Hybrid Battery Energy Storage System for Off-Grid Solar Power System on Po Toi Island

HKIE Environmental Division Technical Seminar on 29/1/2018

Presented by CK Lau

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- Background
- RE Portfolio of HK Electric
- EV Fleet of HK Electric
- Retired EV Batteries for Po Toi
- Feasibility
- Value and Impact
- Conclusion

Background (1/2)

- Southernmost Island of Hong Kong
- Area 3.68 sq. km
- Historical max. 1,000 population
- Now around 25 households
- Famous landscape: 佛手巖、棺材石、靈龜上山、僧人石
- Historical Relics: Rock carving (1500-700 BC bronze age), Tin Hau Temple (1832), Mo's Old House, Lighthouse

Background (2/2)

Current electricity supply system on Po Toi Island

- Electricity for residential and public facilities such as lighting is supplied by the government-owned diesel generators
- Daily electricity supply is confined to 12 hours (6 p.m. to 6 a.m.)
- Transportation and refilling of fuel for the generators are arranged by local residents

RE Portfolio of HK Electric (1/3)

- To explore the wider use of renewable energy in HK Electric's power generation system aiming at achieving better environment and supporting government policy.
- To make contributions to the improvement of Local Air Quality
- To utilize Renewable Energy, especially wind and solar, as the source for power generation to supplement fossil fuel

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RE Portfolio of HK Electric (2/3)

- Grid Connected RE Systems in service

Wind	Capacity	Type
Lamma Winds	800 kW	Horizontal Axis
Marsh Road Station	2.5 kW	Horizontal Axis
Lamma Power Station Extension	2.5 kW x 2	Horizontal Axis
Photovoltaic (PV)	**Capacity**	**Type**
Lamma TFPV	1,000 kW	Thin Film
10 Substations	43 kW	Crystalline

RE Portfolio of HK Electric (3/3)

- Can we supply Po Toi Island with Solar PV?

RE for Po Toi

Planned Renewable Energy Storage System on Po Toi Island

- On top of the existing electricity network, a total of 58 kW solar panels and battery energy storage system would be installed to provide electricity in both day and night times
- Relieve heavy burden on local residents
- Mitigate pollution problem caused by diesel generators

Existing Government-owned Diesel Generators

Existing Electricity Distribution System

Solar PV System

Battery Energy Storage

EV Fleet of HK Electric (1/3)

- Development of HK Electric EV Fleet





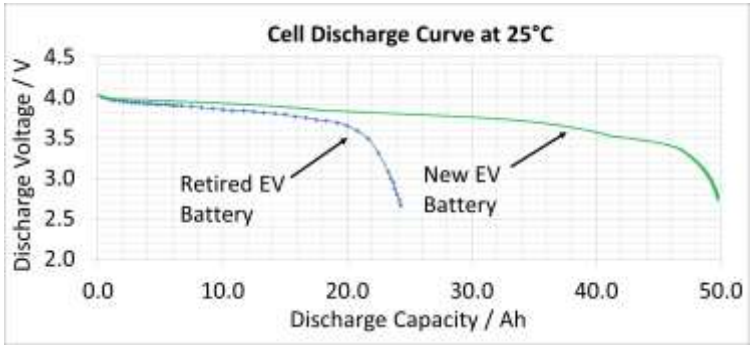


1984 → 1995 → . . . . . → 2015 → 2016

  - First launch of two Beford CF2 electric vans in the company fleet in 1984
  - Since then, different kinds of EV have been launched
  - The 100th EV has been introduced in the company fleet in 2016

EV Fleet of HK Electric (2/3)

- Batteries from retired EVs in HK Electric EV Fleet



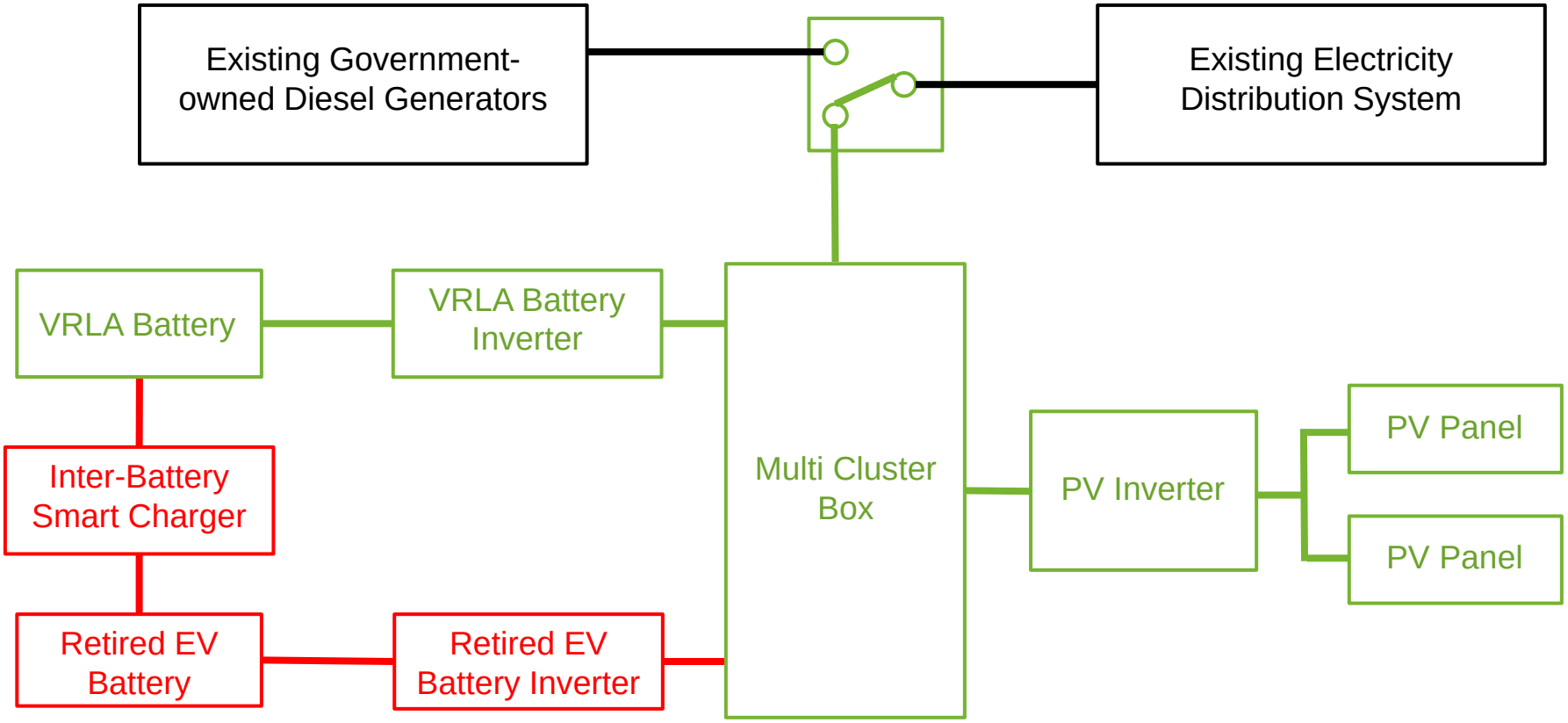
- EVs purchased in early years are about to be retired
- About 50% capacity is remained in the retired EV batteries
- Simple disposal would easily cause problems, such as wastage, pollution, and etc.
- Have to think of the way out

EV Fleet of HK Electric (3/3)

- Can we make use of retired EV batteries in Poi Toi Project?

