Beyond JUMPSmartMaui

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Agenda

1. EV Infrastructure Installed by JUMPSmartMaui
2. Demonstration Result Overview
3. Beyond JUMPSmartMaui
4. Triple-Active-Bridge (TAB) Converter for
5. Autonomously Distributed Power Network

1. EV Infrastructure Installed by JUMPSmartMaui

1-1. Hawaii's Environment for Vehicle-Grid Integration

- 100% renewables in **electricity generation** by 2045
  - Action plans in Hawaiian Electric's Power Supply Improvement Plans (December, 2016)
    - Maximize distributed energy resources
    - Make high use of demand response programs

- 100% renewables in **ground transportation** by 2045
  - Ranks second in the nation behind CA in the number of EVs registered per capita
  - 4 county mayors in Hawaii signed proclamation in December
  - Honolulu and Maui to transition all of their fleet vehicles to clean energy by 2035

External evaluation of JUMPSmartMaui

V2G: A Global Roadtrip - an Everoze & EVConsult report

everoze

“We delivered V2G at scale…from real world families we had no control over”
Hitachi

2012–16

JUMPSmartMaui

Deployed 80 V2H chargers which demonstrated discharge, in response to grid signals, over 6–9pm peak period thereby helping manage distribution system loads and frequency events.

The project was part of major broader smart grid project seeking to integrate renewable energy, electric vehicles, energy storage, and controllable loads in Maui, Hawaii.

PROJECT VALUE *N/A*

PARTNERS

- HITACHI — *Lead*
- NEDO — *Funder*
- Mizuho Corporate Bank and Cyber Defense Institute, the State of Hawaii; the County of Maui; Maui Electric Company and Hawaiian Electric Company; Hawaii Natural Energy Institute; Maui Economic Development Board, Inc.; University of Hawaii Maui College

PROJECT FOCUS

1. TECHNICAL
1. SOCIAL
1. COMMERCIAL

SERVICE PROVISION

BENEFICIARY	DSO/TSO (same organisation on Maui)	DSO/TSO (same organisation on Maui)	
SERVICE	Peak reduction	Frequency response*	*) Service provided in the demonstration project led by Hawaiian Electric that followed JUMPSMartMaui
V2G?	Yes via V2H	Yes via V2H	
WHEN TO ACT	Forecast based on system req.	Change in frequency	
TRIGGERING ACTION	Backoffice control signal	Control signal from DSO	
RESPONSE SPEED	< 4 secs	< 4 secs	
DURATION OF SERVICE	3 hours (6-9pm)	2 hours	
STATUS	Proven	Proven	

READINESS

HAWAII, USA

SERVICE	3 in trial. Commercial deployment exp. 2018/2019	3 in trial.	
TECHNOLOGY	9	Commercially available	
MARKET	M>H	At time of trial, active demand response market, although limited to I&C. Now revised to allow access by broader range including V2H	
REGULATION	M	Interconnection standards were challenging – now revised to UL certification	

http://www.nedo.go.jp/content/100864936.pdf

CUSTOMER SNAPSHOT

PLUG-IN TIME: 0hrs … NIGHTIIME

SEGMENT	*INDIVIDUAL*	CHARGING LOCATION	*HOME*
CHARGE POINT	*6kW Hitachi DC*	VEHICLE	*Nissan LEAF 80 cars*
CUSTOMER OFFER	Free charger provided, with no other economic incentive. Participants involved due to environmental or community interest reasons		

Lowest average SoC was at 7pm but even then half of vehicles had 70% or more SoC.

Lack of incentive to plug in may have reduced how often people plugged in when they got home, particularly when they could charge using the public fast charging stations.
Complicated to get new users interested. Significant and targeted recruitment campaign, with jargon free branding, marketing material and one to one visits

OPERATIONAL SNAPSHOT

BATTERY USAGE FOR V2G: **30–95%**

USER BEHAVIOUR

80 families using the vehicles 'normally', typically plugging in on return from work. This meant limited diversity and restricted when V2G could be provided.
Families often used other DC fast chargers, which meant only plugged in on average every other day.
Trial ran in 2013–2014 with V1G which made easier to introduce V2G as good data on driving patterns.

ARCHITECTURE

Energy control via autonomous, decentralized system. Hitachi developed integrated DMS, with localised autonomous DMS. EV charging utilised these DMS with EV Control Centre to create a charging schedule so as to fill up the gap between the estimated power generated by renewable energy and load of the next day. It then takes account of each EV's connection status to the normal charger and the desired charge end time to instruct the charge start time to each EV. ChaDeMo protocol used.

AVAILABILITY & PERFORMANCE

Export limited to 1kW, although 6kW modelled. Interconnection standards were onerous and Hawaii specific. (These now been replaced with US-wide UL certificate which is helpful).
Forecast of vehicle behaviour in aggregate was challenging.
Hawaiian electric have totally revised demand response programme, ~~partly due to success of this programme~~. V2G directly not included but V2H, as a form of DR will be eligible. Bidding underway for delivery late 18/19. EVs are very fast and flexible and when combined with other resources can be very valuable to grid

1-2. JUMPSmartMaui Project (2011~2016)

- Install / operate infrastructure to help the Island transition to clean energy transportation
- Help electrical grid introduce more renewables by utilizing distributed energy resources especially electric vehicles (EVs)

Project Lead

*The project was supported by Japanese government (METI / NEDO)

1-3. Installed DC Fast Charging Stations

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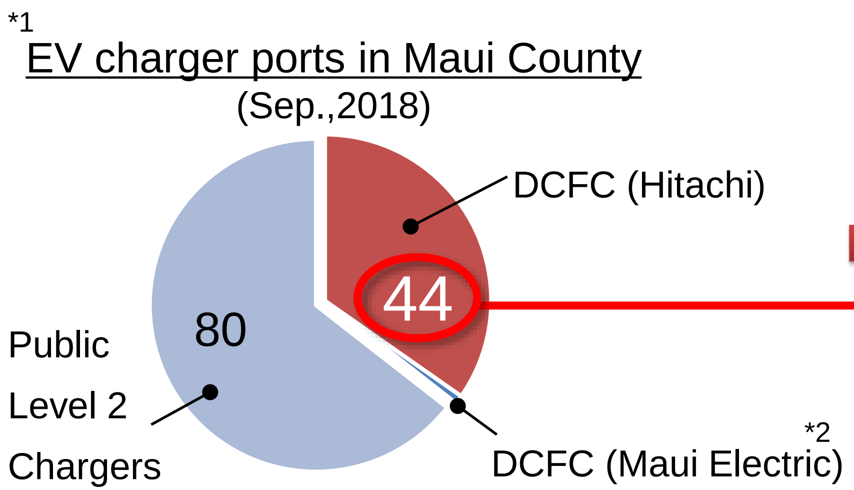
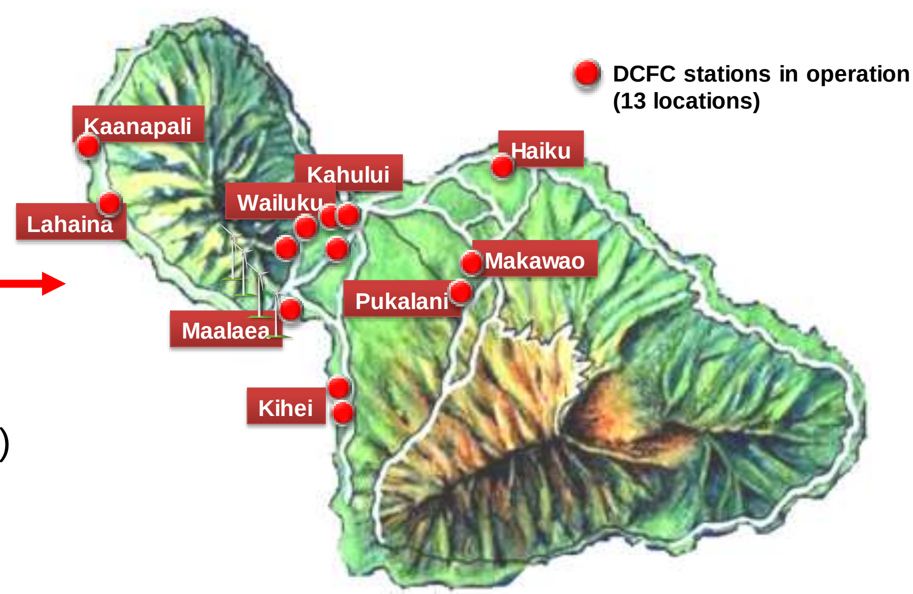
- **13 stations with 44 ports** were installed in JUMPSmartMaui project
- They are **now in operation on commercial basis**

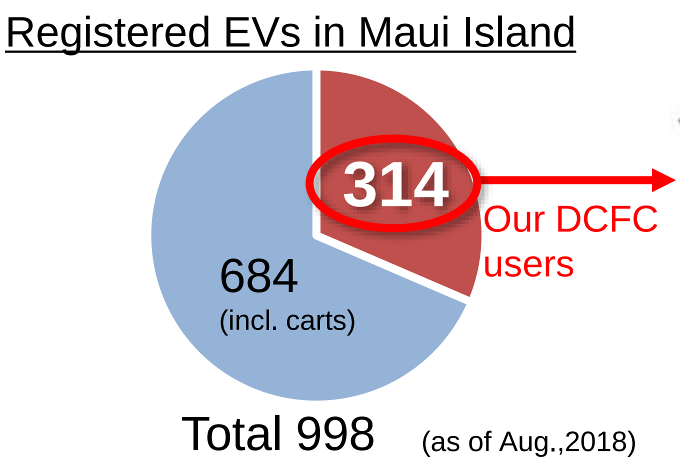




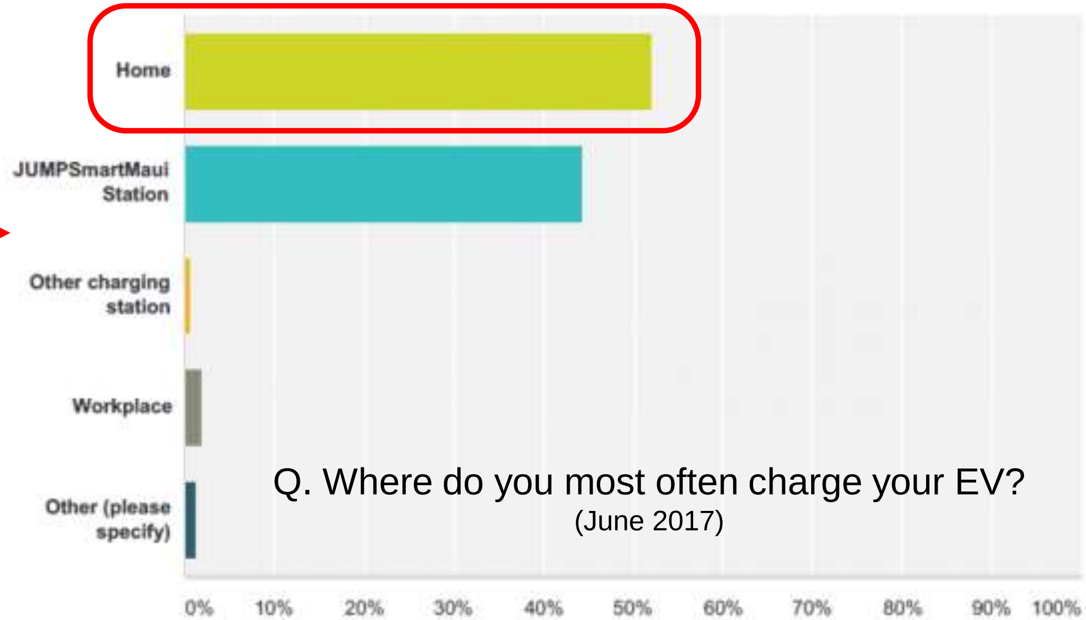
*1) Hawaii Energy Facts & Figures (June, 2018) / State Energy Office
*2) based on HECO website as of Sep.,2018

