The work described in this poster was substantially supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China.

About the Project

Project Period: 2014 – 18 (5 years)

Project Lead:

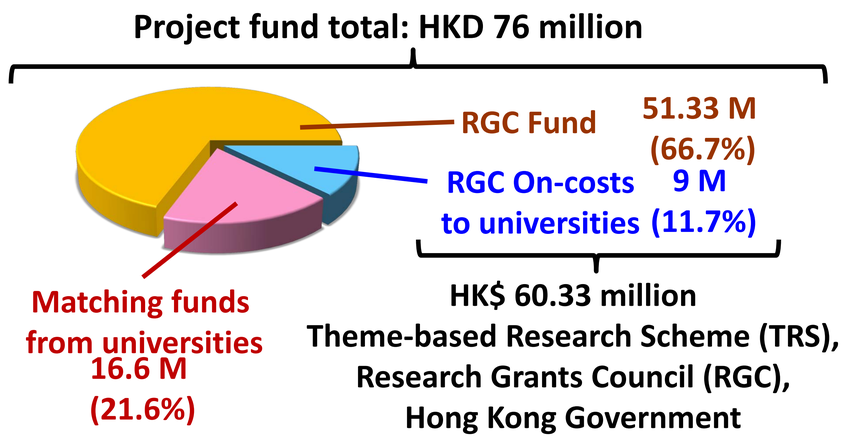
The Chinese University of Hong Kong

Partner Institutions:

The Hong Kong Polytechnic University

The Hong Kong University of Science and Technology

The University of Hong Kong



Abstract

The fast-growing demand for energy and the recognition of man-made global climate change underscore the urgency of developing clean and renewable energy resources to replace fossil fuels. Harvesting energy directly from sunlight by photovoltaics (PV), photocatalysis, artificial photosynthesis, and other enabling technologies is a promising way to meet such requirements.

The project aims to strengthen the competitive edge of Hong Kong in solar energy technologies and their market penetration by combining the newly developed PV modules with the intelligent system integration. The holistic approach covers:

- **Harvesting:** The development of thin film PV devices and modules to enhance the performance of solar harvesting;
- **Storage:** The design of highly performed electricity storage;
- **Utilization:** To enhance the performance and security of solar smart grid systems to better meet the electricity demand under various operating modes.

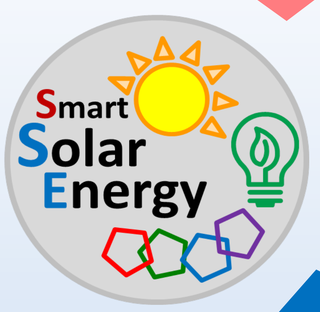
Project Team

- Six sub-topics, each led by one senior professor
- More than 20 expert scholars from CUHK, HK PolyU, HKUST and HKU
- More than 150 research staff and students since project commenced in 2014.

Harvesting

Storage

Utilization



High Performance Vacuum Deposited Thin Film PV Cells and Modules

Leader: Prof. Xudong XIAO
(Physics, CUHK)

Solution Processed Excitonic Solar Cells

Leader: Prof. Jianbin XU
(Electronic Engineering, CUHK)

Alternative Solar Technologies

Leader：Prof. Jimmy YU
(Chemistry, CUHK)

Energy Storage

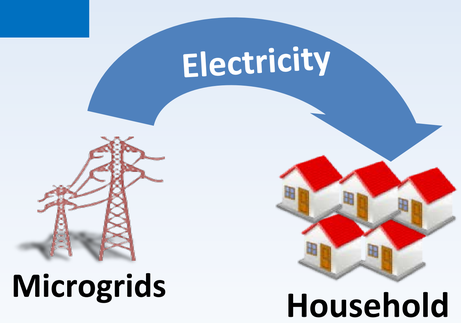
Leader: Prof. Ching-ping WONG
(Dean of Engineering,
Electronic Engineering, CUHK)

Microgrid Monitoring, Management, and Comprehensive Security

Leader: Prof. Minghua CHEN
(Information Engineering, CUHK)

