Appendix 3-2-2 Attendant list, and Q&A, of the 2nd Energy Efficiency Workshop(Jamaica)

Technical Cooperation to Promote Energy Efficiency in Caribbean Countries

2nd Energy Efficiency Workshop (Jamaica)
List of Participants for Online Attendance (28 Mar 2023)

Venue: Zoom

No	Name	Agency
1	Barrington Jackson	MSET
2	Todd Johnson	MSET
3	Horace Buckley	MSET
4	Leneka Rhoden	MSET
5	Steve Dixon	MSET
6	Richard Venner	BSJ
7	Nigel Davids	BSJ
8	Brian Richardson	BSJ
9		
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Technical Cooperation to Promote Energy Efficiency in Caribbean Countries

EE Workshop on Mar 28: Q&A

No	Day	Item	Content	Name	Answer	Further Notes
1	28-Mar	Question	According to the pie chart, lighting in terms of energy conservation is almost equal to AC and Refrigeration. Our information is that lighting contributes to less than 10% both for residential and commercial energy use however according to the pie chart the overall conservation is almost 30% making all of them almost equal but lighting in Jamaica contributes to less than 10%, could that be explained?	Steve Dixon	In developing EE roadmap, EE Index was assumed to be 1. That is, energy efficiency of currently used including old types at all households/offices, etc. is assumed to be 1. Meanwhile, LED with EE of 200 lm/W is already in the market while conventional EE of LED is between 60-90 lm/W. So there is a plenty of rooms for energy savings just only LED. It can be assumable/reasonable that EE of lighting will be 3 times higher in 2031 compared with those currently used by introducing MEPS.	
2	28-Mar	Question	How did Japan get the commercial and residential sector to start complying with the energy efficiency requirements for buildings in particular?	Brian Richardson	That is a topic to be presented later however the Japanese government is planning to establish mandatory energy efficiency regulations for houses in the upcoming years.	
3	28-Mar	Question	In terms of the percentage of energy for household, etc that lighting would have used, where was the data collected and did the energy balance that the energy division produce help to make those figures more practical in terms of our reality?	Horace Buckley	Firstly, the energy balance data was extracted from the MSET website. Secondly, power consumption ratio at households was extracted from the data/material prepared by Barbados government.	To grasp actual power consumption by appliance/device, the data logger was handed over to MSET. When you collect data, it should be taken into account that the family structure (single, wife & husband and 4 people family, etc), annual income and locations/regions.
4	28-Mar	Question	I had a question regarding Dual inverters for air conditioners. Hoping to find out the impact this has made for reduction in residential load demand.	Richard Venner	I am not familiar with dual inverters in split type air conditioner with one compressor. But some air conditioners have two compressors. In that case, both could be equipped with an inverter for each compressor. Anyhow, this question will be addressed later.	

Appendix 3-3-1 Material for the 1st RE & Grid Stability Seminar (Jamaica)

Technical Cooperation to Promote Energy Efficiency in Caribbean Countries

Progress and Discussion for RE and Grid Stabilization in Jamaica

Oct 2022

Nippon Koei Co., Ltd.
PADECO Co., Ltd.

Overall Project Schedule

	1	2	3	4	5	6	7	8	9	10	11	12	13	…	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	-
	Phase 1 (Baseline Survey)						Phase 2 (Technical Transfer)																								
	Year 2019									Year 2020				…	Year 2021		Year 2022												Year 2023		
	4	5	6	7	8	9	10	11	12	1	2	3	4	… … … … … …	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3

Output 1
The basic information is confirmed for the capacity building for the introduction of RE

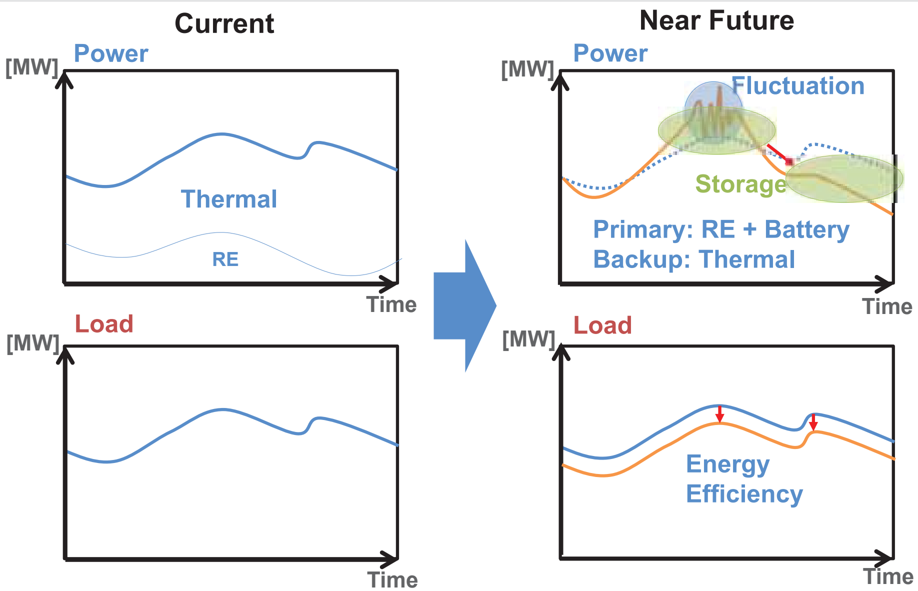
Output 3
The human and institution capacity are enhanced for the mass introduction of RE