1-4. Charging Behavior at DC Fast Charging Stations

- Currently in commercial operation with **>300 users**
- Even DCFC users charge at home often

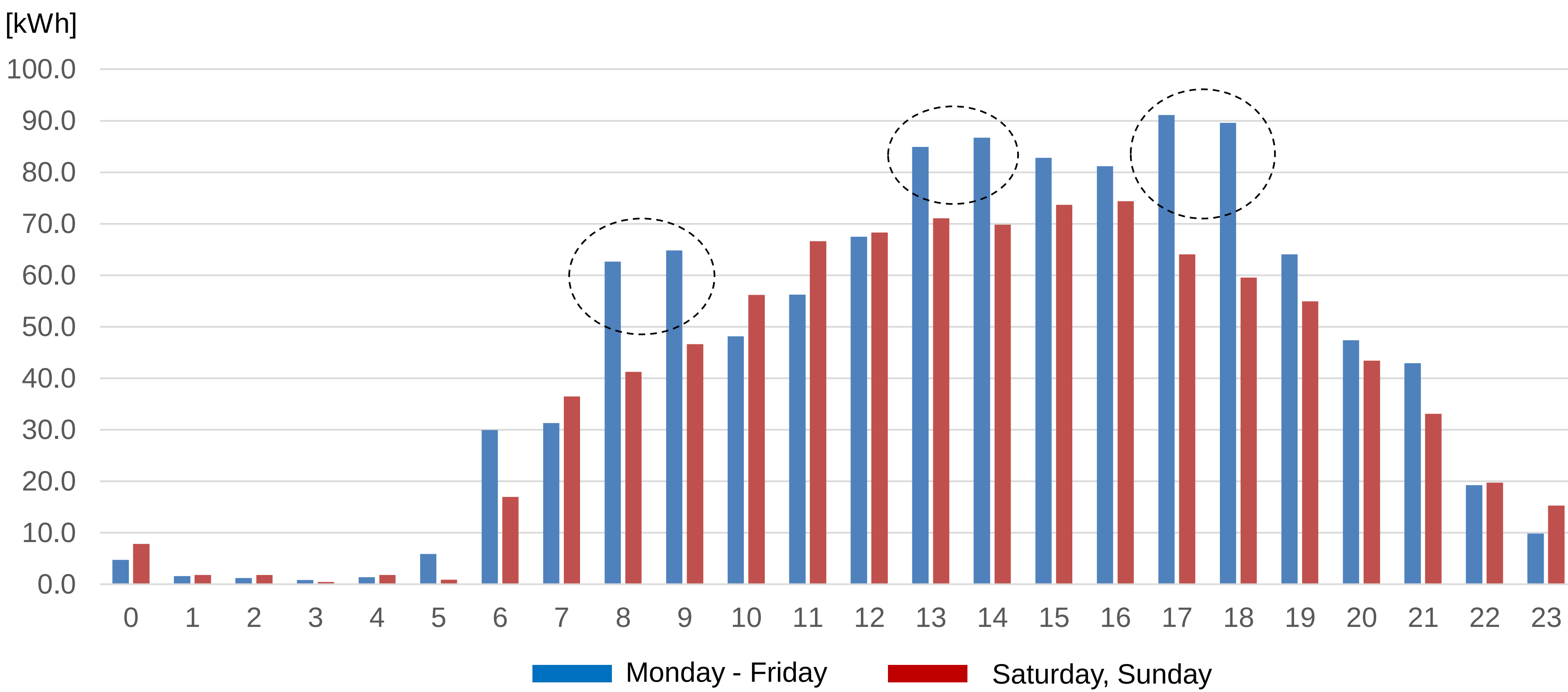


Source : Hawaii State Energy Office



1-4. Charging Behavior at DC Fast Charging Stations (cont'd)

- Usage peaks at 5~6pm in weekdays
- Unless DCFC ports are enough, increase in charging at home after 6pm is expected (**inconvenient for the grid**)



1-5. Bi-directional Charger - Maui Demonstration Model

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Hitachi installed its **bi-directional charger(EV-PCS) at 80 real residents** as a part of EV infrastructure in Maui.

Features of the bi-directional charger

- Charging and discharging in CHAdeMO protocol at 6kW
- Remotely controlled by IEEE2030.5 (SEP2.0) interface
- Real and reactive power capability
- Vehicle-to-Load available when disconnected from the grid

1-6. Demand Response Programs demonstrated

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- Hitachi has demonstrated various DR programs as shown below

= already demonstrated

	Program	Forecast･Meter Data	Notification	Communication	Response Speed	Accuracy	Duration	Annual limitation	Number of event
1	Regulating Reserve	Near Real time	**Continuously**	DNP3 to head-end	**4 sec**	Less than 0.1MW	**30 min - 2 hrs**	182 hrs	max 2/day
2	Capacity	15 min or Less than 15 min	**One day before**	**Internet (5 minutes) VTN-VEN 2way**	**1 hr**	10% of forecast	Minimum 4 hrs	N/A (Daily)	N/A
3	10 min Reserve	**5 min**	**Same time that event happen**	**Internet (5 minutes) VTN-VEN 2way**	**10 min**	10% of forecast	Max 1 hr	100 hrs	max 2/day
5	FFR (Contingency Reserve)	15 min or Less than 15min	Same time that event happen	Parameter setting, Performance confirmation (2way)	12 or 30 cycles	Set-point:: ±0.02Hz Time Delay Setting: ±0.0167 cycle	Max 10 min	25	max 2/day

Not Covered

2. Demonstration Result Overview

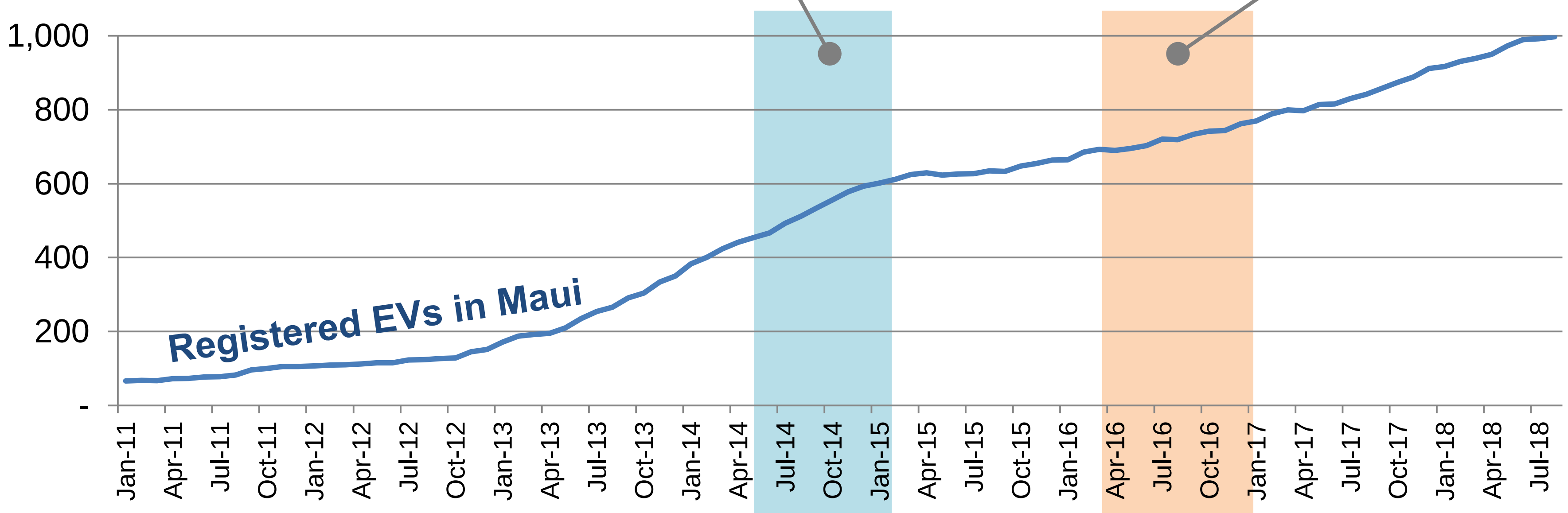
2-1. Demonstrations Overview

Managed Charging (V1G)

- **200 houses participated with level-2 chargers**
- Managed charging based on utility's forecast and the participants' needs

Vehicle-to-Grid (V2G)

- **Additional 80 houses** participated with Hitachi **bi-directional charger**
- Managed charging / discharging



2-2. Electrical Grid in Maui

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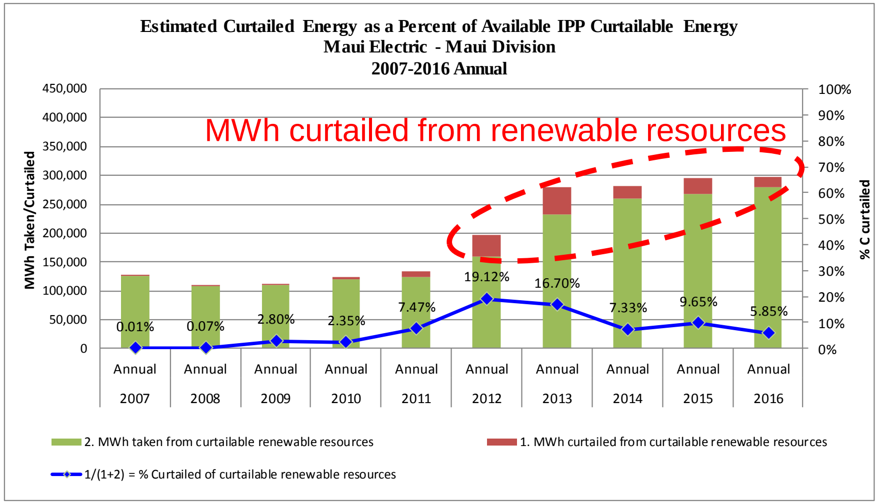
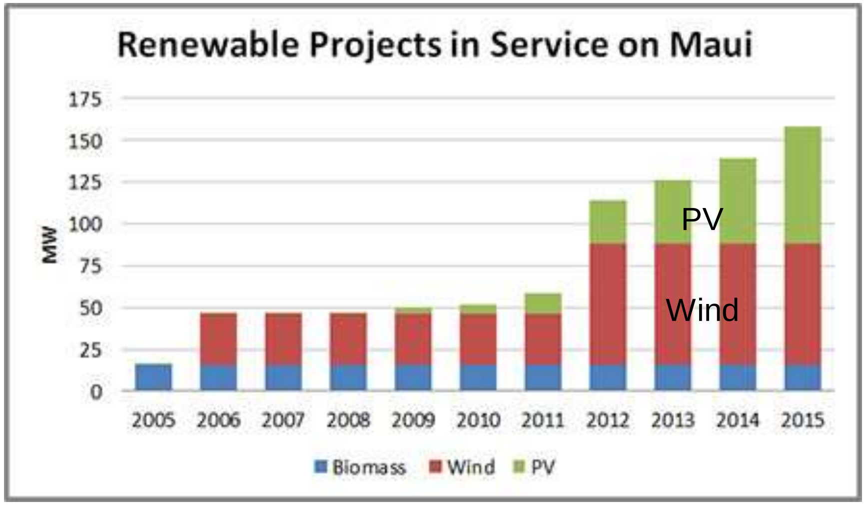
Renewable energy percentage in Maui was already *34% in 2017

