Apparatus and Method of Providing Dimming Control of Lamps and Electrical Lighting Systems" (2008).

[R6] U.S. Patent 8,189,351 B2: H Chung, SW Leung, and KM Chan, "Multi-input DC/DC Converters with Zero-Current Switching" (2012).

(4) Details of the impact

Proposed by Prof. Chung [R2], the APSO algorithm avoids the trapping at local optima that typically occurs in classical particle swarm optimization techniques. The paper was cited for more than 1484 times and was placed in the top 1% of this field in 2018. The technique was adopted for the mass spectrometer in the Rosetta mission of the European Space Agency [E1].

In 2014, with the support from ITC, a smart battery diagnostic system for monitoring the condition of batteries on ambulances, mobile post offices, and data centers was developed. This research project was carried out in collaboration with the **Electrical and Mechanical Services Department (EMSD) of the HK Government** [E2-E4]. The smart battery diagnostic system facilitates real-time estimation of the state-of-charge (SOC) and state-of-health (SOH) of batteries, which helps operators to determine the optimal charging profile, discharging control, and capacity balancing scheme for extending the lifetime of batteries. The system also allows operators to remotely monitor the SOC and SOH of batteries, and make replacement at an optimal time before any failure occurs. EMSD has classified such development as successful [E3].

In a project completed in 2019, the battery diagnostic technology was further extended to develop an IoT-based diagnostic device that can perform remote condition monitoring of solar-powered lamp-posts. The device includes Long Range (LoRa) and Narrowband IoT (NB-IoT) communication technologies. A large-scale installation of these diagnostic devices for solar-powered lampposts along

the Ng Tung River in the Sheung Shui District in HK was completed. The river is 7-km long with 148 lampposts, and each lamppost consists of an LED light source, a solar panel, and batteries [E3]. The diagnostic device can report the status of the light source, health condition of the solar panels and batteries, and temperature of the lamppost. The Secretary of the Development Bureau of the HK Government has commended the development of this battery diagnostic technology [E4].

The battery diagnostic technology has also been transferred to [redacted] Ltd. to develop a battery tester that is used to test the conditions of car batteries and generators [E5]. Under a contract research project with a sum of [redacted], a foreground IP has a patent granted [E6] with the technology background described in [R4]. The technique has many merits when compared with prior art. Particularly, it is non-dissipative as a result of a patented energy recycling technique [E6] that allows the battery-under-test to undergo both charging and discharging processes. In addition, the technique has the capability of reusing the power of a battery system to perform the testing, thereby eliminating 90% of the energy loss. The energy saving is due to the patented technique which allows charging the battery without discharging it completely first. With the APSO algorithm described in [R2] and [R4], the intrinsic parameters of the battery-under-test can be obtained in less than three minutes.

A spin-off company, e.Energy Technology Ltd., was founded by Prof. Chung and his colleague Prof. Ron SY Hui at CityU in 2006. The company has productized the patented dimming technology for the lighting management systems for high-power outdoor and low-power indoor lighting networks [R5]. The high-power systems were successfully installed in different road lighting systems, such as the Highways Department of the HK Government and Heshan City, Guangdong, China. The project conducted in Heshan City resulted in a **power consumption saving of between 20% and 40%** across the network of large-scale public lighting. The work was reported in *Research Frontiers – The Newsletter of the HKRGC* [E7]. The low-power systems were used by property developers, such as the [redacted] of public housing estates and [redacted] in HK for several thousands of apartments. The distinct feature of these systems is that they can turn a non-dimmable lighting system into a dimmable one without major changes in the lighting infrastructure. The team received The Hong Kong Awards for Industries: Innovation and Creativity Award for the lighting management system [E8].

Based on the patented concept on energy management technologies [R5], applications of smart thermostats for controlling the flow of the fan coil unit in a central air-conditioning system were developed [E7]. With support of the ITC, **EE students under Prof. Chung have founded [redacted] Ltd.** in 2015. The start-up company productized a technology on smart thermostats for central air-conditioning systems that can save more than 25% on overall power consumption and improve indoor comfort levels [E9]. The smart thermostats integrate the energy management technologies with IoT technologies. With the addition of new investors, a new company called [redacted] Ltd. [redacted] was set up recently and the company has a value of [redacted]. After rigorous performance tests, the energy-saving technology has been attested by EMSD of HK. The devices have been categorized as successful by EMSD [E10]. More than 100 units have been installed at the headquarter building of EMSD. Such a testing platform implemented in the EMSD has been commended by the Development Bureau of the HK Government. The energy-saving and carbon-reduction features are well aligned with the objectives of the "Energy Saving Plan for HK's Built Environment 2015/25+", which was mentioned in the policy address of the HK Government.

The power supply burn-in system developed for [redacted] Ltd. can save electric energy by more than 75%, as compared with conventional burn-in systems. The pay-back period is less than 9 months. According to [redacted], an annual cost saving of HK$5M on conducting burn-in processes can be achieved. The core technology for aggregating power from power supplies with multiple outputs has been patented and reported [R6, E7]. The technology was a success and was later acquired by [redacted] Ltd..

The team has established close research partnerships with local and global leaders in power electronics technology and government departments. It has developed basic research and applied technologies for complex power electronic circuits and various practical problems. Their work is visionary as they included machine learning technique for power electronics 20 years ago. With recent advancements in microelectronics and power electronics, these effective machine learning algorithms have been applied to diagnostics technologies which resulted in substantial energy saving.

(5) Sources to corroborate the impact

[E1] A Bieler, K Altwegg, L Hofer, A Jackel, A Riedo, T Semon, P Wahlstrom, and P. Wurz, "Optimization of mass spectrometers using the adaptive particle swarm algorithm," *J. of Mass Spectrometry*, vol. 46, pp. 1143-1151 (2011).

[E2] **Newspaper** reports on CityU's smart system for battery monitoring that can significantly save time and energy: Ming Pao Daily News, Singtao, STHeadline, and Wenweipo (in Chinese). See the attachment for the English reports.

[E3] (a) **Letter of Support** from the Electrical and Mechanical Services Department (EMSD) of the HK Government verifying the success of the battery diagnostic technology. (b) Posting on EMSD: https://inno.emsd.gov.hk/en/success-case/index_id_20.html

[E4] **Message from the Secretary of the Development Bureau** of the HK Government on the use of 100 batteries from government fleet by CityU researchers: www.devb.gov.hk/en/home/my_blog/index_id_260.html

[E5] **Letter of Support** from [redacted] Ltd..

[E6] Australia Patent 2018278995: CS Cheng, WH Lau, and H Chung, "Efficient Battery Tester" (2019).

[E7] **Newsletter of HKRGC** on energy saving light dimming technology and green burn-in system: www.ugc.edu.hk/minisite/rgc_newsletter/rgcnews15/west/07.htm

[E8] **HK Awards for Industries: Innovation and Creativity Award** was presented to e.Energy Lighting Ltd. for the lighting management system: https://www.tid.gov.hk/hkindustryaward/english/winners/2011.html#c4

[E9] **Newspaper** reports on energy saver and smart thermostat for central air-conditioning system: Ming Pao Daily News, Wenweipo, Takungpao, Singtao and Singpao (in Chinese). See the attachment for the English reports.

[E10](a) **Letter of Support** from the EMSD of the HK Government verifying the success of Jacky Instruments Ltd. in saving power consumed by the central air-conditioning systems without modifying the infrastructure, which led to saving more than 25% of fan coil energy consumption in the EMSD Headquarters building of the HK Government. (b) Posting on EMSD: https://inno.emsd.gov.hk/en/success-case/index_id_67.html