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: Reliable Electrical Energy Systems

(1) Summary of the impact

HKU's Centre for Electrical Energy Systems (CEES), established in 1996, carries out research in power systems engineering science and industrial application, including: security analysis, economic operation, automation, system recovery and smart grids. Results from the Centre have been deployed in power companies and used by governments in Hong Kong, Mainland China and internationally, including the USA and Australia. The impacts in the period of review have been to:

(i) enable improvements in local power industry operation in Hong Kong to achieve 99.999% reliability, in the assessment period, which is among the highest in Asia;
(ii) allow China Southern Power Grid to achieve specific improved security control requirements;
(iii) contribute to the design of self-healing power systems for the power industry in USA and China, so reducing damage from cascading collapses;
(iv) influence Government policies in Hong Kong on smart metering for improved system reliability and improved capability for increasing renewable power generation.

(2) Underpinning research

Large power systems are arguably the most complex human-made systems in the world. They are multi-level networks, and the power flow follows physical laws, both static and dynamic. System operation requires instantaneous real-time power balancing. Power system security issues, particularly avoiding cascading failures after fault events and contingencies, have been the major challenges to system operators. These were recently expressed in terms of achieving resilience and self-healing capability, and ultimately contributing to overall reliability expressed in terms of lost load.

In 1996, HKU appointed Prof. Felix Wu from UC Berkeley to establish CEES. The Centre, which has been led by Prof. David Hill since 2013 and includes team members Dr. Jin Zhong, Dr. Yunhe Hou, and Dr. Tao Liu, bases its distinctive research on fundamental principles in engineering science. Since the Centre's foundation, all research has been conducted with a rigorous mathematical modelling and analysis, and yet factoring in the reality of industrial practices. Much of the Centre's research has therefore been driven by the future needs of its industrial partners. The research that forms the basis of this case study can be divided into three main separate but related themes:

(a) Power system economic operation [R1, R2]

Focus for CEES has been in economic operation and electricity markets. Research led by Prof. Wu established a theoretical analysis of the operation modes of power systems in terms of optimal bidding in an oligopolistic electricity market [R1]. Later research led by Dr. Zhong included new technologies with fundamental power system operations to

provide a platform to apply smart technologies in power system dispatch and operation in the control center. Based on the theoretical analysis, new methods to solve the close-to-real-time generation scheduling optimization problem has been developed. The resulting fast scheduling algorithm can accommodate more renewable energy generation than previously possible [R2].

(b) Security and recovery of power grids [R3, R4, R5]

Power grid dynamics in phase angles (synchronism), frequency and voltages, is made even more complicated by diverse loads, mixed alternating current (AC) / direct current (DC) systems and renewable power sources. Prof. Wu and his team studied stability issues of both High Voltage AC and DC systems. They developed new algorithms and mathematic models to improve the analysis of power systems, including the identification and computation of dynamic security regions [R3]. After the appointment of Dr. Hou in 2009, this research extended to the development of a systematic theory and comprehensive tools for self-healing grids. The team established a comprehensive methodology called Generic Restoration Milestones (GRM) for constructing self-healing smart grids [R4, R5]. The GRM-based methodology divides the system restoration process into a sequence of generic milestones, such as restarting generating units, energizing the transmission grid, restoring loads, synchronizing electrical islands, and connecting with neighboring systems. Algorithms were invented and developed for each milestone, enabling an adaptive system restoration methodology [R5].

(c) Demand analytics and modeling [R6]

Part of the smart grid agenda involved work in CEES on customer data analytics to identify consumer segmentation and demand control capability driven by trials in China Light and Power (CLP). CEES widened its research to include issues related to high renewables such as the use of demand-side factors and energy storage in dealing with generation variability. Many research questions were addressed through demand-side modeling and analytics [R6].

(3) References to the research

[R1] Y. Liu and F.F. Wu, "Generator bidding in oligopolistic electricity markets using optimal control: fundamentals and application," *IEEE Transactions on Power Systems*, Vol. 21, No. 3, pp. 1050-1061, July 2006.

[R2] Y. Tang, J. Zhong, and J. Liu, "A generation adjustment methodology considering fluctuations of loads and renewable energy sources," *IEEE Transactions on Power Systems*, Vol. 31, No. 1, pp. 125-132, February 2015.

[R3] A. Xue, F.F. Wu, Q. Lu, and S. Mei, "Power system dynamic security region and its approximations," *IEEE Transactions on Circuits and Systems I: Regular Papers*, Vol. 53, No. 12, pp. 2849-2859, December 2006.

[R4] Y. Hou, C.-C. Liu, K. Sun, P. Zhang, S. Liu, and D. Mizumura, "Computation of milestones for decision support during system restoration," *IEEE Transactions on Power Systems*, Vol. 26, No. 3, pp. 1399-1409, December 2010.

[R5] H. Liu, X. Chen, K. Yu, and Y. Hou, "The control and analysis of self-healing urban power grid," *IEEE Transactions on Smart Grid*, Vol. 3, No. 3, pp. 1119-1129, July 2012.

[R6] S.C. Chan, K.M. Tsui, H.C. Wu, Y. Hou, Y-C. Wu, and F.F. Wu, "Load/price forecasting and managing demand response for smart grids: methodologies and challenges," *IEEE Signal Processing Magazine*, Vol. 29, No. 5, pp. 68-85, August 2012.