*) proportion to total electricity sales(kWh)

- Curtailed renewables in 2016 was equivalent to full charging of 1,000 EVs with 40kWh battery every day
- Highly populated customer-sited solar generation causes issues on grid operations

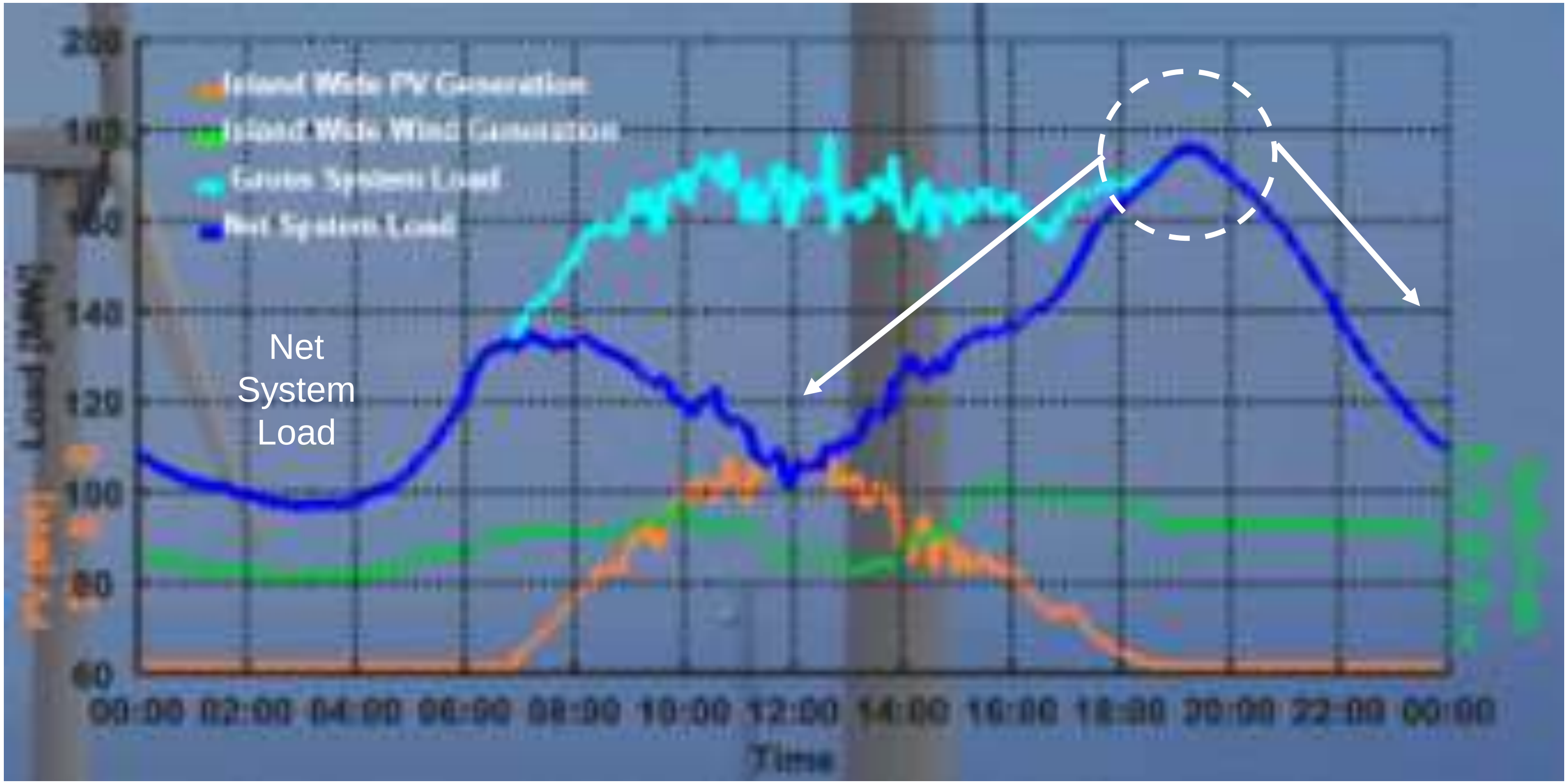




2-2. Electrical Grid in Maui (cont'd)

EVs can both cause and mitigate issues

- Loads in peak period (7~8pm) are **expected to shift either during daytime or midnight**



Source: Maui Electric

2-3. Natural Charging Behavior at Home

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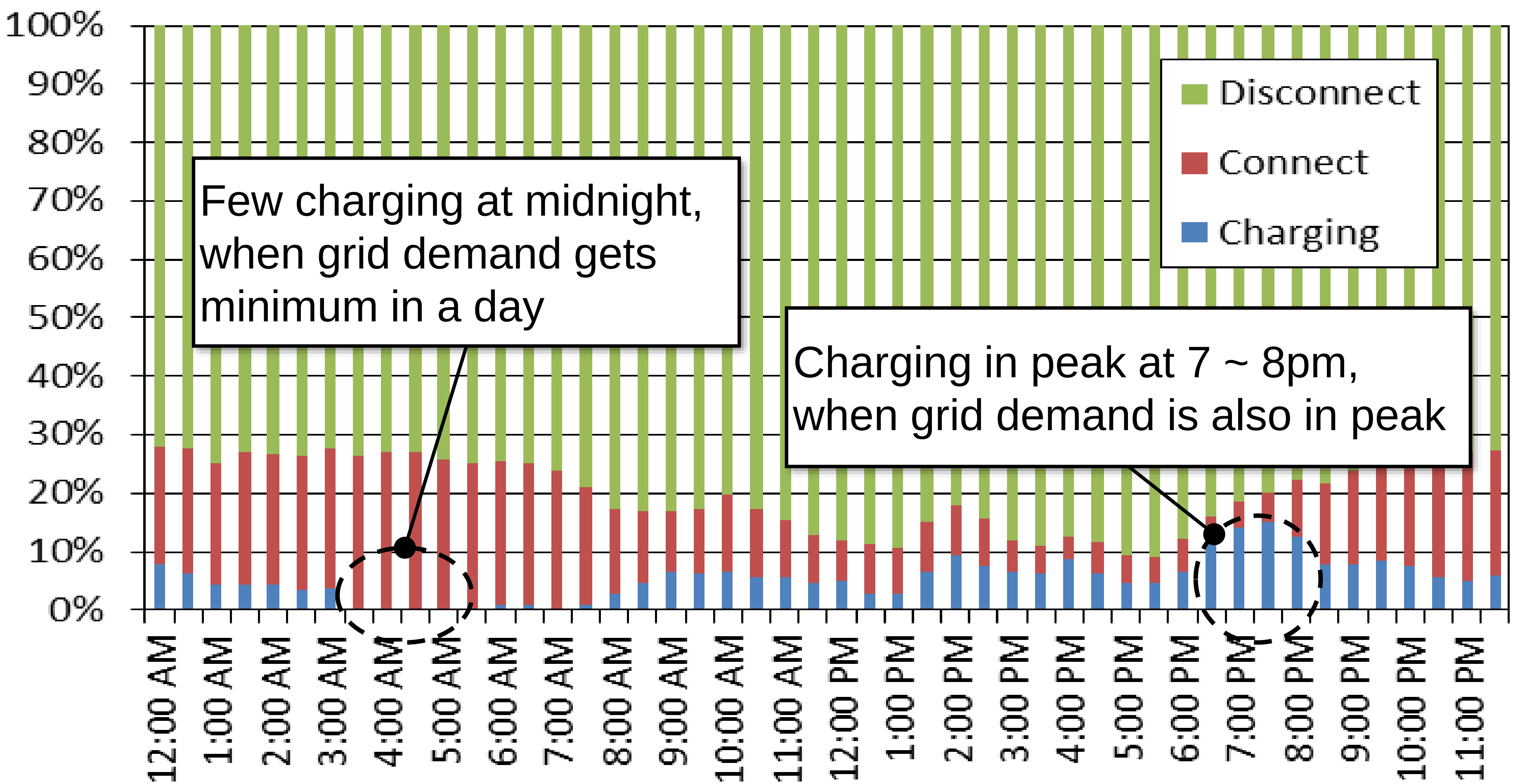
- Charging in peak at 7 ~ 8pm, when grid demand **is also in peak**
- Few charging at midnight, when grid demand **gets minimum in a day**



2-4. Managed Charging (V1G) Results

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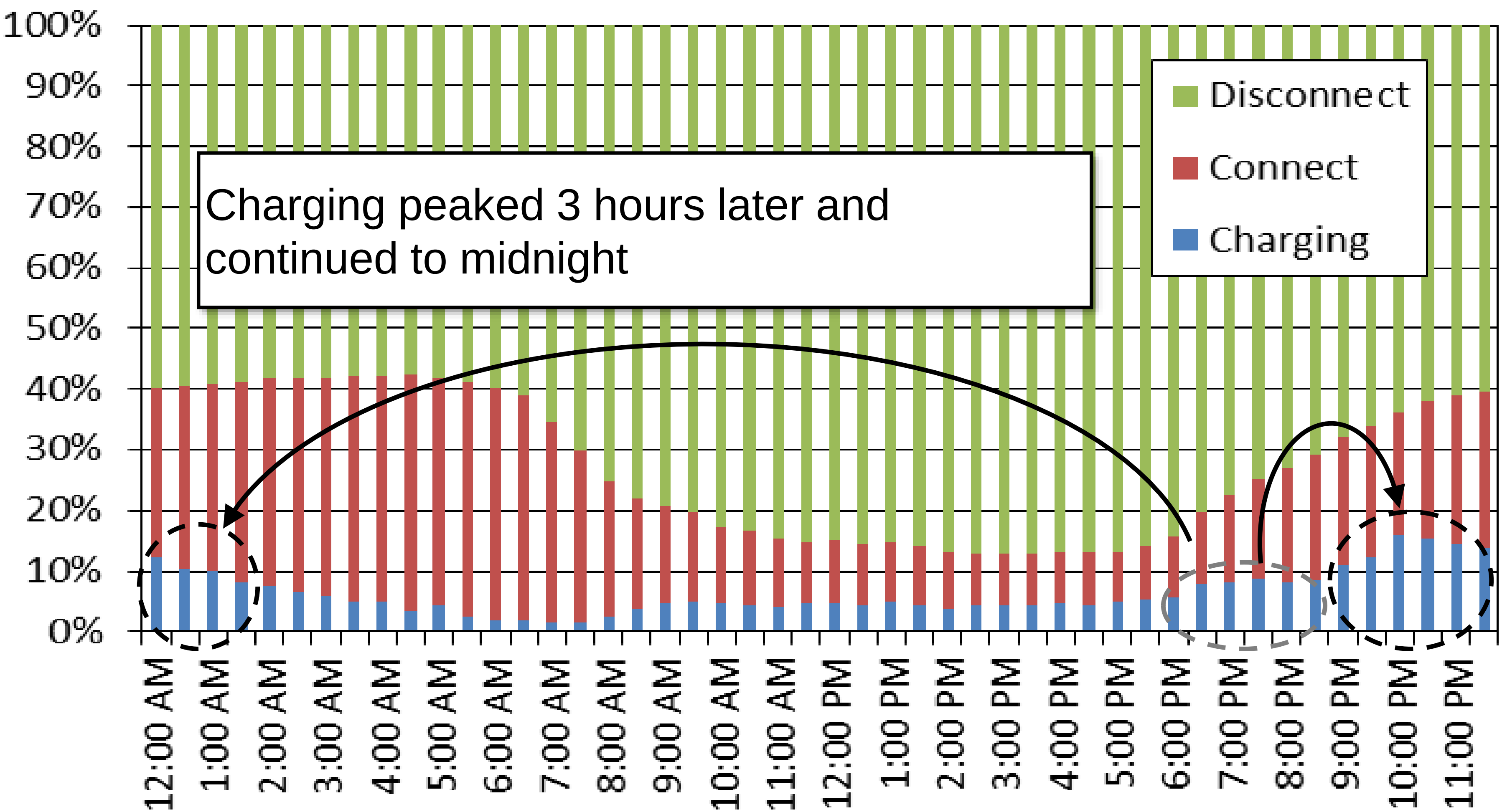
- **Scheduled charging** based on hourly grid needs and requirement of each participant (e.g. to be fully charged by 4am) **shifted charging peak to 3 hours later**