Laboratory and Field Demonstration of MGs with PV Modules and Smart Storage

Leader: Prof. Zhao XU
(Electrical Engineering, Hong Kong Polytechnic University)



Field Demo: LWS College at CUHK

Since mid-2016, the project collaborated with the Lee Woo Sing College of CUHK by establishing a field demo at the north and south rooftop of student hostel. The installation validating the performance of the renewable energy system derived from the project:

- **Installed 396 pieces of CIGS solar panels (Around HKD 300,000)**, funded by TRS.
- During May – Aug 2017, **13,600 kWh of electricity** was generated (North block 9,360 and South block 4,240), equivalent to around HKD 15,400.
- Hence, the system is expected to save around **HKD 40,000 electricity fee** per year.
- This amount is around **2.4% of the total power consumption** (570,000 kWh) of the entire College.

In the future the project is going to further explore even more breakthroughs, with the ultimate goal of integrating diversified systems for high-performing smart microgrids.

Contact Us

Project Manager: Mandy Tse

Email: mandytse@cuhk.edu.hk

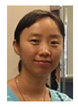
Tel: 852-3943-8450

Project Website:

https://sse.erg.cuhk.edu.hk/sse/

Project Milestones: Harvesting

Device Optimization of CIGS Solar Cells

Profs. Xudong Xiao and Xinhui Lu
Dept of Physics, CUHK

The team successfully developed copper indium gallium selenide(CIGS) thin film solar cells that feature low production cost, high efficiency and extensive application prospects since 2011. **Its conversion efficiency (20.6%) is one of the highest among the same kind of solar cells in the greater China region and reaches world-class level**, representing a great breakthrough in the development of renewable energy.

The full-set technology of fabricating efficient CIGS cells and modules by the team leads to a high-efficiency CIGS PV system in CUHK, as well as a start-up company **"Shinetech Co Ltd"** in the Xiuzhou National High-tech Zone, Jiaxing, Zhejiang of China since 2015, with estimated capacity 2MW/year.

旭科新能源股份有限公司
Shinetech Co., Ltd.

Established in: 2015
Registered capital: RMB 52 million
Estimated capacity: 2MW/year
Location: Xiuzhou National High-tech Zone, Jiaxing, Zhejiang province, China

Company staff	71 people
Research staff	51
PhD	12
Masters	8

About the "Xiuzhou National High-tech Zone"

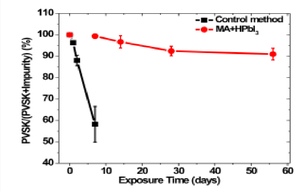
The "Xiuzhou National High-tech Zone" (the Zone) is located at the west of the Jiaxing prefecture of Zhejiang province, China, which was approved to be a province-level development zone in 2006. In Sep 2015, the State Council approved the Zone to be upgraded to a **National High-tech Industrial Development Zone**. After the developing for more than 10 years, the Zone now becomes an important base for economic transformation and upgrade in Jiaxing. In Aug 2017, the Zone joined the National high-tech zone ranking in China for the first time, and its overall ranking entered the first half nationally, and is the **highest rank among all newly upgraded national high-tech zones**.

More info

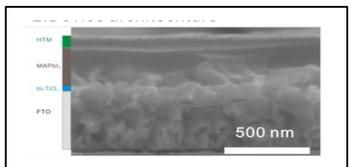
Highly Crystalline Large-grain Size Perovskite Thin Film Crystals with Good Stability


Profs. Jianbin Xu and Keyou Yan
Dept of Electronic Engineering, CUHK

The team successfully established a technique named "non-stoichiometric acid-base reaction (NABR)" to significantly improve the stability of $MAPbI_3$ perovskite thin films through reaction route optimization in organic and inorganic hybrid perovskite. **The perovskite material prepared through their NABR methodology is stable for two months under a humidity of approximately 65%, whereas perovskites prepared by traditional methods degraded distinctly after one week.** The study sheds light on the development of highly efficient PSC with low cost and high stability, which is promising to be applied in the stability enhancement work of another type of perovskite. The breakthrough has been published recently in the renowned journal *"Nature Communications"*.



Stability of the pervoskite thin film was significantly improved from 1 week into 2 months by NABR.