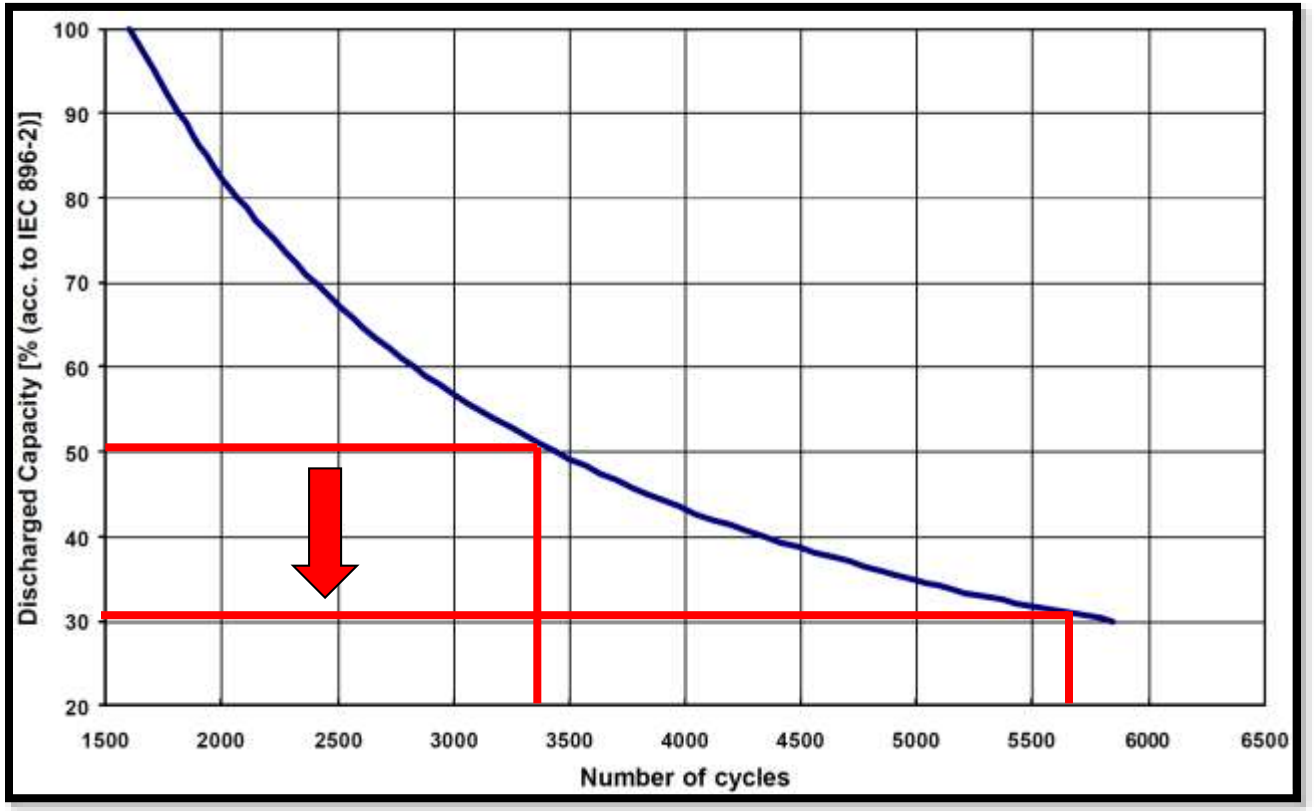
Application of Retired Batteries from EV in Po Toi Project (1/6)

- "Hybrid Battery Energy Storage System" for extending service life of VRLA batteries



Application of Retired Batteries from EV in Po Toi Project (2/6)

- Extending service life of VRLA batteries by:
  - Reduction of Depth of Discharge (DOD)
  - Control of Charge/Discharge Rate by Temperature
  - Advanced Charging Method



Application of Retired Batteries from EV in Po Toi Project (2/6)

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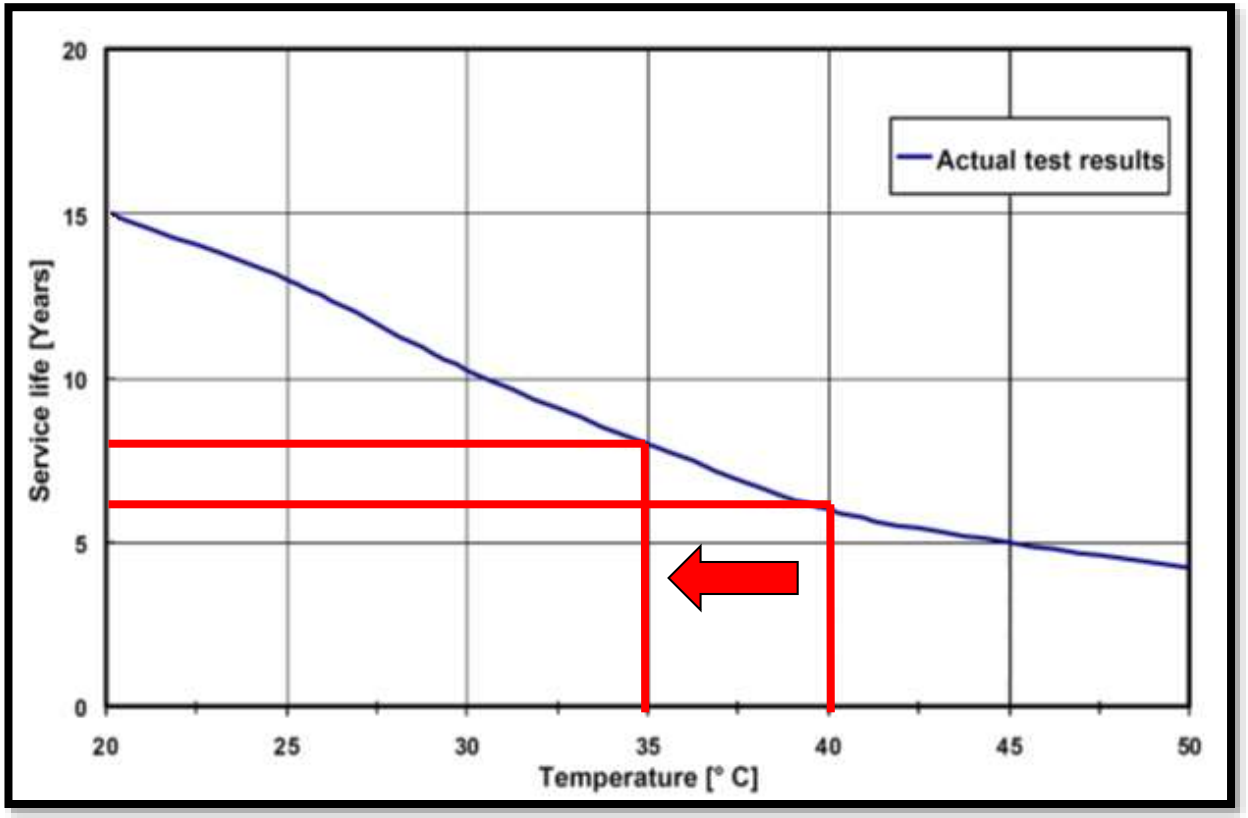

