Research Assessment Exercise 2020
Impact Case Study

University: The University of Hong Kong
Unit of Assessment (UoA): 12 electrical & electronic engineering

Title of case study: Power Electronics as an Enabling Technology for Sustainability

(1) Summary of the impact

Since the 1990s, the Power Electronics (PE) group have impacted the world with several important technologies, including (i) wireless power transfer, (ii) sustainable lighting; and (iii) smart grids. These technologies have led to:

(i) Wireless power technologies that reshaped consumer electronics industry with wireless charging standard revised in 2016 and power industry with the world's first "weather-independent" wireless power supplies for smart grid.
(ii) Change of industrial practices in lighting industry with the world's first light-emitting diode (LED) system theory leading to "sustainable" lighting products installed in over 20 countries.
(iii) Change of practice in power and smart grid industry with new inventions.

(2) Underpinning research

The PE group has pioneered "sustainable technologies" with three criteria of success: (i) high energy efficiency, (ii) long product lifetime and (iii) recyclability. Led by Prof. Ron Hui (FREng) and Prof. SC Tan, the PE group focuses their research on: wireless power transfer, LED lighting, and power conversion technologies.

(a) Wireless power transfer (WPT) [R1, R2, R3]

Prof. Hui's previous inventions have been adopted in Qi (pronounced as "chee" representing the Chinese word 氣 (qi)) standard launched in 2010. Since joining HKU in 2011, he has further impacted both academic and industrial WPT communities by classifying for all near-field magnetic WPT works under two fundamental engineering principles, eliminating confusion and misconceptions about magnetic resonance in the global WPT communities [R1]. This article points out clearly that "maximum energy efficiency" principle instead of "maximum power transfer" principle should be adopted for highly efficient WPT systems. Working closely with electronics industry, his team co-invented the 3-coil WPT structure with industry [R2], making it possible for incorporating "extended distance" option into the 2019 revised Qi standard. Instead of achieving maximum efficiency at one point or over only a narrow operating region, they pioneered "maximum energy efficiency tracking" [R3], ensuring that optimal energy efficiency can be achieved over the entire charging process for achieving sustainability aims. In addition, his team laid down basic principles for "omnidirectional WPT", taking such technologies to new heights.

(b) Sustainable lighting technology [R4, R5]

His team pioneered the Photo-Electro-Thermal theory [R4] that has become the world's first LED system theory and design tool for lighting industry. Based on this, a new

generation of active and passive "LED drivers without electrolytic capacitors" have been developed. New passive LED drivers do not have electrolytic capacitors, power switches, gate drivers and closed-loop control. The simple structure and the use of passive components make them extremely efficient, reliable and recyclable (meeting the 3 sustainable criteria), which led to the possible design of passive LED street lighting systems without noticeable flickering. After successful installations in China (since 2015) and Hong Kong (2018), these sustainable lighting products are available in over 20 countries. Also, Prof. Tan's breakthroughs in dimming and color control for LED systems [R5] has achieved unprecedented precision, leading to commercialization of a group of patents.

(c) New inventions for power/smart grid industry [R6, R7]

Since 2011, the PE group has invented and has been working on smart grid devices called Electric Springs [R5] as a new and the fastest (order of milliseconds) demand-side management technology to absorb disturbances in the alternating current (AC) mains voltage and frequency caused by the intermittent nature of wind and solar power generation. This technology enables substantial increase of intermittent renewable power without system instability, making it an effective solution to reduce fossil fuel consumption and greenhouse gas emission.

Millions of online-monitoring systems in high-voltage transmission towers are traditionally powered by "weather-dependent" photovoltaic systems. His team invented the world's first "weather-independent" solution for such applications by harvesting energy from the magnetic field around the high-voltage cable and transferring such energy via insulation rod with embedded WPT coil-resonators to the transmission tower [R6]. This research led to the world's first "weather-independent" wireless power supply.

These two inventions have been adopted by China Southern Power Grid for implementation in China. They influence the industrial practice of power industry.