Structure of the MAPbI3 perovskites solar cell.

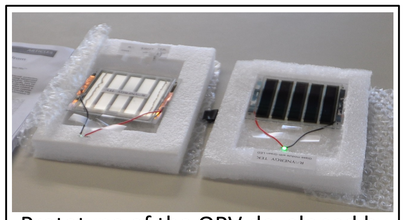
Subsequently, the team successfully fabricated highly crystalline and large-area large-grain size perovskite, significantly improved its humidity and thermal stability. In addition, the gas-solid reaction process and reactor developed by the team was able to fabricate **large-area perovskite thin film (5×5 cm^2) with dense structure,** which substantially fostered their potential in commercial application applications. The breakthrough has been published recently in the renowned journal "*Advanced Energy Materials*" under the Wiley series, and "*Nano Energy*".

More info:

Design and Synthesis of New Organic Photovoltaic (OPV) Materials

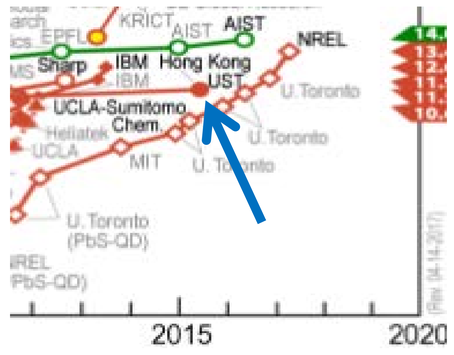
Prof. Henry Yan
Dept of Chem, HKUST

The team discovered a novel material system that would revolutionize the future development of Organic Solar Cells (OSCs). Currently, the best-performing OSC only has an efficiency of 12 - 13%. An essential step for solar cells to generate electricity - charge separation – required a significant driving force which had been a fundamental limitation for OSC's development.



Prototype of the OPV developed by the team.

The team reduced the required driving force to nearly zero and **increased its maximum efficiency to 20 – 25 %, a level comparable to the most advanced inorganic solar cells nowadays.** The finding showed that the more environmentally-friendly OSCs may be able to perform as good as inorganic solar cells in the future.



Earlier in 2015, **the team achieved single-junction organic solar cells with a record efficiency of 11.5%,** which has been officially certified. This achievement is **noted as a major technological breakthrough in the renowned National Renewable Energy Laboratory (NREL) (US Dept of Energy)** chart of "best research-cell efficiencies".

More info:

Precision Design and Control of a Flexure-based Multi-layer Roll-to-roll Printing System

Prof. Shih-Chi Chen
Dept of MAE, CUHK

Roll-to-Roll (R2R) printing technology has been widely adopted in various industrial applications, e.g. paper, textile and steel industries. Its characteristics include continuous printing and high throughput, simplified process, environment-friendly and low cost, hence considered promising in future applications.

World record high precision

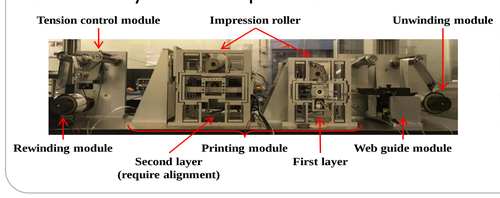
The team successfully developed a **world record technology in precision R2R printing, realizing continuous printing on 4" web with 100 nm resolution** with the following merits:
1: High resolution and repeatability
2: High throughput
3: Multiple DOFs misalignment correction capability
4: Real time contact pressure monitoring
5: Submicron layer-to-layer registration accuracy

R2R printed gold electrodes on flexible substrate (PET web)

Patent

This technology already obtained two US patents. Owing to its high precision, the technology is very suitable for manufacturing high-resolution and ultrathin flexible electronics and photoelectronic devices. By adopting this technology, the design of more tiny size and wearable devices would become possible, substantially fostering the manufacturing of portable products. Currently, the web width is 4 inch and it is able to be upgraded to 1 – 2 m.