Application of Retired Batteries from EV in Po Toi Project (2/6)

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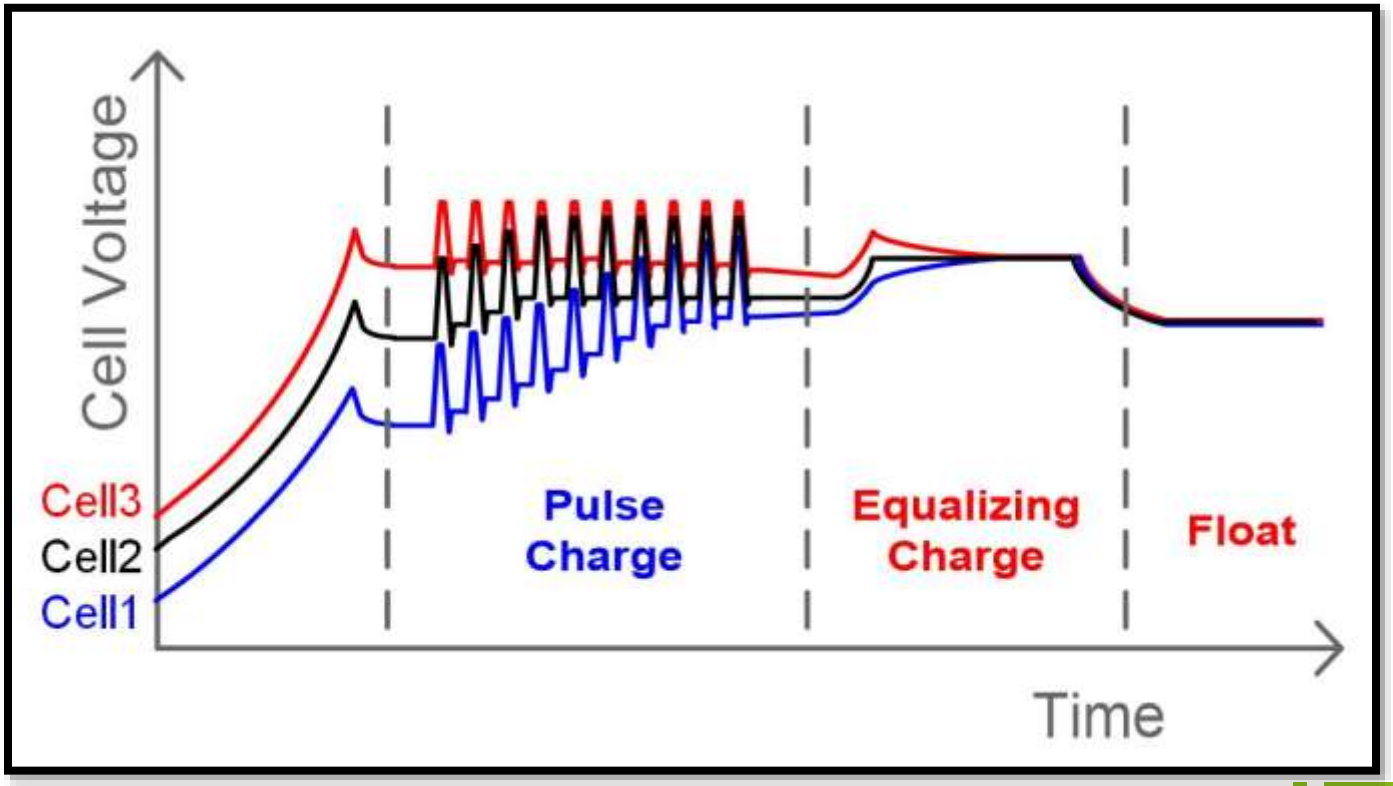
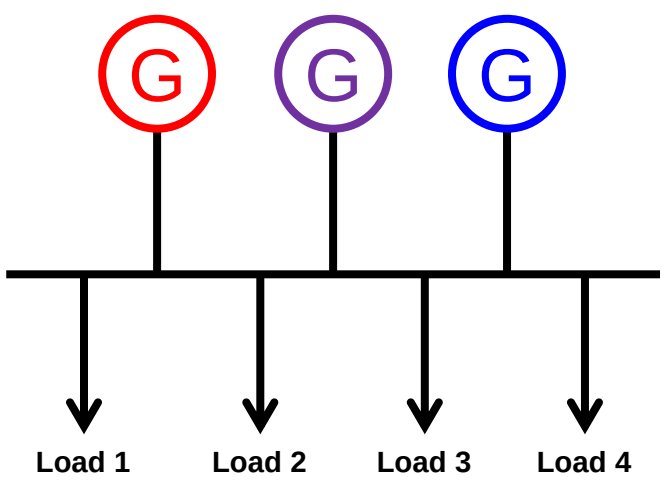
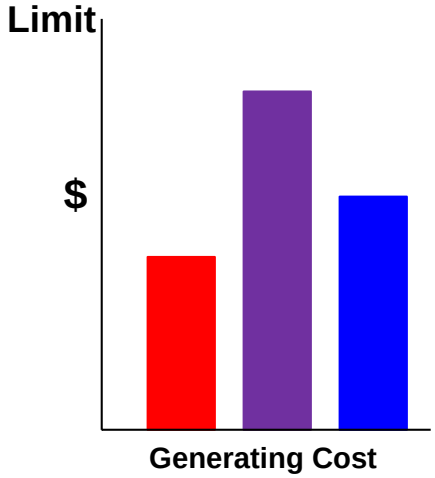
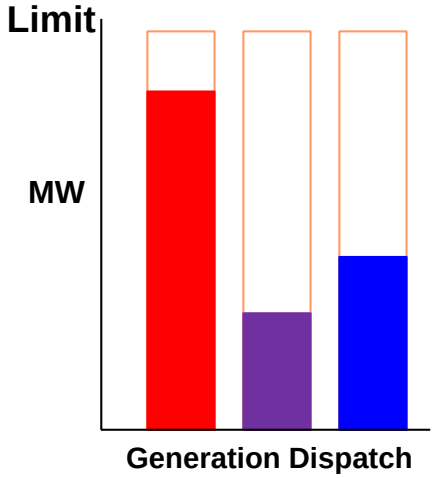