(3) References to the research

[R1] S.Y.R. Hui, W.X. Zhong, and C.K. Lee, "A critical review on recent progress in mid-range wireless power transfer," *IEEE Transactions on Power Electronics*, Vol. 29, No. 9, pp. 4500-4511, March 2013, [IEEE PELS 1st Place Best Transactions Paper Award 2014]. (cited over 750 times)

[R2] W.X. Zhong, C. Zhang, X. Liu, and S.Y.R. Hui,, "A methodology for making a 3-coil wireless power transfer system more energy efficient than a 2-coil counterpart for extended transfer distance," *IEEE Transactions on Power Electronics*, Vol. 30, No. 2, pp. 933-942, March 2014. (cited over 120 times)

[R3] W.X. Zhong and S.Y.R. Hui,, "Maximum energy efficiency tracking of wireless power transfer systems," *IEEE Transactions on Power Electronics*, Vol. 30, No. 7, pp. 4025-4034, August 2014, [IEEE PELS 1st Place Best Transactions Paper Award 2015]. (cited over 160 times)

[R4] S.Y.R. Hui, *Photo-Electro-Thermal Theory for LED Systems: Basic Theory and Applications*, Cambridge University Press, September 2017 [https://www.cambridge.org/core/books/photoelectrothermal-theory-for-led-systems/D719D334C5E6BB77D260676BAFF43CEF].

[R5] A.T.L. Lee, H.T. Chen, S.C. Tan, and S.Y.R Hui, "Precise dimming and color control of LED systems based on color mixing," *IEEE Transactions on Power Electronics*, Vol. 31, No. 1, pp. 65-80, June 2015.

[R6] S.Y.R. Hui, C.K. Lee, and F. F. Wu, "Electric springs- a new smart grid technology," *IEEE Transactions on Smart Grid*, Vol. 3, No. 3, pp. 1552-1561, June 2012.

[R7] C. Zhang, D.Y. Lin, N. Tang, and S.Y.R. Hui, "A novel electric insulation string structure with high-voltage insulation and wireless power transfer capabilities," *IEEE Transactions on Power Electronics*, Vol. 33, No. 1, pp. 87-96, May 2017.

(4) Details of the impact

The impacts resulting from the research works conducted by the PE team that are relevant to power electronics cover these 3 major areas.

(a) Wireless power transfer (WPT): new technologies, products and industrial standard [E1, E2, E3, E4, E5]

We are the first team who classified the WPT principles and pinpointed the advantages of "maximum energy efficiency" (MEE) over "maximum power transfer" (MPT) to the global WPT community. This seminal article [R1], cited over 750 times since 2014, helps the global WPT community to differentiate various WPT approaches and dispels the misconception about magnetic resonance proposed by the MIT team in 2007 [E1]. It helps to end the "rival standard war", resulting in Qi (which adopts MEE) as the de facto global wireless charging standard used by over 550 companies worldwide [E2].

Our R&D supported ConvenientPower [E2], and helped it develop as a global Qi-technology provider (shipping >395 million units in 2018) and launch the world's first wireless charging pad inside Toyota cars in 2013 [E1] based on the underpinning research in [R2], [R3]. Our co-invented 3-coil WPT system with extended charging distance influenced the "2019 revised Qi standard" as the new transmission distance specification extending from 5 mm to 4 cm [E3]. On pages 20-21 of its 2019 revised Qi standard document [E3], our 3-coil WPT structure [R2] is classified as the "Power Transmitter Design MP-A16".

Existing online-monitoring systems of high-voltage transmission lines are placed in the transmission towers and powered by photovoltaic (PV)-battery systems, with the limitations of (i) limited/unreliable solar time, (ii) requirement for large batteries and (iii) maintenance problems. In 2008, prolonged bad weathers in China caused the batteries of the online-monitoring systems to run out, resulting in massive power blackout, financial losses of 80 billion RMB and 80 human lives [E4]. We invented the world's first "weather-independent" power supply for high-voltage transmission tower [R7] by harvesting magnetic energy from the current-carrying power cable and wirelessly transmitting it via the insulation rod to the tower. This invention has re-shaped the industrial practice of power industry. China Southern Power Grid (providing electricity to over 285 million people) has invested $2 million to implement our technology with a plan to replacing all existing PV-based online monitoring systems with our invention [E5].