Other applications include:
1: Diffraction gratings
2: High resolution ~85% transparent metal grids
3: Flexible organic photovoltaic cells that utilize the metal grids as electrodes
4: Organic thin-film field-effect transistor
5: Photonic metamaterial, e.g. terahertz perfect absorber
6: Multi-layer flexible printed circuit



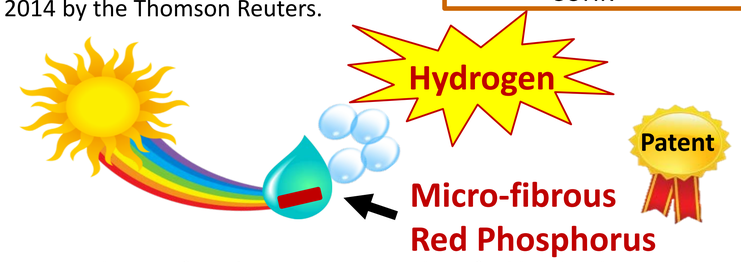
Prototype of the flexure-based multi-layer R2R printing system

More info

Using Micro-fibrous Red Phosphorus to Produce Clean Fuel (Hydrogen) from Water with High Efficiency

Prof. Jimmy Yu
Dept of Chem, CUHK

Prof. Yu holds several patents for his inventions, and was named as the "World's Most Influential Scientific Minds" in 2014 by the Thomson Reuters.



Patent

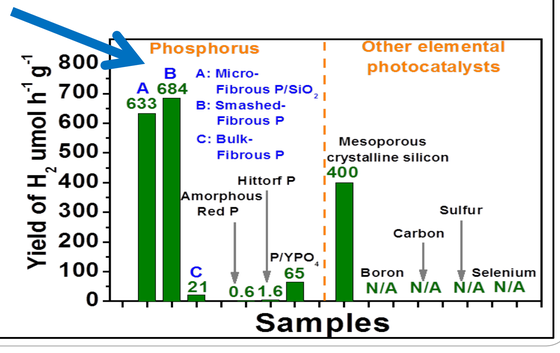
The research team found a way to create clean fuel by simply exposing water (laced with a secret ingredient) to sunlight. The key ingredient is red phosphorus. Their research discovered that **the hydrogen yield by a particular type of red phosphorus (micro-fibrous phosphorus) is much higher than that of other types, and is the highest among elemental photocatalyst at a much lower cost.**

A photocatalyst operates much as chlorophyll does in a plant, absorbing energy from light and causing a chemical reaction. The process of photocatalysis is simply a form of artificial photosynthesis. There are hundreds, if not thousands, of materials that can be used as photocatalysts. But most of them are heavy-metal oxide compounds that are expensive and complicated to produce. Very rare elements are often used to enhance their efficiency. So chemists have been searching for a single element that can perform the same function. **Red phosphorous is abundant in the earth's crust and can be extracted fairly easily.** At the same time, hydrogen has a high fuel capacity and creates more energy than other chemical fuels. The process of conversion leaves only water as a by-product, not toxic gas.

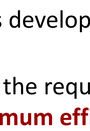
The hydrogen yield by micro-fibrous phosphorus/SiO2 is much higher than that of other red phosphorus, and is the highest among elemental photocatalyst.

More info

Youtube Video



Development of Thermoelectric Generators (TEGs)



Prof Dongyan Xu
Dept of MAE, CUHK

Patent

Thermoelectric Generators (TEGs) are devices that can directly convert heat (temperature difference) into electricity. In our daily life, a lot of heat energy was wasted, e.g.:
- Industrial heat (High / low quality waste heat)
- Transport vehicles (exhaust gas)
- Environmental heat (solar heat, hot spring)
- Others (hot water pipe, residential appliances)

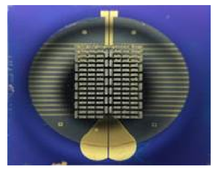
If these heat sources are harvested well, they can be utilized again.

TEGs have many advantages including high reliability, long lifetime, and environmental friendliness. Especially, compared to conventional heat engines, TEGs are compact, scalable, and can be easily driven by small temperature differences. However, its low energy conversion efficiency hindered its widespread applications.