2-5. State-of-Charge (SoC)

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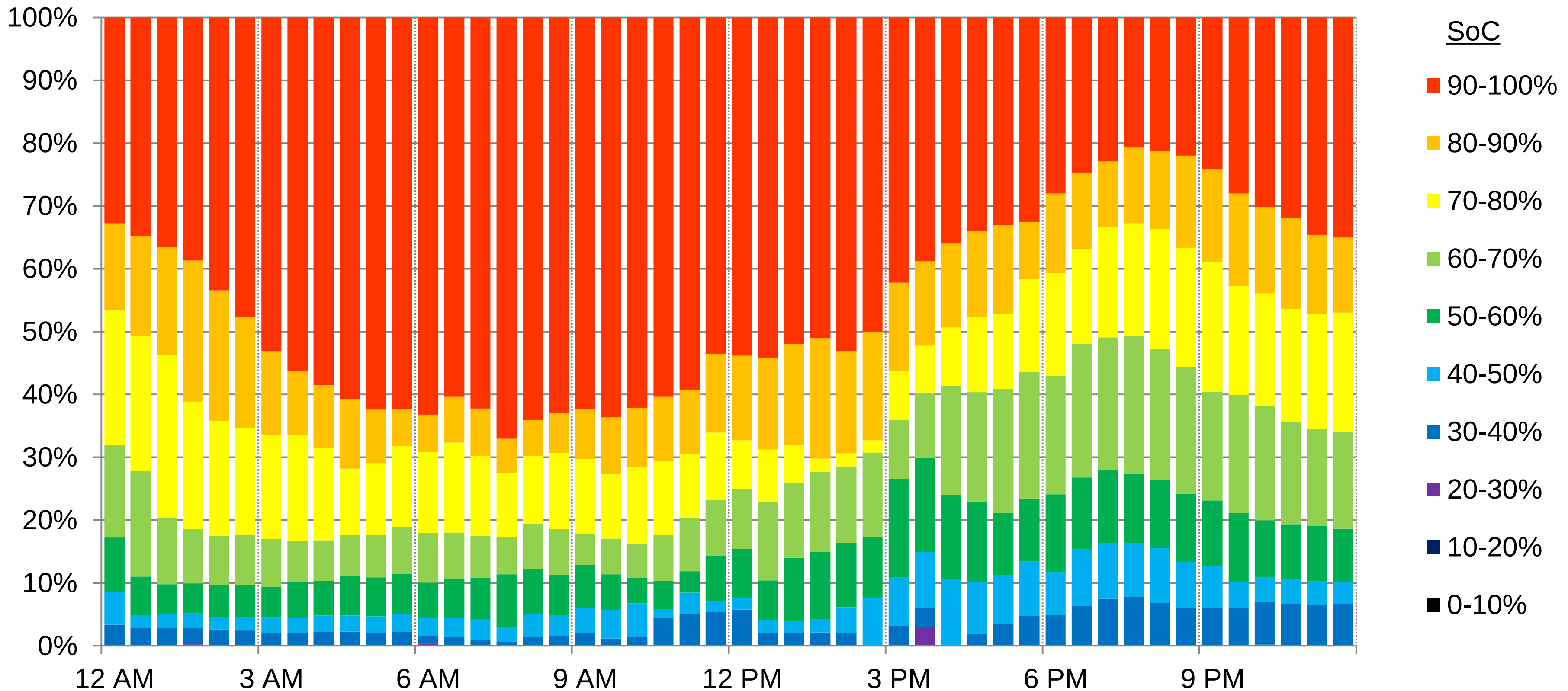
- SoC of the EVs gets minimum ~7pm but still half of them have **70% or more left**
- Enough to support grid's peak demand period (and then to be fully charged afterwards)



2-6. Managed Charging / Discharging (V2G) Results

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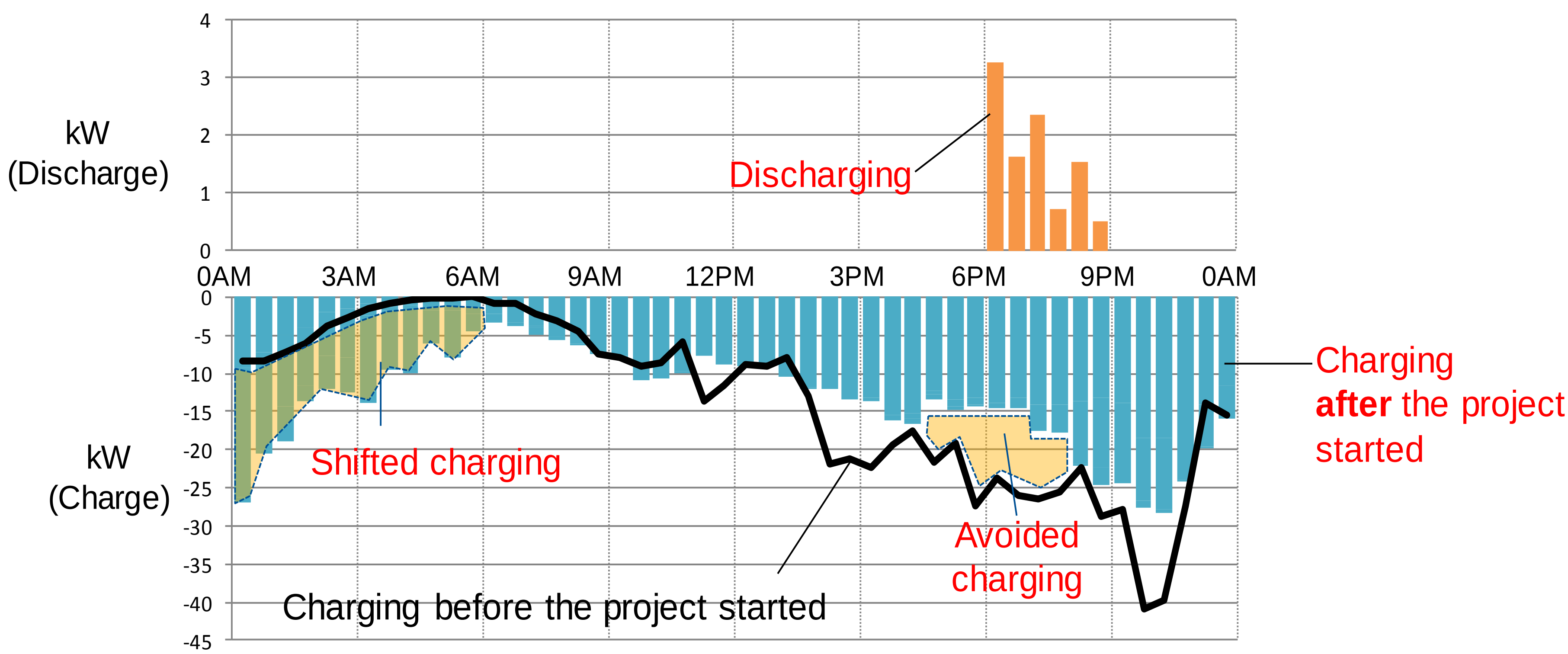
- Charging shifted to midnight (similar to V1G results)
- Also, **discharging** occurred during system load peak period



2-7. Communication with Community

- Using EVs as energy resources is quite new for users and can be complicated
- Having EV charging infrastructure and interactions with grid are local interests
- Information sessions have been helpful to receive acceptance from community

2-8. Summary of V1G / V2G Demonstrations in Maui

Charging behavior at home can impact on grid operation

- Natural charging peak at home overlaps system peak.

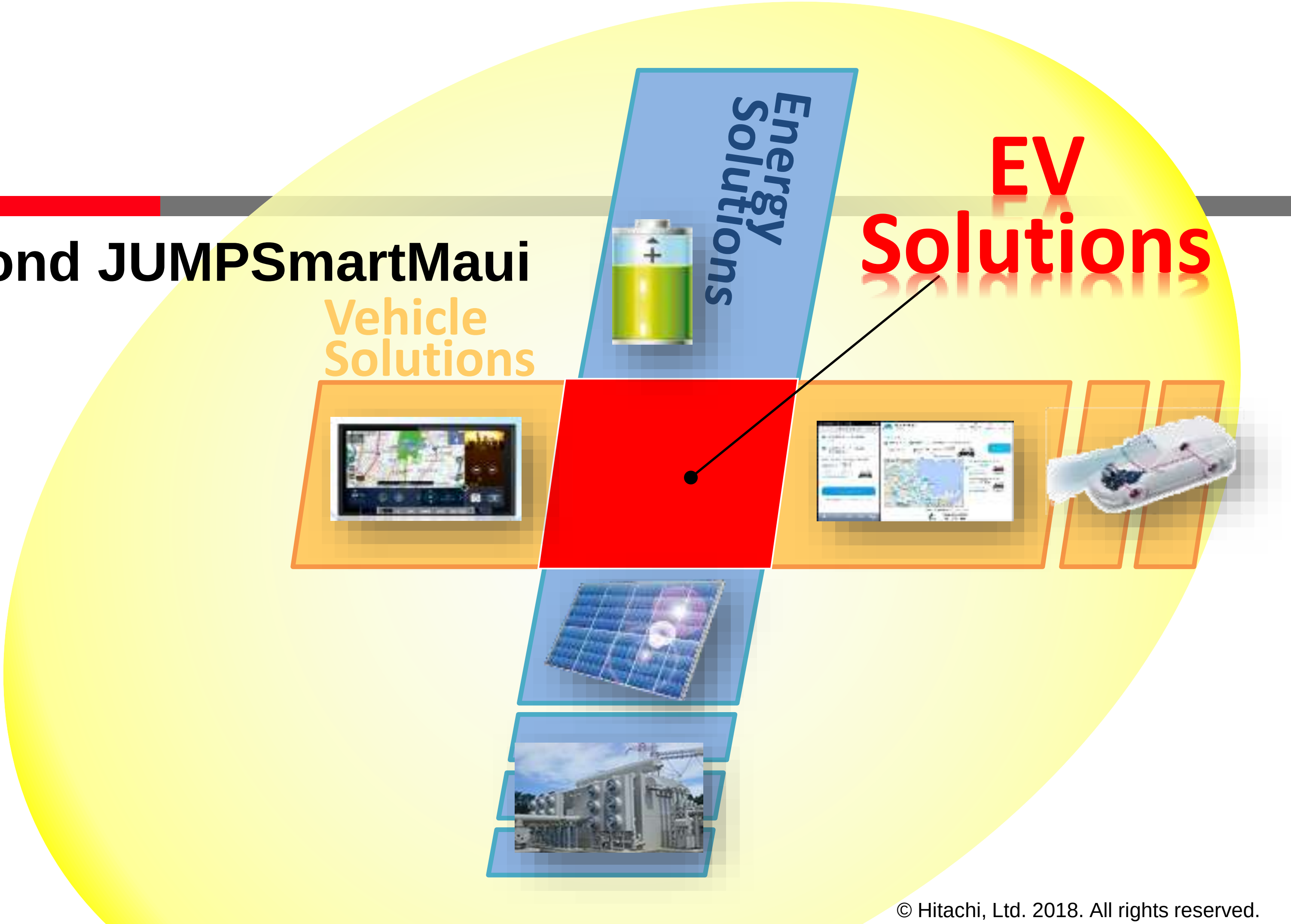
Charging EVs can be controlled without losing user's convenience

- Charging EVs during period with fewer system load is beneficial both for utilities and users.
- EVs avoided being charged during system peak can still be charged enough by morning.