(b) Lighting technology meeting sustainability criteria [E6, E7, E8, E9]

The failure of the China's large-scale LED street lighting program (national program conducted in 2003-2008) pinpointed the reliability issues of LED drivers. Grand challenges of LED were that the lifetime of LED drivers (<3 to 5 years) is shorter than that of LED (8 to 10 years) and the lack of LED system for optimal design. We filled these technological gaps successfully.

Prof. Hui pioneered the Photo-Electro-Thermal theory [R4] as the world's first unifying LED system theory. It has been widely adopted by major lighting companies as an optimal LED system design tool [E6].

Our patented passive LED drivers offer lighting industry a unique and cost-effective solution. With only a few passive components and optimized with the LED system theory for continuous operation with unnoticeable flickering, they have been certified with high energy efficiency (>90%), long estimated lifetime (>10 years usage) and recyclability (>80%) of product materials [E7], [E8]. United Technologies has installed them in Heshan City, China (with population of 500,000 people) and Hong Kong [E8]. Mass production has several landmark implications. Firstly, this product is the first in lighting history that the LED driver has a lifetime longer than that of the LED devices [E6]. Secondly, this passive technology highlights a fundamental principle to lighting industry that "outdoor" LED drivers should adopt the "passive" approach rather than the active approach for reliability reasons. This research has fundamentally changed the industrial practice towards the design of outdoor LED lighting systems. United Technologies has invested over $4 million to market this sustainable LED street lighting in over 20 countries [E8]. In addition, 9 of our patent-pending lighting technologies on color and dimming control, pioneered by Prof. Tan [R5], have been licensed to Zyne [E9].

(c) Smart grid–Influence to steer major power company to new R&D directions [E10]

Increasing use of intermittent renewable energy leads to power grid stability issues because power supply and load demand must be balanced in real time. The Electric Spring technology developed at HKU [R6] can provide both active and reactive power compensation for stabilizing emerging power grid with increasing intermittent renewable energy sources. Unlike traditional demand-response methods adopted by power companies (such as day/hour ahead load forecasts), the electric springs are an extremely fast (almost instantaneous) demand response technology with response times in the order of milliseconds.

The invention has influenced China Southern Power Grid (CSG), which supplies electricity to over 285 million people, to initiate new policy and programs to evaluate the effectiveness of electric springs. CSG has invested RMB 1.85 million ($ 2 million) to build the hardware for site tests in China. Several 10 kVA units have been installed in China to stabilize a microgrid in Guangdong since 2017 [E10].

Impacts generated by our power electronics research are also reflected by the industrial funding support for the filing of 35 patent applications.

(5) Sources to corroborate the impact

[E1] Letter from Dr. Ken Liu, Vice-chair, Specification Work Group, Wireless Power Consortium.
[E2] Letter from Camille Tang, Co-founder and Head of ConvenientPower.
[E3] The Qi Wireless Power Transfer System Power Class 0 Specification: Version 1.2.4 Addendum for Power Transmitter MP-A16, pp. 20-21, March 2019.
[E4] BBC News, "Snow-hit China welcomes New Year," 7 February 2008, online [http://news.bbc.co.uk/2/hi/asia-pacific/7231622.stm].
[E5] Letter from Tang Niang, Head of Power Electronic Division, China Southern Power Grid, on wireless power technology for online-monitoring in high voltage transmission systems.
[E6] Letter from Jianwen Shao, Senior Manager of Power Applications, Wolfspeed, a Cree Co.
[E7] Test report from China Electronic Product Reliability and Environment Testing Research Institute.
[E8] Letter from Paul Wong, Chairman, United Technologies Global Ltd.
[E9] Letter from William Fu, CEO, Zyne Ltd.
[E10] Letter from Tang Niang, Head of Power Electronic Division, China Southern Power Grid, on electric spring technology for power systems.