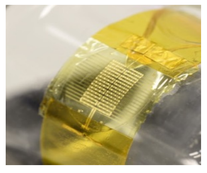
World record high power density

The team developed thermoelectric generators (TEGs) by combining pulsed electroplating with microfabrication processes. It achieved a **power density as high as 9.2 mW cm^{-2}** at a temperature difference of 52.5 K, **which is the highest value reported so far** for the electroplated micro-TEGs in the literature (*J Microelectromechan. Syst. 25*: 744-9). A US patent has been filed.

Flexible TEGs could be used for thermal energy harvesting from the human body to power microelectronic devices (such as wearable medical sensors and wristwatches). They are very flexible, making them well adhered to the skin and comfortable for the users. Applications include health, sport, and environment monitoring, as well as entertainment such as virtual reality (VR).



Non-flexible TEG



Flexible TEG

More info:

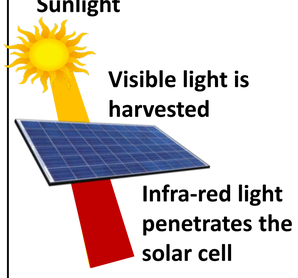
Project Milestones: Harvesting

Plasmonic and Upconversion Nanomaterials

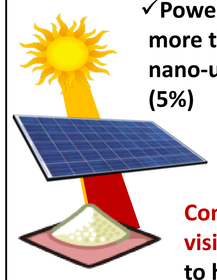
Prof. Jianfang Wang
Dept of Physics, CUHK

49% of sunlight energy falls in infrared region. Due to the limitation of bandgap in semiconductor solar cells, majority of infrared energy was not absorbed and converted into electricity. The team invented an **innovative lanthanide-sensitized oxide, reaching a maximal power upconversion efficiency of 16% for infrared light, which is at least double the efficiency of traditional nano-upconversion materials**. This material is stable, with simple fabrication and low cost, and able to successfully convert infrared light into visible light. The team also designed solar cell models of this new material. The technology also has the commercialization potential in lighting and computer monitors. This work has been published in "*Nature Communications*" in 2014.

Traditional semi-conductor solar cells



Research of CUHK



Merits
- ✓ **Power conversion (16%) is more than double of traditional nano-upconversion materials (5%)**
- ✓ **Stable performance**
- ✓ **Simple fabrication**
- ✓ **Low cost**

Converts infra-red into visible light for solar cell to harvest

Patent

Under near-infrared, the lanthanide-sensitized oxide powder developed by the team emitted strong visible light to the eye.

Infra-red

More info

High-energy-density and Low-cost Zinc/iodine-bromide Redox Flow Battery (ZIBB)

Prof. Yi-Chun Lu
Dept of MAE, CUHK

The team developed a high-energy-density zinc/iodine-bromide redox flow battery (ZIBB) which **achieved the highest reported energy density for aqueous redox flow batteries to-date**. The breakthrough was published in the renowned journal Energy & Environmental Science in early 2017, and was recently featured by the magazine Chemistry World, published by The Royal Society of Chemistry, United Kingdom.

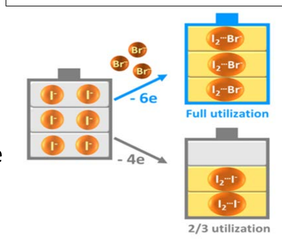
Aqueous Redox Flow Battery (RFB) is a device that generates electricity by electron transfer between two electrolytes. RFB is safe, friendly to the environment, with high design flexibility and long life (several decades), and it appears to have a high commercialization potential. With the introduction of Bromide ions (Br-), **the team boosted the energy density of ZIBB to as high as 101 Wh L^{-1}, achieving the highest reported energy density to-date**, i.e. an improvement of at least 20% in capacity relative to a control system.

Patent

The zinc/iodine-bromide redox flow battery prototype.

Potential Applications
- Electric vehicles
- Large-scale energy storage system

During the charging process, bromide (Br-) replaces iodide as the complexing agent to form iodine bromide ions, releasing the iodide (I-) to contribute energy capacity.