Many EVs at home have enough energy left for power loads during the peak time

- EVs can not only be avoided being charged during system peak and also export power to home then.

3. Beyond JUMPSmartMaui



3-1. Validated technologies in V2X space (Summary)

- Our experiences in different projects/demonstrators have proven the validity of individual technologies in V2X space
- The key going forward is how we connect and mobilise these technologies on a platform

<u>Examples of technological categories/functions proven in our projects</u>

Categories	Regulating power (⊿kW)	Power (kWh)	Voltage control (reactive power)	Distribution grid congestion mgmt	Power (kWh)	V2B (kWh)	EV mgmt
Functions	Frequency regulation	Power supply	Grid stabilization	Optimization of grid capacity	Surplus energy absorption (PV etc)	Load leveling Peak cut/shift	SOC mgmt CPO functions

3-2. Toward Commercial Demand Response Programs

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- Hitachi aims to apply technologies acquired and lessons learned in the demonstration to the commercial demand response programs

= to be addressed in the following slides

	Program	Forecast・Meter Data	Notification	Communication	Response Speed	Accuracy	Duration	Annual limitation	Number of event
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4	FFR (Contingency Reserve)	15 min or Less than 15min	Same time that event happen	Parameter setting, Performance confirmation (2way)	12 or 30 cycles	Set-point:: ±0.02Hz Time Delay Setting: ±0.0167 cycle	Max 10 min	25	max 2/day

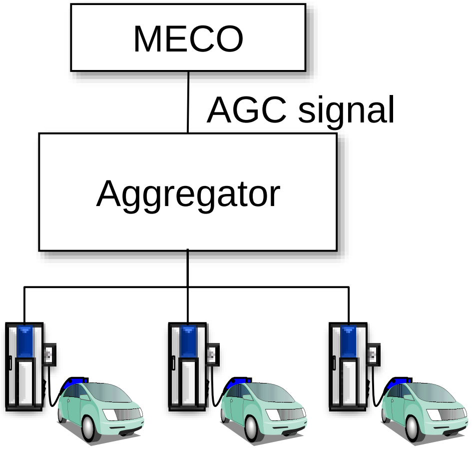
Not Covered

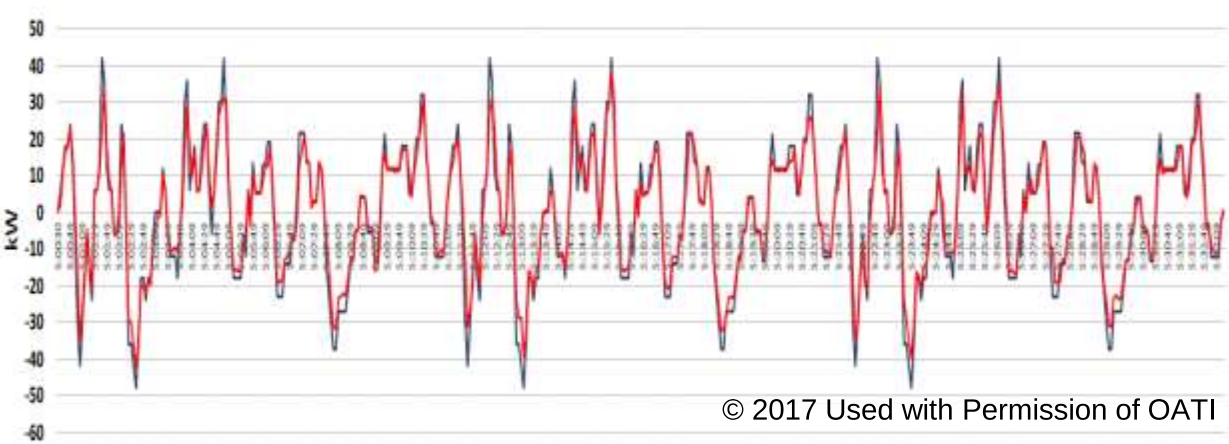
3-3. Frequency Control Example

Demonstration in Maui by Hawaiian Electric (2017)

- 40 EV-PCSs used to evaluate performance for Regulating Reserve
- Chargers controlled according to AGC signal in several second interval
- Evaluated high (> .97) in PJM scoring

Source : Hawaiian Electric “Implementation Phase I Status Report #5” (July 10, 2017)





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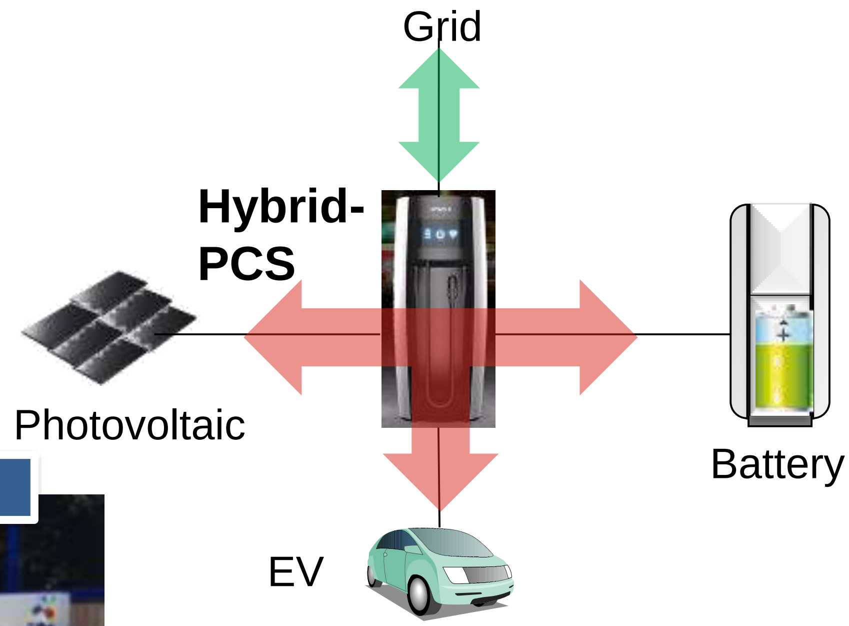
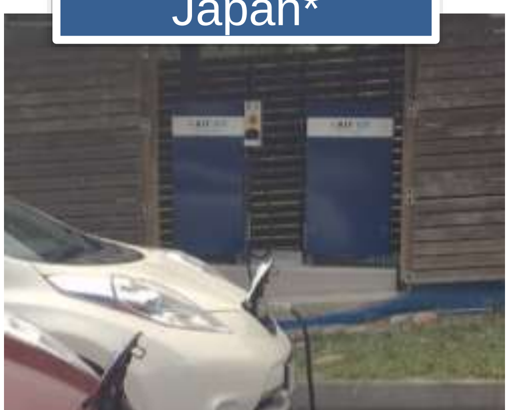
3-4. Bi-directional Charger - Hybrid-PCS

- EV, PV and battery support with single PCS (power conditioning system)
- Efficient DC-DC EV charging from PV
- Commercially available now in North America, Europe and Japan

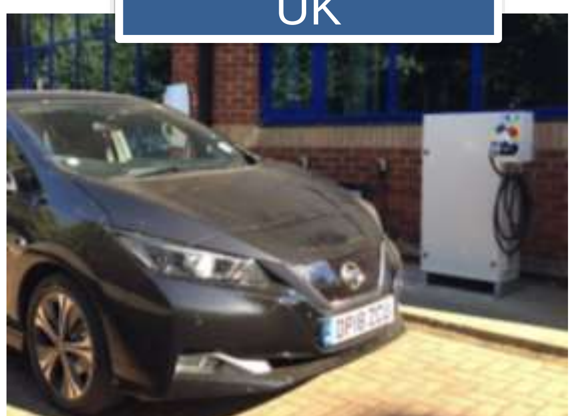
Netherlands



Japan*



UK



* Located at the Hakusanroku Campus of Kanazawa Institute of Technology

3-5. Locating Mobile Energy Resources

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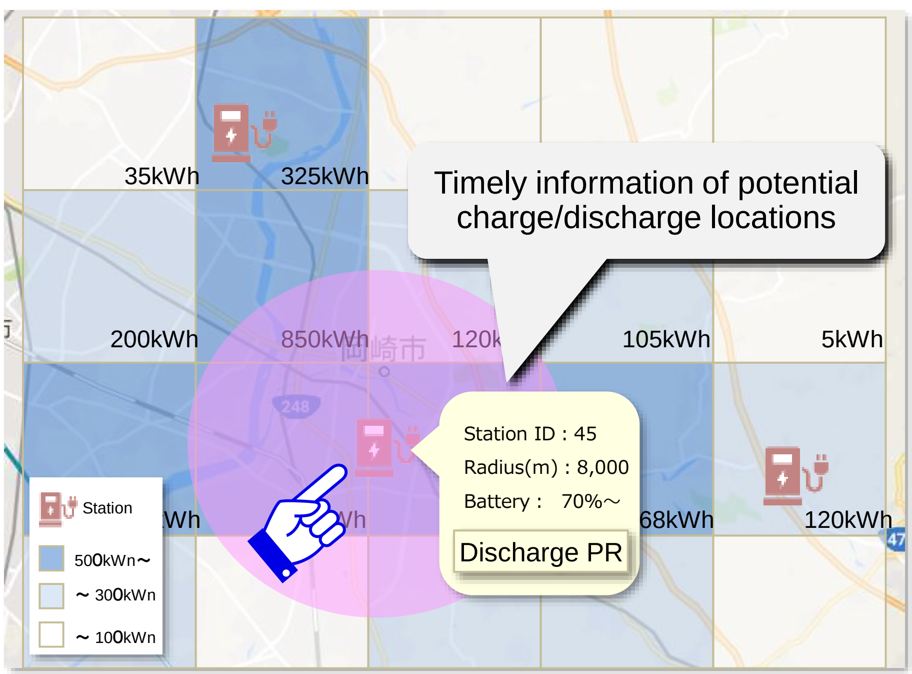
EV Battery Energy Density

- Calculating potential EV battery energy at each area from EV related information (e.g. EV location , SOC)
- Display the level and amount of potential energy