Application of Retired Batteries from EV in Po Toi Project – (3/6)

- Coordinating charging and discharging processes between retired EV batteries and VRLA batteries by adopting the concept of **"Economic Dispatch"**







➢ ***Instead of fuel and operating cost, SOC & temperature control are used***

Application of Retired Batteries from EV in Po Toi Project – (4/6)

- Evaluation on performance of retired EV batteries from HKE's retired EV

Aging Equations:

Decrease in capacity: $C_a = 1 - \alpha_c \cdot \sqrt{t} - \beta_c \cdot \sqrt{Q}$

Increase in resistance: $R_a = 1 + \alpha_r \cdot \sqrt{t} + \beta_r \cdot Q$

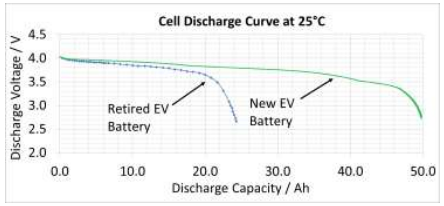
Calendar | Cycle

t: time ; Q: charge throughput

EOL Capacity & ESR Estimation Function for 2nd Life:

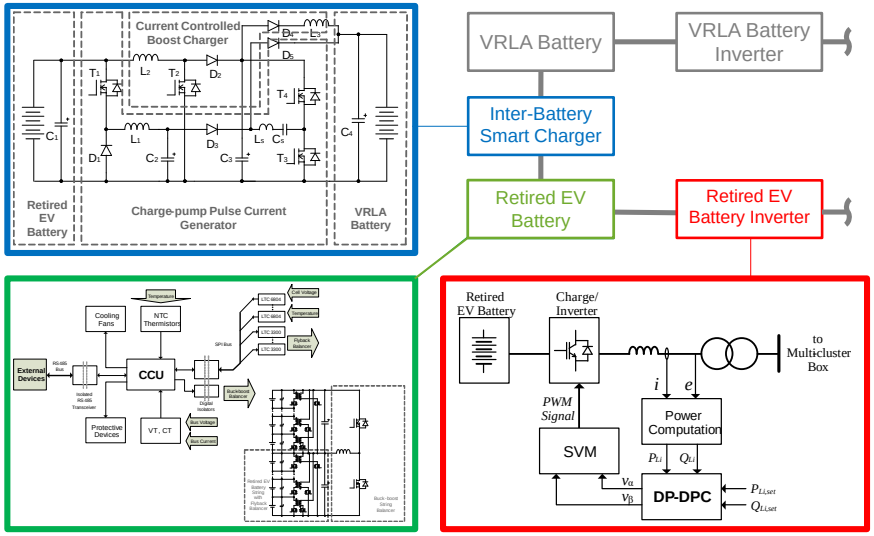
$$\begin{cases} C_{EOL} = 1 - \alpha_{c@26°C} \cdot \sqrt{9.39 + T_R} - \beta_c \cdot \sqrt{\left[1 - \left(\frac{1 - C_{EOL}}{1.5}\right)\right] \times 2 \times 365 \times (9.39 + T_R)} \\ \frac{R_{EOL}}{1.8} = 1 + \alpha_{r@26°C} \cdot \sqrt{8.54 + T_R} + \beta_r \cdot \left[1 - \left(\frac{1 - C_{EOL}}{1.5}\right)\right] \times 2 \times 365 \times (8.54 + T_R) \end{cases}$$

- The 6.5 years old retired Mitsubishi i-MiEV NMC Li-ion batteries have ~40% remaining capacity and 5mΩ ESR (~94% cycle efficiency)
- From the aging equation, the 1st life is equivalent to about 8.5 years in the proposed HBESS
- If the 2nd life of the EV batteries is also defined to be 8.5 years, the derived function gives ~20% EOL capacity and resistance of ~6.5mΩ



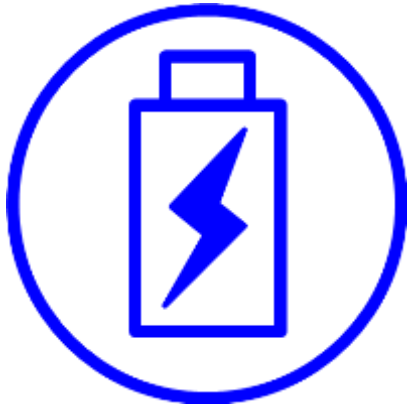
Application of Retired Batteries from EV in Po Toi Project – (5/6)

- Design of major equipment for the retired EV batteries
  - **Dedicated charger/inverter with DPC** which is capable of **real-time management** of real & reactive power
  - **Specially designed Battery Management System (BMS)** with advanced balancing, real-time cells' SoC, SoH, remaining useful life (RUL) estimation
  - An **auxiliary inter-battery charger** linking the retired batteries and VRLA batteries to **enhance the useful life** of the new batteries