(4) Details of the impact

Our research works have impacted in both general and specific ways, both local and oversea power industries during the assessment period. This includes China Light and Power (CLP) and Hong Kong Electric (HKE), which are the local Hong Kong power utilities serving the entire Hong Kong population of 7.38 million people. Together, they have combined assets (excluding substantial overseas holdings) of over HK$156 billion (US$20 billion) and revenues of HK$48 billion (US$6.2 billion). The Centre's research has also had direct impact on Guangdong Power Grid (GPG), which serves over 250 million people. GPG is a subsidiary of China Southern Power Grid (CSG), which is the second largest power utility in the world. The CSG has total assets of RMB 745 billion (US$106 billion) and revenue over RMB 495 billion (US$70 billion). The principal impacts are:

(a) Facilitate operational excellence in local HK Power Industry [E1, E2] and CSG [E7]

The Centre's multifaceted contributions via its research on system operation [R1, R2], close collaboration and consulting have provided "improvement of our supply reliability and customer services in the past years" towards the power utilities' achievement of one of the highest reliability rates in the world – 99.999% [E1]. The research in the "following areas: 1) Security and recovery ... ; 2) Power system economic operation and 3) Demand analytics … is of the utmost importance to the Industry as a whole" [E2] – see letters from CLP and HKE [E1, E2].

Recent energy policy discussions in many countries have featured a debate about the effect of high renewable power on load balancing, stability and ultimately security and reliability. The smart grid agenda has been adopted in HK with initial consideration of improved network situation monitoring via trials with an advanced metering infrastructure (AMI) system. A key methodology is data analytics carried out for the utilities to determine societal segmentation for availability of demand-response in a time-of-use and peak load rebate senses. This work used the prior CEES research in collaboration with the signal processing area [R6]. Prof. Wu and later Prof. Hill were also key advisors who provided "valuable advice … on the planning and implementation of our Smart Metering … projects" for CLP [E1].

Based on research in economic operation [R1], "Prof. Hou has been playing a critical role in developing the electricity market in CSG …. leading a research team to develop the electricity spot market trading system. The rule for the electricity spot market, which was designed with his support, has been released recently" [E7]. The performance of this trial market is being used as a guide to a similar development across all China.

(b) Improved security control in Southern China [E3]

CEES research described in Section (2) has been applied directly to several power system operations and smart technologies for CSG, and CLP in 2013, 2016, and 2017. For example, the Centre's research led by Dr. Zhong has resulted in a report ("*Study of Smart Control Center and Its Core Technologies and Practices*") that was presented to GPG in 2015. The results from this report have been applied in the actual power system. Specifically, the *fast zonal separation method*, underpinned by [R3], was developed for GPG to quickly separate the whole grid into zones to isolate the insecure area from safe areas after large fault events or contingencies. The method "was verified with Guangdong Power 1018-bus system and the effect was obvious" [E3]; it has been proved to be successful in real system operation by the GPG Power Dispatching Control Center. It helps the system operator to quickly

make fast decisions in contingency states, while lowering the possibility of blackout and maintaining the security operation of the system. "The project has received the *First Prize* of CSG Science and Technology Award in 2015" [E3].

(c) Self-healing for USA industry [E4, E5] and China Power Grids [E6, E7]

The Electric Power Research Institute (EPRI) is the R&D institute for all of the USA power industry with membership representing approximately 90% of the electric utility revenue generated in the United States and extends to participation in more than 35 countries. The worldwide membership that supports their work comprises more than 1,000 organizations. While most members are electric utilities, others are businesses, government agencies, regulators and public or private entities engaged in some aspect of the generation, delivery, or use of electricity.

CEES research led by Dr. Hou has had ongoing collaboration in EPRI projects. Within the assessment period, the Centre's main focus has been to implement the "seminal contributions in theory and tools for constructing self-healing smart grids … called *Generic Restoration Milestones* (GRMs)" [E5] described in [R4] and [R5] above. CEES's decision support system, called *System Restoration Navigator* (SRN) has been tested on real systems supported by EPRI and "have been well-recognized and accepted by industry members of EPRI". The decision support tool successfully reduces the restoration time, and thus improves the system reliability and resilience. The SRN was deemed by IEEE (the largest technical professional organization in the world) as "*The Healing Touch*" that brought the capability of self-healing smart grids into practice [E4, E5]. During the past six years, EPRI has continuously supported CEES research in a series of five research projects. Notably, SRN was awarded a *Tech Transfer Award* from EPRI in 2014 [E5]. In addition, State Grid Corporation of China (Hubei), and CSG (Guangdong) also set up RMB 1.5 million and RMB 10 million respectively to support the research. Two provincial power grids control centers (Guangdong and Hubei) in China are in turn using the SRN and the related research results, which "were successfully used and accomplishment was highly recognized" [E7]. SRN was also awarded a First Class Award for Progress in Science and Technology by Guangdong Power Grid. The letters from China EPRI and CSG [E6, E7] testify to these impacts in more detail.

(5) Sources to corroborate the impact

[E1] Letter from Paul Poon, Managing Director, China Light and Power (CLP) (2014-17) on impact in CLP by CEES.
[E2] Letter from S.T. Ip, General Manager, Hong Kong Electric (HKE) on impact in HKE by CEES.
[E3] Letter from Power Dispatching Control Center of Guangdong Power Grid (GPG) on impact in GPG by Dr. Zhong.
[E4] IEEE Power & Energy Magazine: "The Healing Touch", Jan/Feb 2014, pp. 54-63.
[E5] Letter from P. Zhang, Program Manager, Electric Power Research Institute (EPRI), USA, on impact in power system and restoration theory and commercial tools by Dr. Hou.
[E6] Letter from S. Feng, Director, China Electric Power Research Institute on impact in power system operation and planning by Dr. Hou.
[E7] Letter from H. Zhou, Deputy Director, China Southern Power Grid (CSG) on impact in CSG by Dr. Hou.