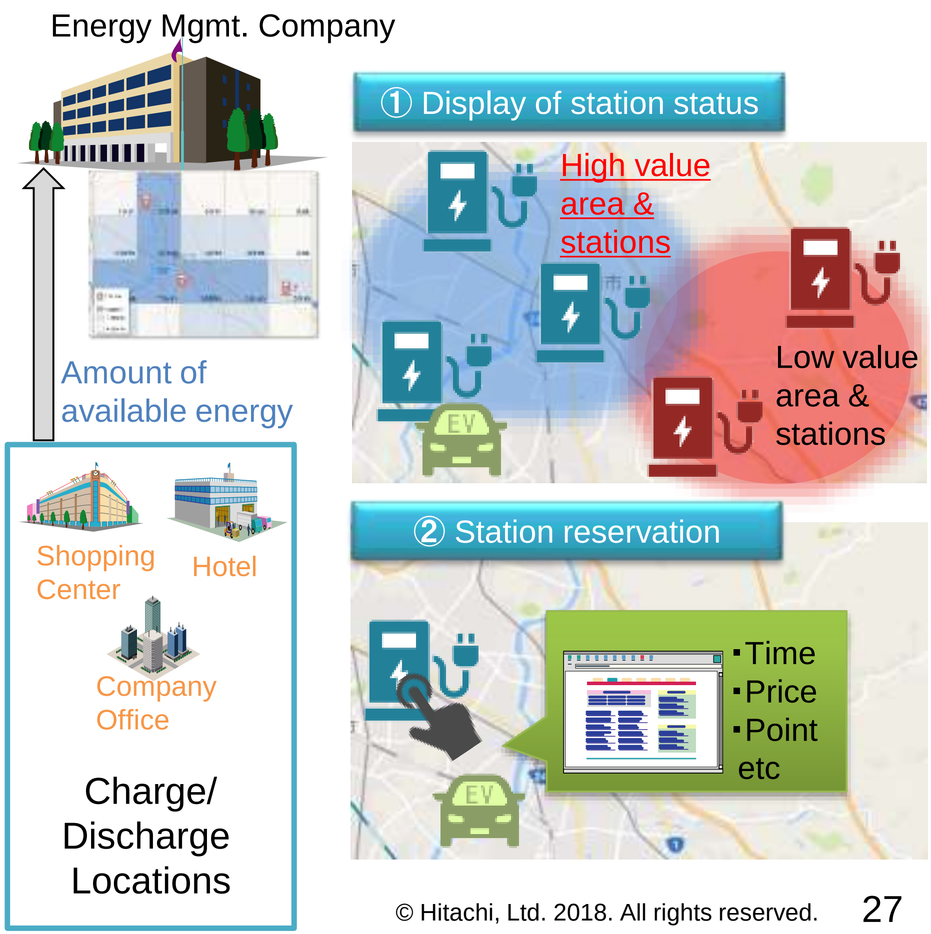
Mesh colored display according to potential energy (Ranking can be displayed)

Sending information of charging stations to users inside the high potential energy area



Local Grid Status & Charge / Discharge Locations

- Send message/information of charge/discharge to all EV users inside the specific area
- Reservation & navigation of charge/discharge stations which have higher merits for users



3-6. EV Platforms

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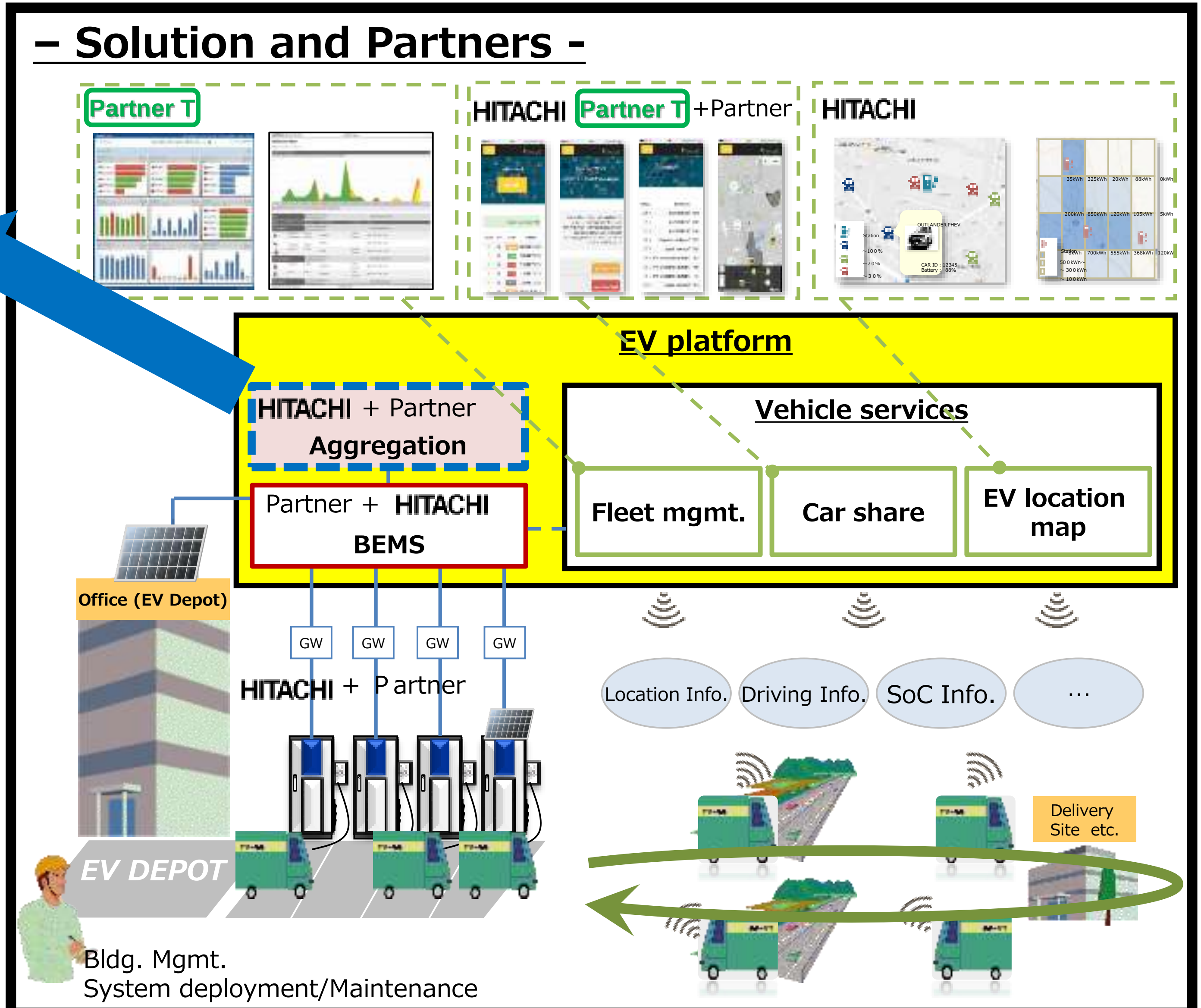
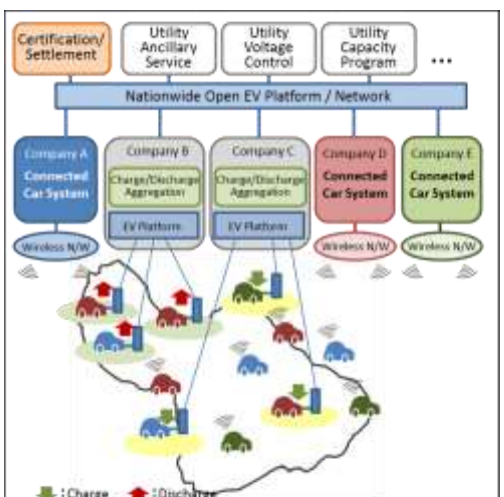
Distributed Energy Optimization



EV platform concept at the end of JSM



3-7. V2X Use Cases

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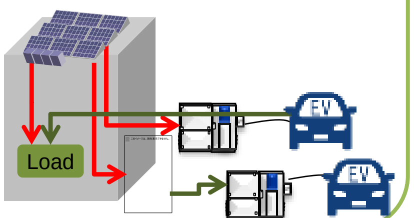
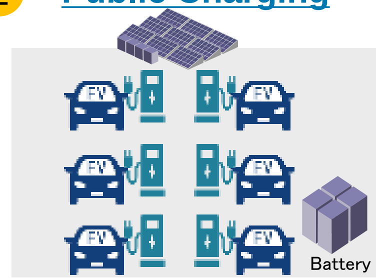
1 Vehicle to Building



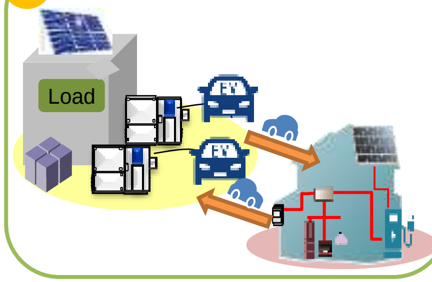
- Energy cost reduction of building
- Efficiency of EV fleet operation

2 Public Charging



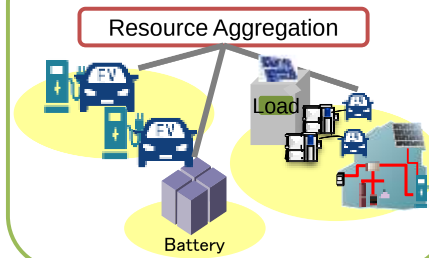
- Using as energy resource while parked lowers charging fee

3 Workplace Charging



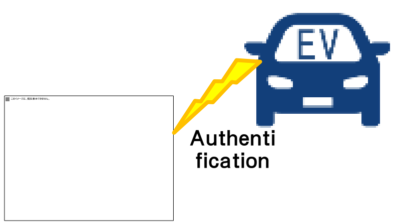
- Benefits of employer
- Benefits of employee

4 Grid Services



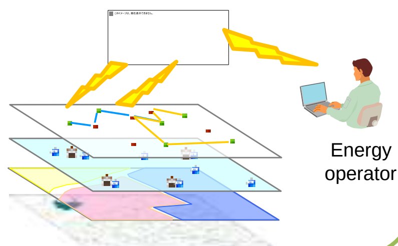
- Potential capacity of resources
- Potential incentives to receive

5 EV Car-sharing



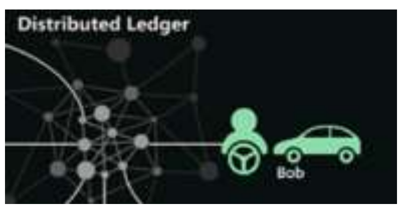
- Efficiency of EV fleet operation
- Energy resource while unused

6 EV Energy Mapping



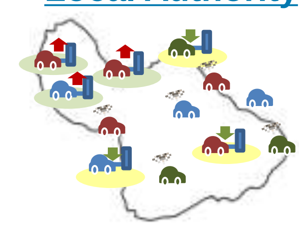
- Efficiency of EV fleet operation
- Value for distribution grid

7 Block Chain



- Enabler of new way of energy transaction

8 Collaboration with Local Authority



- Electrification of Fleet
- Fleet V2B to facilities

【For ref.】Power blackout caused by earthquake in Hokkaido

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#	Situation	Details
1	**Black-out**	**[6th Sep]** 03:07: **Earthquake (magnitude 6.7)** in Hokkaido 03:08: **Two(2) Power Plants shut down** - These plants supply half of power demand - Wind/Hydroelectric plants shut down due to frequency reduction 03:25: **Blackout** *2,950K house's' power failure*
2	**Estimated Economic Loss***	▪**Total : $1,926M** - Includes economic loss in Public works facilities, Agriculture, Forestry and Fisheries industries, Tourism, Power outage damage ▪**Commerce & Industry：$1,198M** ▪**Disposed food in convenience stores etc.: $75M** - due to refrigerator/freezer failure
3	**Recovery of Power Supply**	6th Sep. 21:00 : 16% recovery(480K houses) 8th Sep : 99% 4th Oct. : 100%

*Exchange rate：1USD=110JPY

3-8. Resilience Solutions

Resilience solutions can be achieved by leveraging EV/PHEV batteries and maximized its capabilities with single-phase and three-phase H-PCS.

Examples of H-PCS utilization

1. Achieving Business Continuity Plan (BCP) for convenience store, especially for the frozen foods by using EV/PHEV as backup power supply

2. Ensuring tower mansion residents during disaster by discharging EV to keep elevator operated

3. Securing required power for office and community by fleet electrification and workplace charging

4. During demonstration household had back-up electrical power by EV- PCS even though the black out brought by Hurricane in Maui.