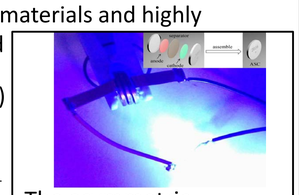


More info

3D Porous Carbon Foam-based Composites for High Performance Supercapacitors

Profs. Ching-ping Wong and Ni Zhao
Dept of Electronic Engineering, CUHK

In general, supercapacitors show high power density, but suffer from low energy density; while batteries exhibit high energy density but low power density. To increase the energy density of supercapacitor, the team developed porous carbon materials and highly pseudocapacitive materials. The team demonstrated a low-temperature chemical vapor deposition method to grow high-quality three-dimensional (3D) curved graphene, which can be used as the supercapacitor electrode to deliver high energy density (40.9 Wh kg^{-1}) and power density (70 kW kg^{-1}) as well as long-term stability. (See *Nano Energy* **2015**, 13,458.)



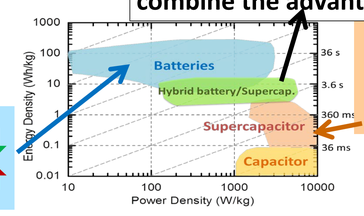
The asymmetric supercapacitors (upper right) provides stable electricity for a light-emitting diode (LED) (below).

The most efficient asymmetric supercapacitors reported to date

Another hierarchically carbon-based free-standing 3D electrode was fabricated via a facile, scalable, and cost-effective route. The integrates a lot of macropores and micropores, thus providing sufficient space for ion transport while offering a large amount of surface sites for energy storage. In addition, the carbon foam can be used as a mechanical support for pseudocapacitive materials (metal oxides or sulfides), showing even better electrochemical performance with a **high energy density of 93.9 Wh kg^{-1} and a high power density of 21.1 kW kg^{-1}, among the highest reported values for asymmetric supercapacitors.** (*Nano Energy* **2016**, 25, 193.)

Potential Applications
- Electric vehicles
- Backup power
- Flexible electronic devices

Target: Developing hybrid system that combine the advantages of the two



Battery Power density ↓ Energy density ↑

Supercap Power density ↑ Energy density ↓

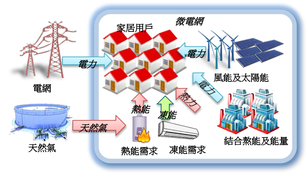
More info

Project Milestones: Utilization

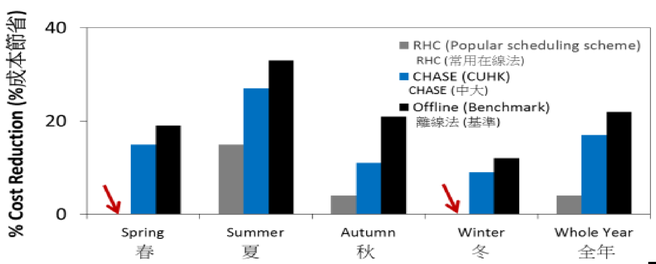
Online Energy Generation Scheduling for Microgrids

Prof. Minghua Chen
Dept of Info Erg, CUHK

Microgrid is a local electric power system with both generation and distribution sub-systems. It can use solar or other renewable energy generation or small gas generators to provide electricity in grid-connected or islanded modes. Microgrid can effectively improve power system stability, energy conversion efficiency, and the percentage of renewable energy integration. Renewable energy generation, however, is affected by weather and thus intermittent in nature, the operator also faces difficulty in accurate prediction of the local electricity and heat/cooling demand. As such, conventional energy generation scheduling solutions based on accurate generation/load prediction fail to work in microgrids with the unique generation/load characteristics.



The team broke through the conventional prediction-based scheduling paradigm and proposed an online algorithm called **CHASE (Competitive Heuristic Algorithms for Scheduling Energy-generation)**, which is based on intelligent tracking of the behaviors of perfect dispatch. In a case study of a virtual microgrid based on traces in San Francisco area, with little or no generation/load forecast information, **CHASE algorithm was able to bring about remarkable 20% cost saving**. Recently, the feasibility and performance of CHASE algorithm have been further validated at the HK PolyU Microgrid Laboratory. Extensive experimental results show that the **cost saving performance of CHASE algorithm is close to that of the lowest value reached by perfect dispatch, off by less than 10%.**



RHC: ~ 5% cost saving (No saving in spring and winter)
CHASE: Statistically ~ 20% cost saving

More info

Smart Microgrid Laboratory at The Hong Kong Polytechnic University

Prof. Zhao Xu
Dept of Electrical Erg, HK PolyU

The team established **the first-of-its-kind in Hong Kong** microgrid experimental laboratory platform - a holistic integration comprising photovoltaics, energy storage and optimization dispatch components, with total capacity of 4 kw. It acts as the implementation verifying platform for various online experimental dispatch and control strategies.