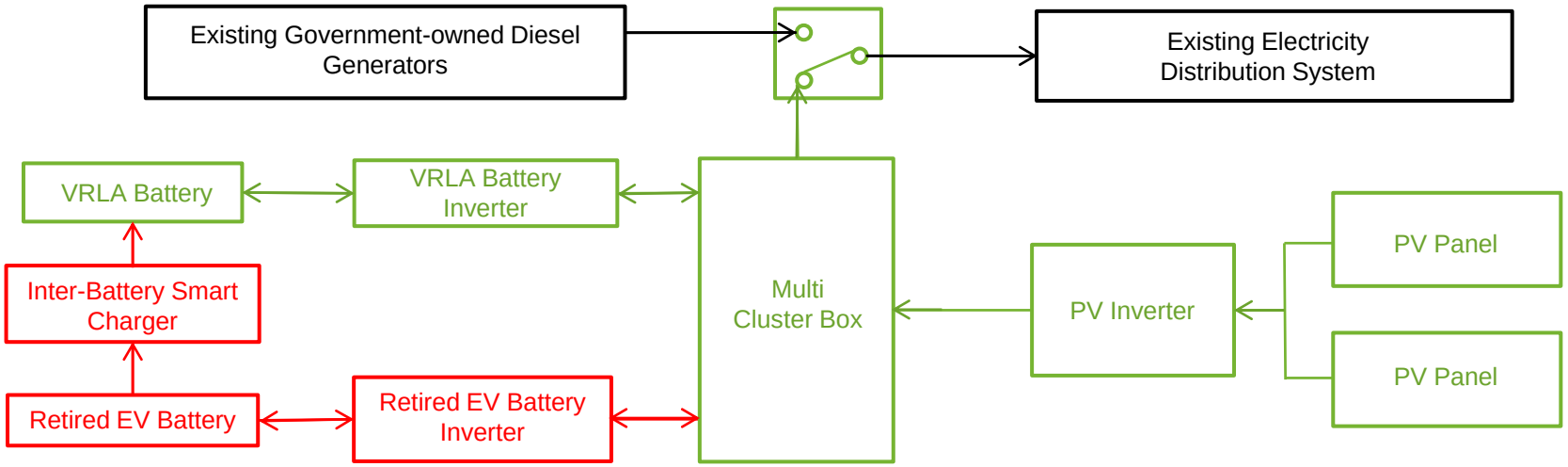
Application of Retired Batteries from EV in Po Toi Project (6/6)

- Contributions
  - Reduction of cost and carbon footprint due to less frequent replacement of VRLA batteries
  - Thorough utilization of RUL of retired EV batteries
  - Provision of useful data for further improvement and research
  - Educating and promoting “Green” concept to the public



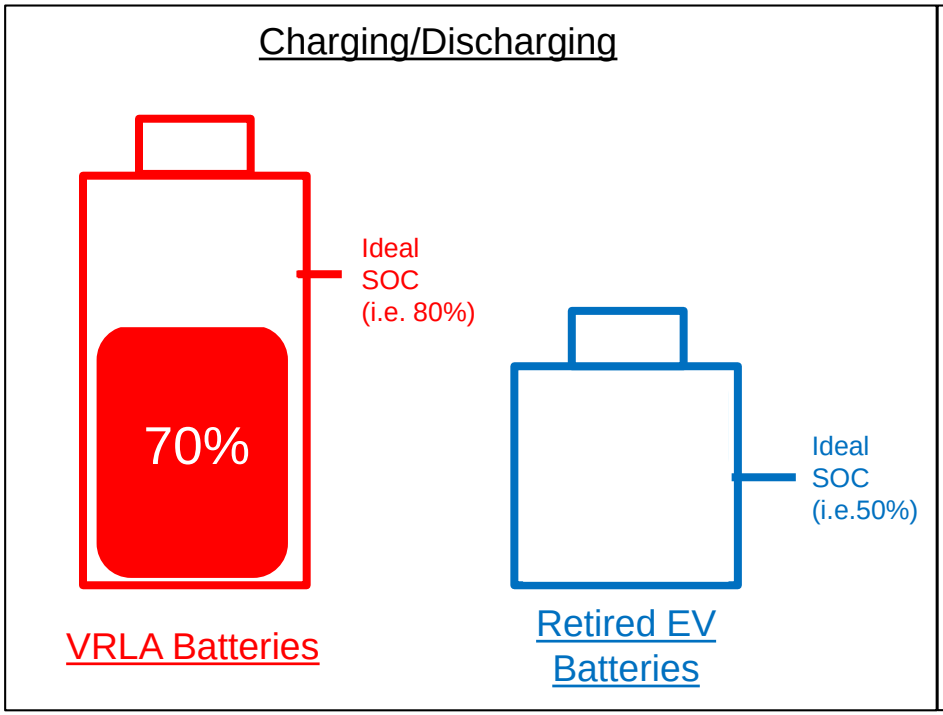
Conceptual Design (1/4)

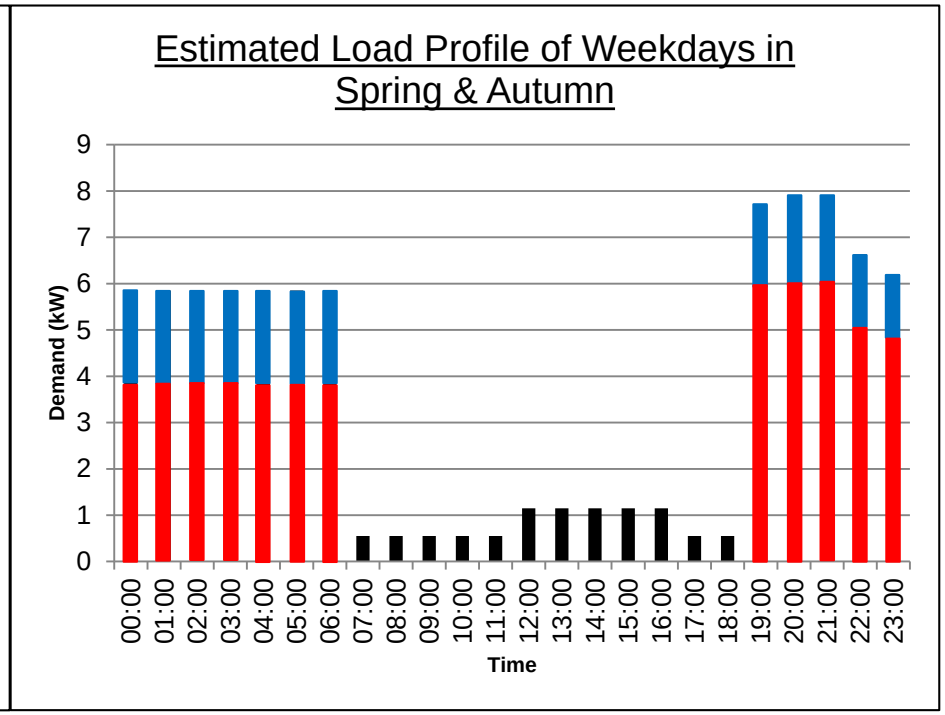
- Make use of retired EV batteries to ***extend*** service life of VRLA batteries
- A high system ***reliability*** is maintained as impact caused by uncertain performance of retired EV batteries is mitigated
- RUL of retired EV batteries is ***fully utilized***