3-9. Resilience Solutions : 1. Power supply for convenience store

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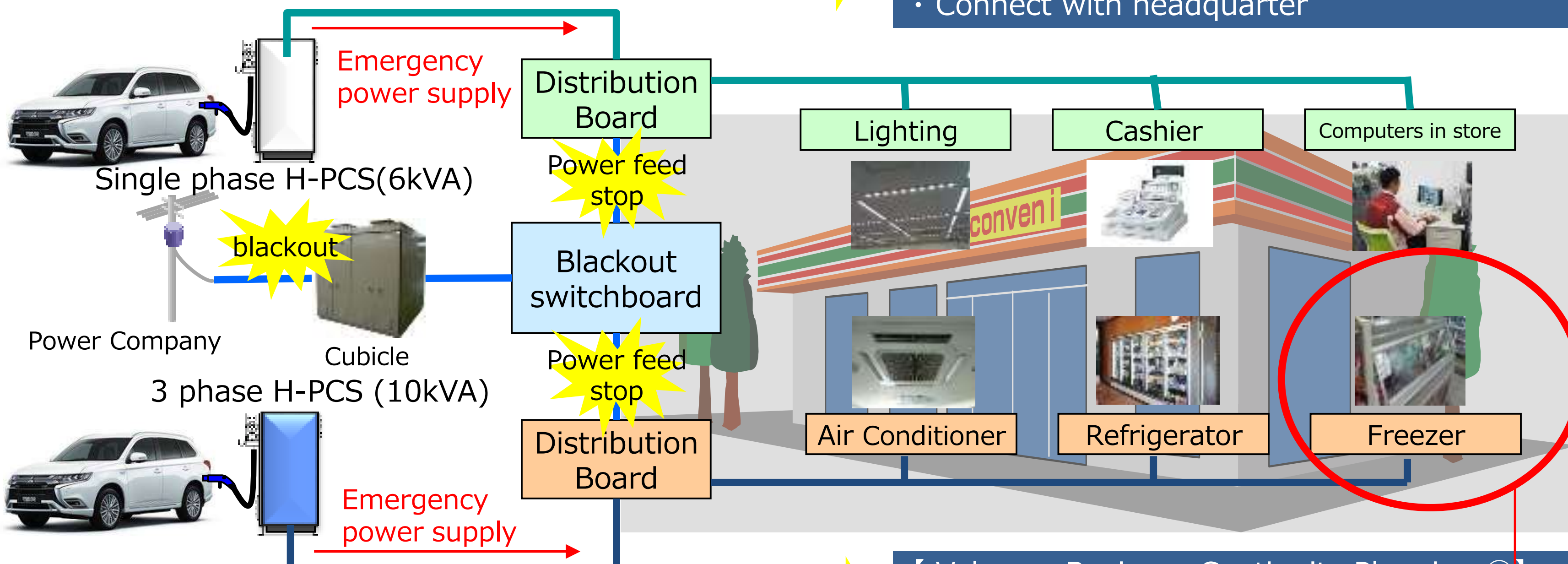
■ Emergency backup power for main equipment

- Backup power solutions are required by convenience stores as a lifeline in a time of disaster to speedily provide emergency support.
- As there are single-phase and three-phase power equipment used in convenient stores, Business Continuity Planning (BCP) by leveraging single-phase and three-phase H-PCS to deliver electricity from EV/PHEV can be achieved.

【Backup power from single phase equipment】
Power supply for lighting, POS, computer used in the store

【Value as Business Continuity Planning ①】
・Provide security/comfort with lighting
・Continue settlement operation with POS
・Connect with headquarter



【 Backup power from 3-phase equipment 】
Power supply for chilled/frozen food, air conditioner, etc.

【 Value as Business Continuity Planning ②】
・Cut loss of damaged frozen food
・Control room temperature
・Continue operation of other equipment

3-10. Resilience Solutions : 1.Power supply for convenience store(cont'd)

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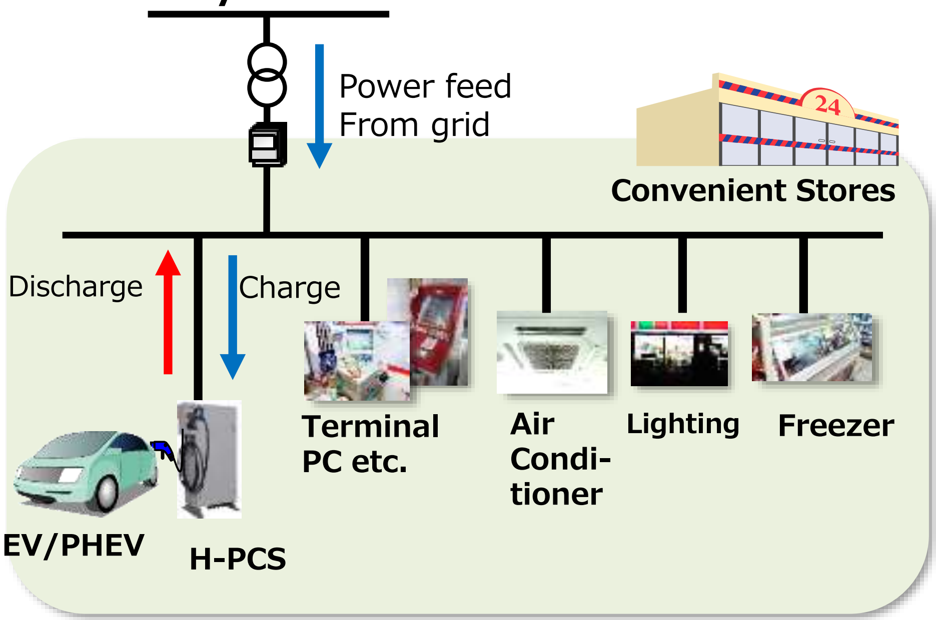
■ Emergency backup power for main equipment

- Backup power solutions are required by convenience stores as a lifeline in a time of disaster to speedily provide emergency support supplies to disaster-stricken areas
- Secure the power to freezer at the time of disaster by discharging from EV/PHEV

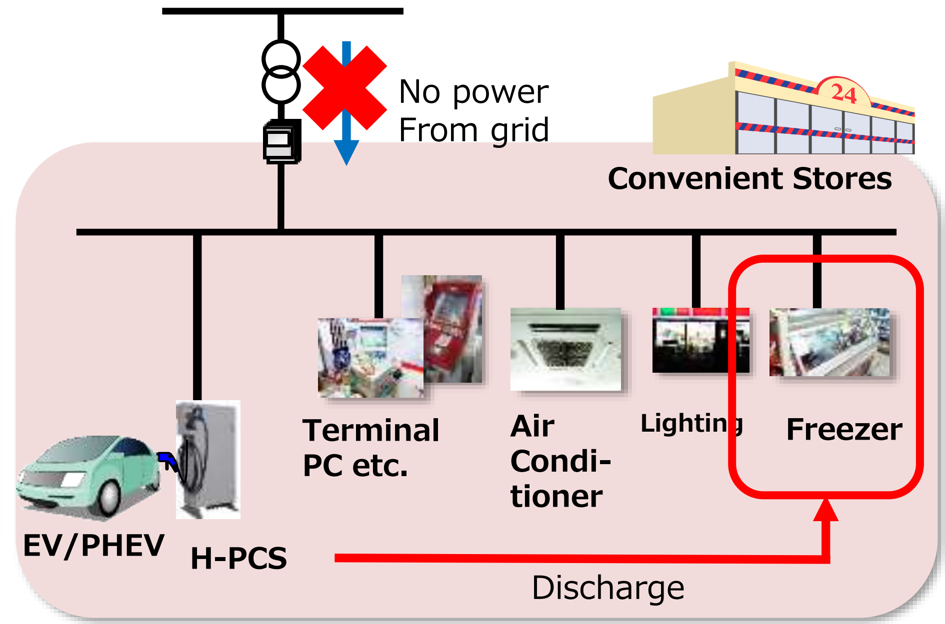
Normal

While there's power from the grid, convenient stores can be used as EV station by installation of H-PCS



Disaster

While there's no power from the grid, backup power for main equipment, e.g. freezer, can be provided by discharging EV



3-11. Resilience Solutions : 2. Power supply for Elevators

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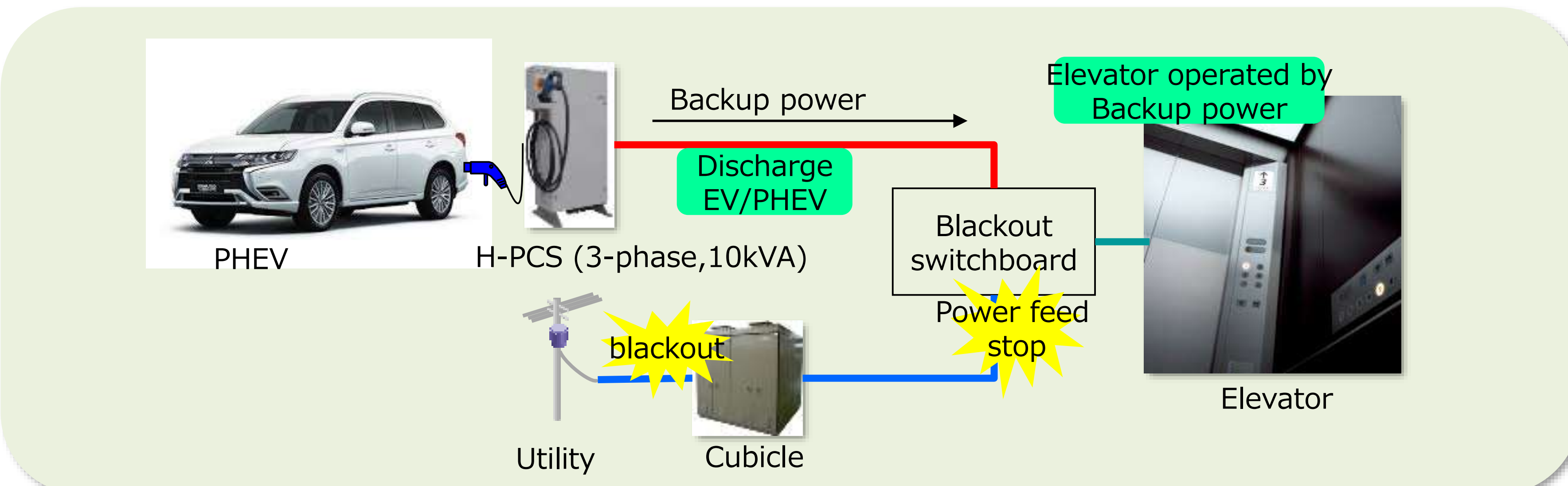
■Elevator operated by discharging EV/PHEV

- Ensure safety and comfort to tower mansion residents at the time of blackout/ disaster by leveraging EV batteries to operate elevator
- Simplify inspection work of maintenance staff

(1) 3-phase H-PCS can directly connect to the switchboard (no transformer required)
(2) When blackout happens, after specific safety inspection required by laws are complete, elevator can be operated by using the power discharged from EV
(3) In case PV panel, battery (13kwh) is connected to H-PCS, elevator also can be operated even though EV/PHEV is not connected