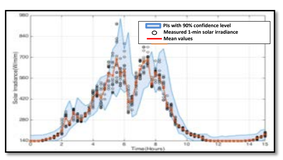
Outlook and network architecture of the laboratory microgrid platform.

First-of-its-kind Smart Demand Controller in Hong Kong

Frequency stabilization is the key factor to ensure power system operation safety. Conventionally, frequency regulation is generally provided by the generation side at high cost. The team successfully developed a real-time smart demand controller, **the first of its kind in Hong Kong,** which can be applied in different home appliances, in sizes as small as a regular credit card, which is very suitable for home use in Hong Kong. **With the controller, the home appliances are able to contribute to frequency stabilization in real time.** That is, non-critical appliances are switched off when frequency significantly drops, and rapidly resume power supply once the frequency is restored. This controller can share the load of frequency stabilization from the user side, bringing great benefits to the entire microgrid system.

Granular Probabilistic Interval Forecasting

Patent



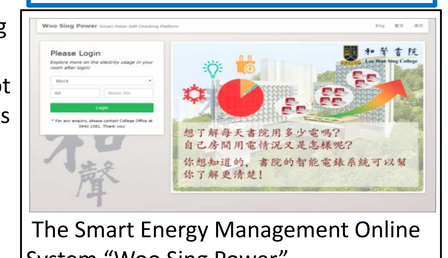
Forecasting the generation and consumption of electricity is essential to achieve energy efficiency. In collaboration with the Hong Kong Observatory, they developed high-performing granular probabilistic forecasting technology, with **90% confidence level of the 15-minute interval prediction results of solar irradiance.** This technology has has been successfully implemented in the short-term probabilistic forecasting of the solar irradiance data of King's Park at the HKO, and is applicable to solar and other renewable energies in future.

More info

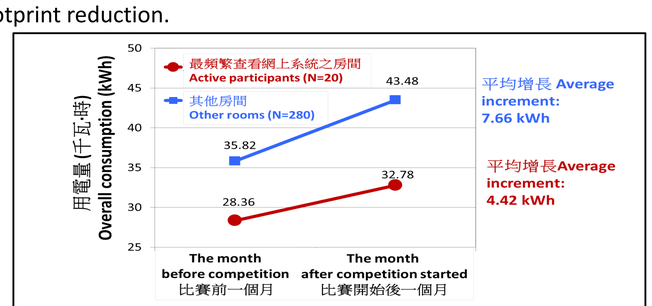
Smart Energy Management Online System: "Woo Sing Power"

Prof. Dah Ming Chiu
Dept of Info Erg, CUHK

LWS College actively invested in smart buildings. **They installed individual smart meters in all 300 dormitory rooms**, as well as monitoring system in VRV air-conditioning systems and hot water systems in public areas to measure all electricity consumption data digitally. Based on the dormitory usage these data, the team built a smart online energy management platform "**Woo Sing Power**", which provides instantaneous feedback to each room, raises the awareness in the students of energy consumption and conservation and assists administrators to find opportunities and policies to save energy. Users are able to know their usage pattern compared to others which encourages good behavior towards energy conservation and carbon footprint reduction.



The Smart Energy Management Online System "Woo Sing Power"



Result of the energy saving competition

During Feb – Apr During Feb – Apr 2017, the team designed an energy saving competition for the students. Result of the energy saving competition shows that **the competition participants have a lower increment of energy consumption (around 40%),** showing a higher awareness of energy conservation and actually saved energy. The LWS College trial project is setting a good example for the whole university.

More info