Conceptual Design (2/4)

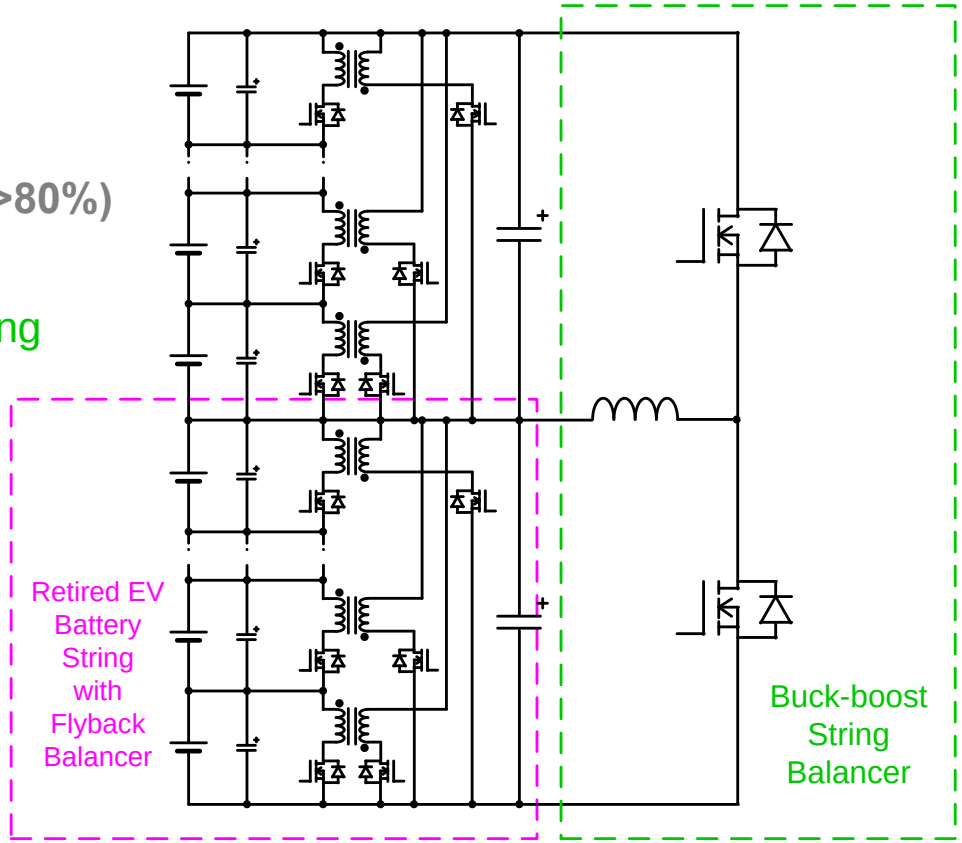
- Applying the concept of “Economic Dispatch” to coordinate the retired EV batteries and VRLA batteries during charging and discharging



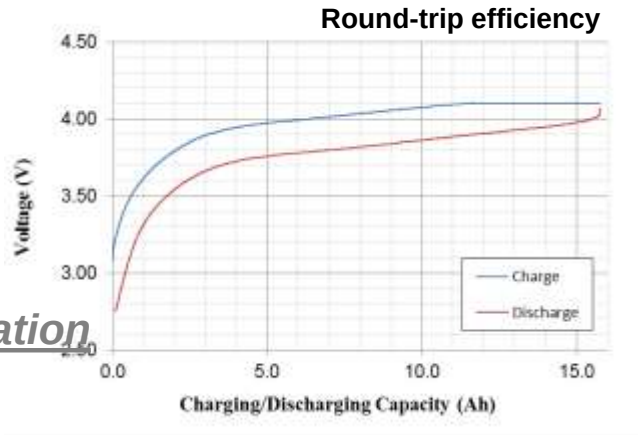


Conceptual Design (3/4)

- Specially designed BMS for the retired EV batteries
  - ***2-stage battery balancer***
  - Retired Batteries: ↑voltage imbalance
  - Conventional balancing circuits
    - ↓speed (<0.1A) dissipative
  - Fully active balancing system
    - **↑speed (>5A) ↑efficiency (>80%)**
    - 1) Flyback: Cell-to-String
    - 2) Buck-boost: String-to-String



Conceptual Design (3/4)



- ***Real-time remaining useful life (RUL) estimation***
- Individual cell (parallel module) monitoring
  - Capacity & efficiency
- Facilitate the maintenance process
- Ratiometric method combining
  - Coulomb counting (Ah estimation)
  - Open-circuit voltage (OCV) (% estimation)
  - Estimation of RUL by the fitted aging functions with predefined EOL capacity and efficiency

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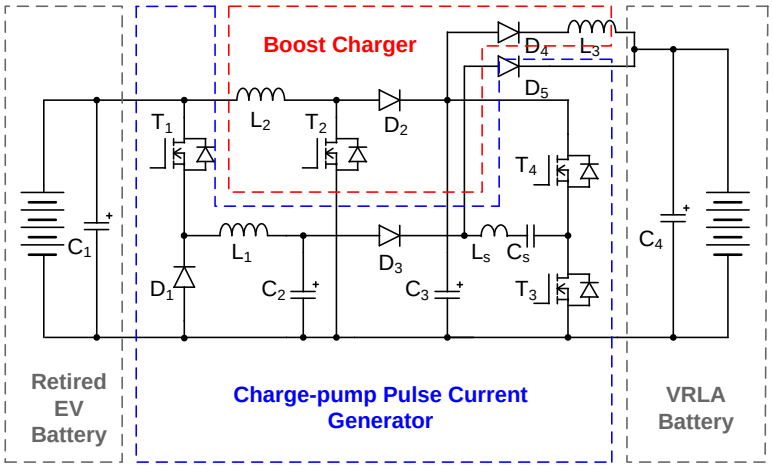
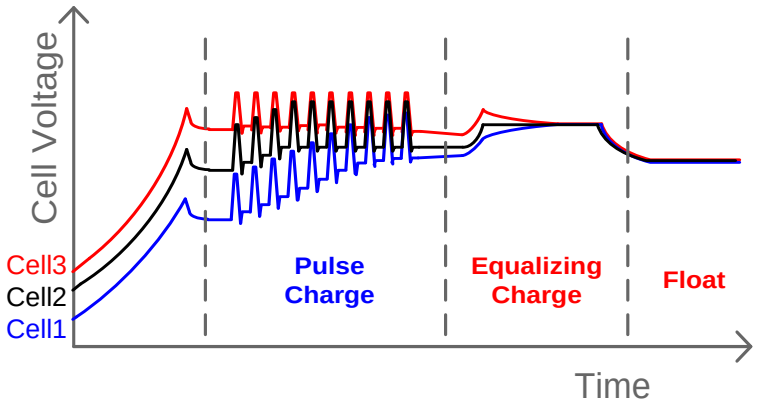
Conceptual Design (4/4)