＊operation test for (1)～(3) is required



3-12. Resilience Solutions : Fleet electrification for disaster

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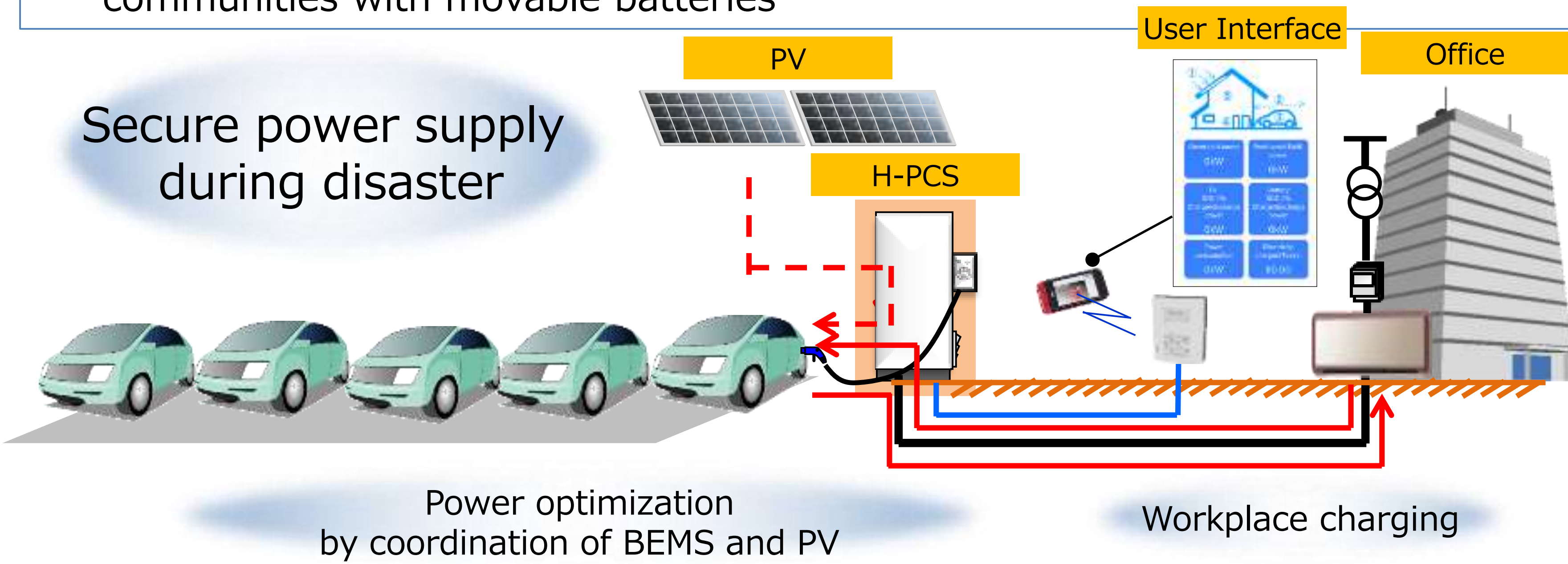
■ EV fleet platform by communities/companies

- Secure power for the most required equipment at the time of disaster/blackout by fleet electrification (switch corporate car to EV/PHEV)
- Secure power not only for the company itself but also provide power for communities with movable batteries



- ■ Optimization of fleet and office energy utilization during normal times
- ■ EV fleet platform can provide;
  - ･Optimization of fleet operation by using telematics/car sharing
  - ･Control of EV charge/discharge by coordinating EV fleet parked at office depot and BEMS (optimization of distributed generation)

※BEMS･･･Building Energy Management System

New Technology for DC Micro Grid

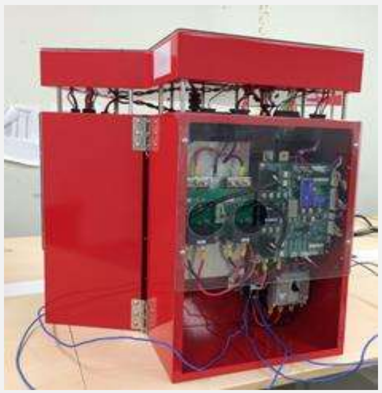
Dr. Kado

Y-type router will be the key device for DC micro grid near future

4.Triple-Active-Bridge (TAB) Converter for Autonomously Distributed Power Network

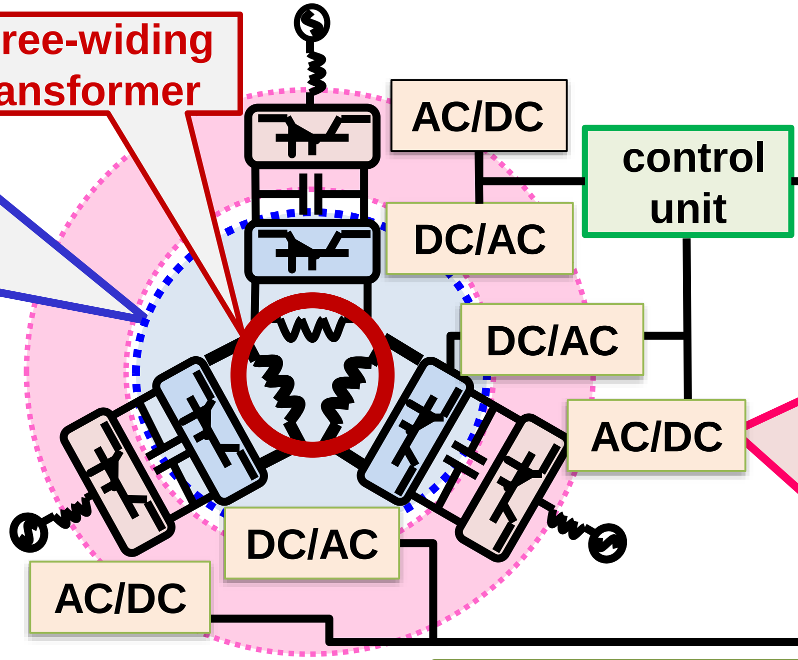
KYOTO INSTITUTE OF TECHNOLOGY

Three-way isolated DC/DC converter



DC 400V, 10 kW

Three-widing transformer

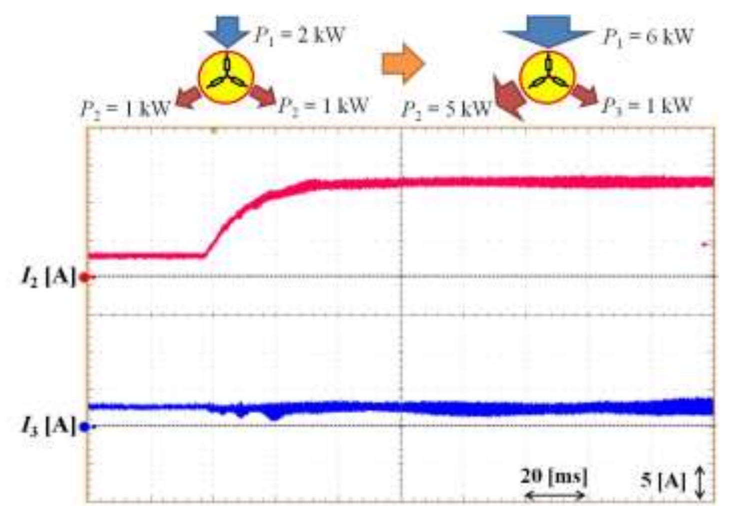


Detachable AC/DC converter

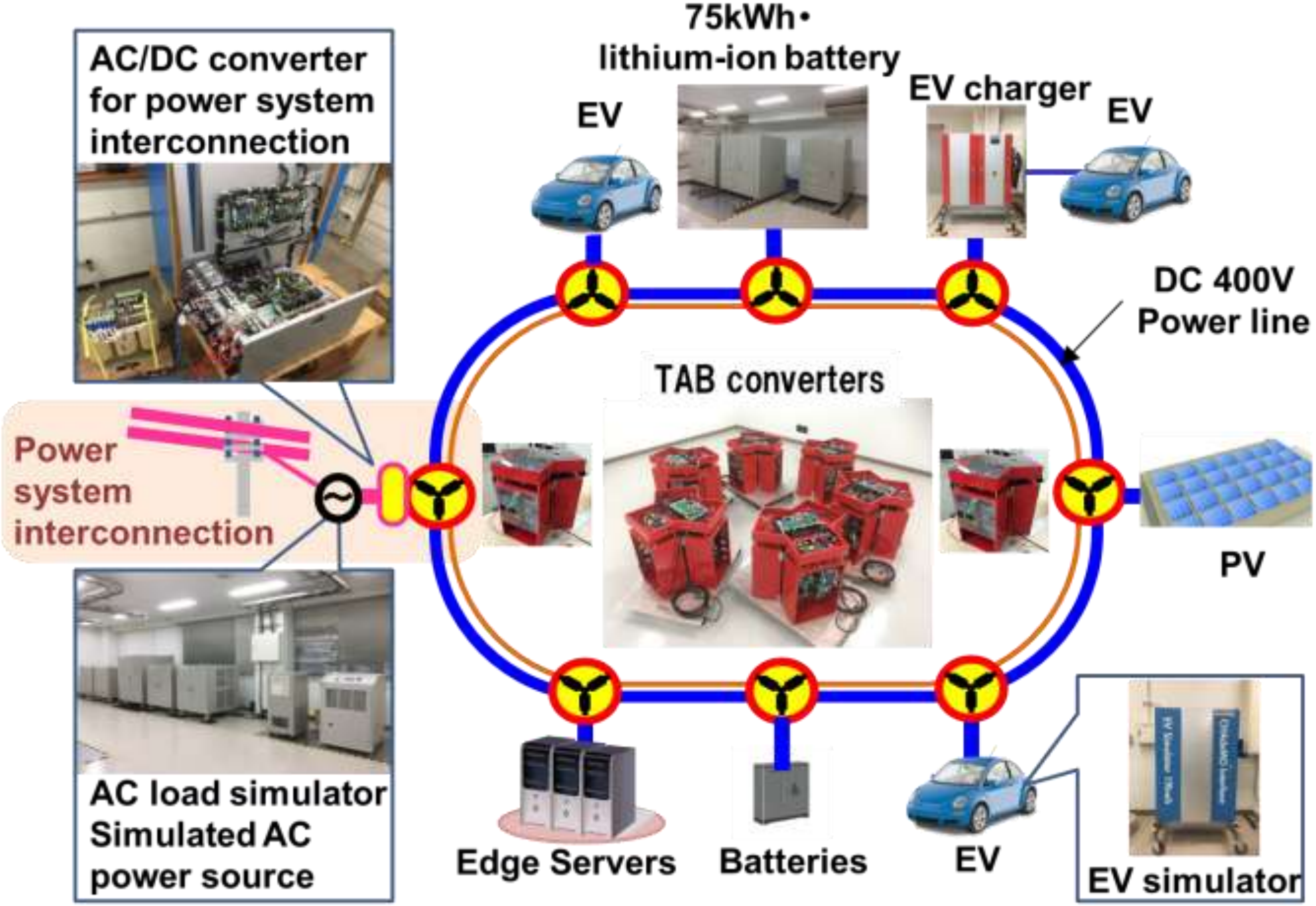
AC 200V ⇔ DC 400V

Decoupling power flow control

Step responses of DC currents I_2 and I_3 when the command value of DC current I_2^* was changed from 2.5 A to 12.5 A in step and I_3^* was fixed to 2.5 A.



5.Autonomously Distributed Network Testbed



Experimental demonstration

- Charging function compatible with electric vehicles from all over the world
- Reliable and resilient DC power supply to edge servers
- ”Plug In and Play” function without disrupting the power supply to the loads such as edge servers
- Redefining its mission against disaster

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Thank you

For more information on Maui demonstrations :

- EPRI Smart Grid Demonstration Assessment Report
  https://www.epri.com/#/pages/product/000000003002007129/
- NEDO Case Study Report
  http://www.nedo.go.jp/english/reports_20130222.html#hawaii

Hitachi,Ltd.