- ***Inter-battery smart charger*** for advanced charging methods
  - In addition to the battery inverter, the VRLA batteries can be charged by the retired batteries to maximizing the benefit of the proposed HBESS
    - **Charge-pump** for **pulse-charge**
    - **Boost charger** for **equalizing charge** & **float**
  - Mitigate the sulfation in VRLA batteries
  - By-passing the inverters to improve energy efficiency





Feasibility (1/3)

- Research and technical support by PolyU
  - Electric Vehicle Research Laboratory
  - Energy Storage Laboratory

  Research facilities for:
    - Electrical system
    - EV technology
    - Battery testing & aging

  Research experience in:
    - Battery management system
    - Energy storage system
    - Power electronics
- Literature review & simulation

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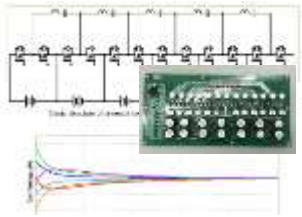
EV Charging System (2012)

Integrated Charger (2009)



Cell Balancing Circuit (2015)

Hybrid Storage System

30 kVA Distributed Storage System

BMS for E-Bus (2015)

Super-capacitor/Li-ion Battery Hybrid Storage EV

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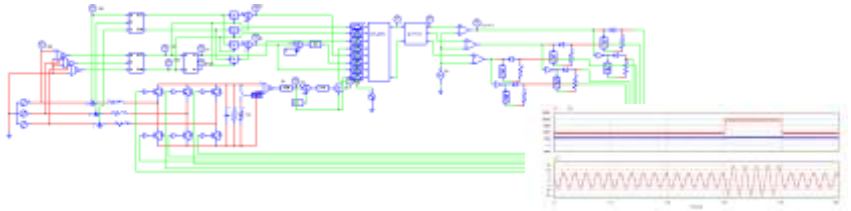
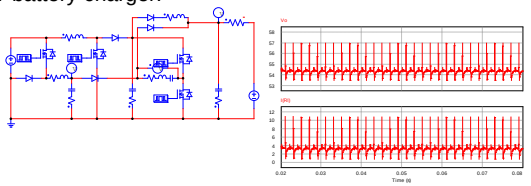
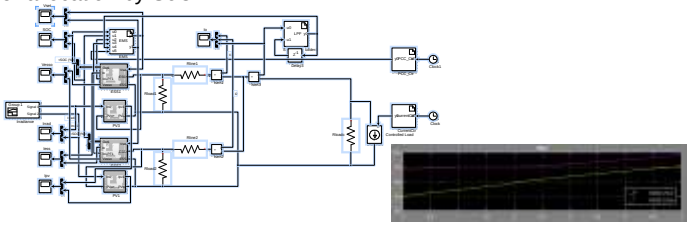
DPC controlled charger/inverter:



Inter-battery charger:

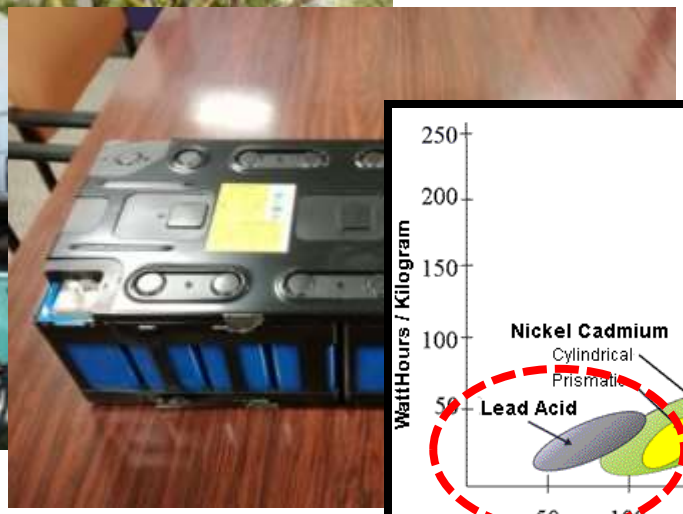


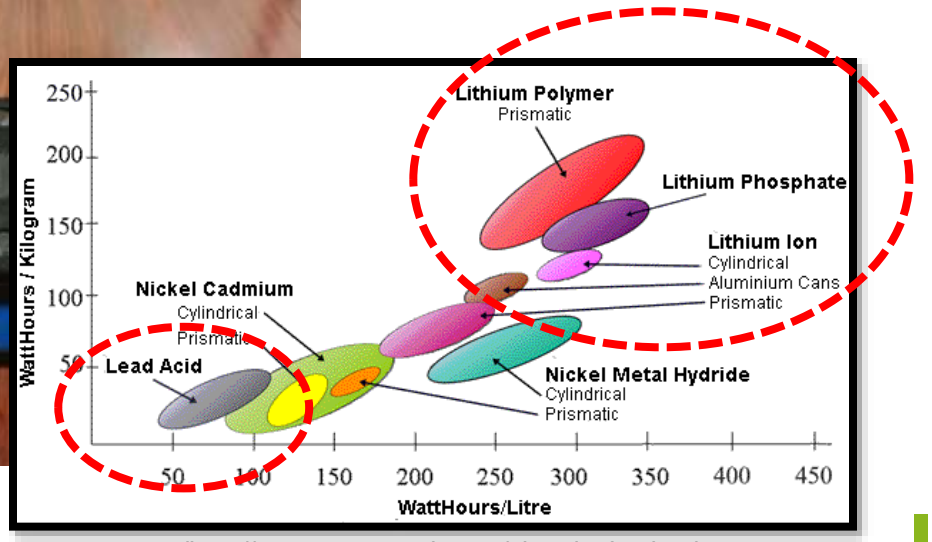
Power allocation by SoC:



Feasibility (2/3)

- Po Toi Project is a realistic project which has been designed in details
- Applying retired EV batteries in Po Toi Project has only tolerable influence to the original system design and project plan (i.e. Cost and space requirement)

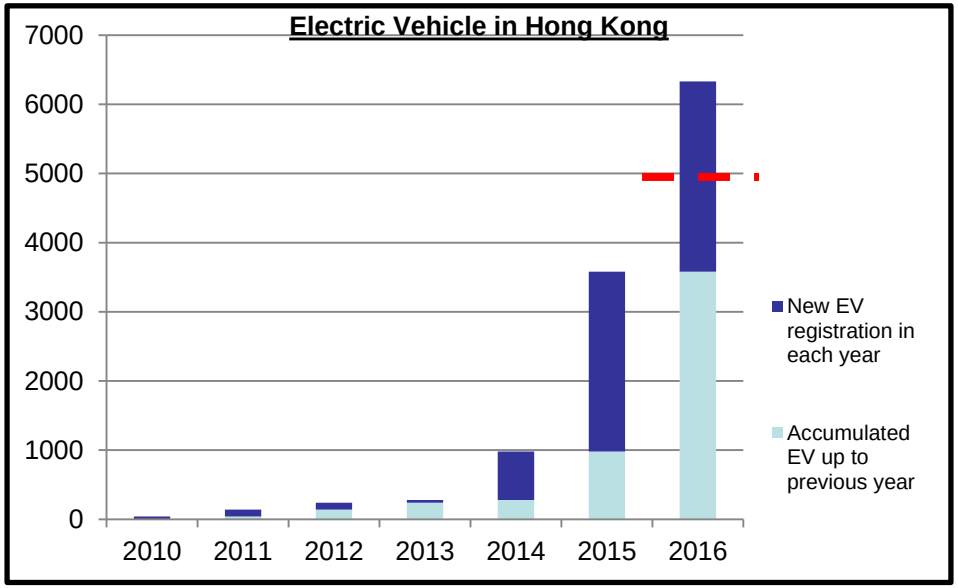




(http://www.mpoweruk.com/chemistries.htm)

Feasibility (3/3)

- To apply retired EV batteries in Po Toi Project, replacement of batteries is required for every several years
- The supply of retired EV batteries should not be a big concern as HK Electric has its own EV fleet
- As EV is becoming more and more common in society, there will be a large amount of supply of retired EV batteries

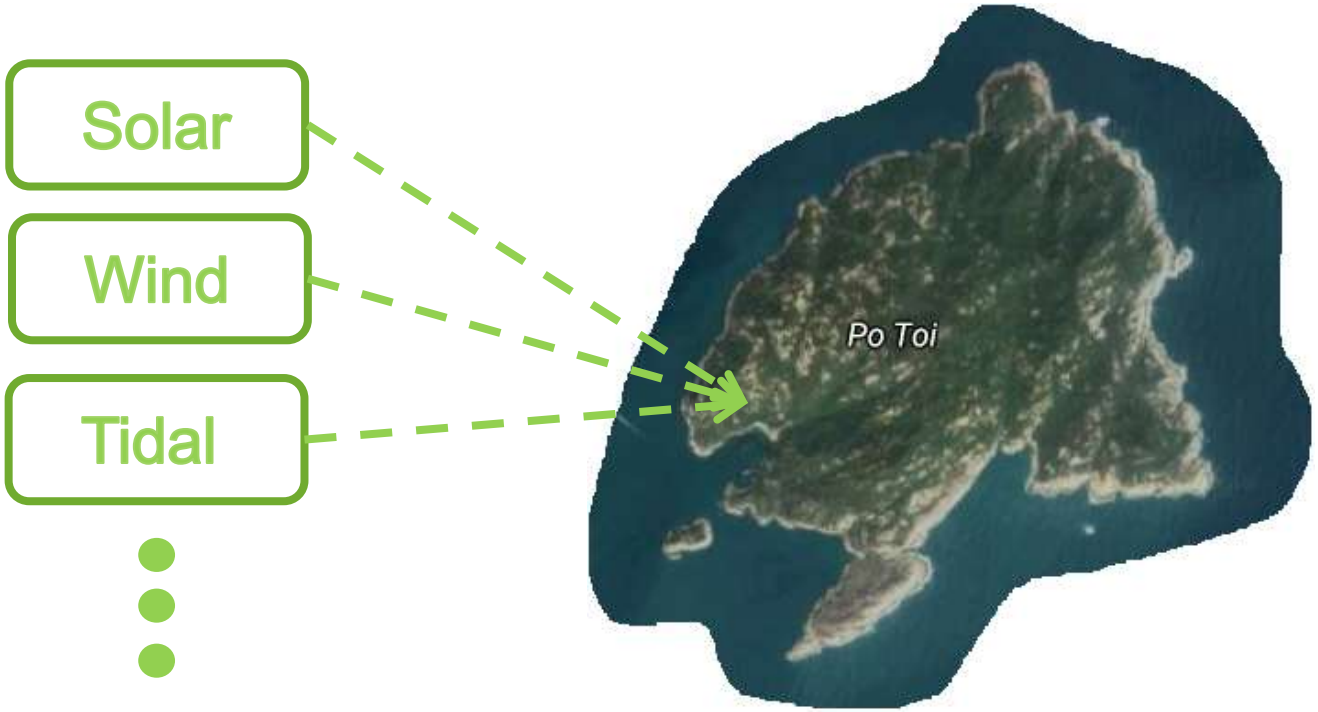


Value and Impact (1/3)

- Reduction of cost and problem of pollution due to less replacement of VRLA batteries
  - 37.5% saving for battery cost
  - Carbon footprint of 55,964 kg is reduced
- Useful data could be obtained from Po Toi Project for further improvement, development, and research purposes
  - Aging behavior of the 2nd life of batteries in the proposed application vs the 1st life
  - Development of specific technologies/equipment for the applications with 2nd life of retired batteries from EV (e.g. charger, SoH estimation, balancing techniques, etc.)

Value and Impact (2/3)

- The “Hybrid Energy Storage System” is compatible to different renewable energy, such as solar, wind, tidal, and etc.
- Turning Po Toi Island into a real-life example for “Green Life” promotion and education



Value and Impact (3/3)

- The application of HBESS in Po Toi Project has won the championship in "International Competition on Second Life for Retired Batteries from Electric Vehicles" organized by Environmental Protection Department in 2017

Conclusion

- Providing a practicable solution and real implementation to deal with the growth of retired EV batteries and hence contributing to promotion of EV
- High system compatibility with support by detailed research and encourages the usage of renewable energy
- Environmental Impact Study and Land Survey are being carried out.
- Developing Hong Kong into a ***"FUTURE GRID"*** with a wide variety of green elements

Thank You