Output 2
The basic information is confirmed for the capacity building for the promotion of EE

Output 4
The human and institution capacity are enhanced for the promotion of EE

RE and Grid Stability activity is to:
- introduce micro-grid concept in one of the agreed areas and develop modelling based on existing grid data.
- introduce computer modelling for grid analysis and examine issues associated with a large penetration of VRE
- propose the way to enhance resiliency
- consider and propose the necessary technologies for achieving the RE goals, including grid stabilization,
- consider and propose additional policy legal system for achieving RE goals
- prepare necessary training plan
- provide recommendations on design of the policy/ legal system

Challenges



Summary: Jamaica

*1 JPS Annual Report 2021 *2 IRP Feb 2020
*3 Interview to JPS *4 Transmission Code

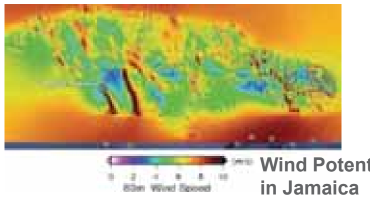
Fields	Findings	Project Activities
Energy Efficiency	• Energy Source: Oil (53%) , Electricity (37%) • Peak Demand: 654.5MW (2018)→622MW (2021)*1 • Generated 4356 GWh (2018)→4,303 GWh (2021)*1 • 1833 kWh/customer/yr, 0.34 USc/kWh (2021)*1 • Peak Period: 6:30pm – 8:30pm	Priority 1: BEMS Priority 2: Mini split AC with inverter Priority 3: LED
Renewable Energy	• RE target 33% by 2030, 49% by 2037 *2 • Hydro 28.6 MW, VRE 175 MW (PV utility 53+ distributed 20? , wind 102) *2, RE 15% of grid • Rooftop 20MW? *3	Recommendation for 50% RE target Micro-grid concept study Introduction of asset management
Grid Stabilization	• >50.5Hz:0.5sec, <49.5 Hz: 20 sec, <48Hz:0.5 sec *4 • RE Fluctuation affects gird stability*3 • JPS 21.5MW/16.6MWh Li BESS +3MW flywheels	
O&M of Thermal Power Generation	• Thermal power plant: total 20 units including IPP • Installed Capacity: Total 1036.5MW including GTCC in Old Harbour P/S (190MW) • Heat rate 11,330(2017)→9,392 (2022) kj/kWh *1 • Predictive Maintenance: Considering to apply	-
Human Resources and Capacity Building	• MSET's Energy Division: 14 employees • Most of capacity building is done by OJT • There is no systematic HR development.	JET experts select topics and develop the most suitable curriculum for technology transfer period

RE Status in Jamaica

Challenges for RE & Grid:

- ✓ Increasing RE capacity >15%. Grid stability and power cut issue
  - ✓ Feeder cut at 49.5 Hz
- ✓ System losses 26.3% (2018) →28.3% (2021)
- ✓ Large number of distributed PV, available database?
- ✓ Wind & PV potential unevenly distributed →less smoothing

Source: JPS, 2019



Wind Potential in Jamaica

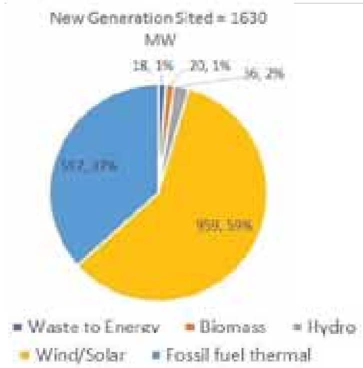
Source: Sustainable Energy Roadmap 2013

VRE Projects in Jamica

Location/Project		Capacity MW	Generation GWh estimated	Year	Tariff USc/kWh	Investment mil USD
Wigton I	Wind	20.7	52	2004	10.21	26
Wigton II	Wind	18	47	2010	10.723	45
Wigton III	Wind	24	63	2016	13.4	46.5
Munro	Wind	3	10.5	2010	(JPS)	
BMR Wind	Wind	36.3	120	2016	12.9	90
Content Solar (WRB)	PV	20	34	2016	18.8	65
Independent roof-top	PV	20?			--	
Eight River (EREC)	PV	33.1		2019	8.5	
Wigton IV	Wind	34		?		
VRE under operation		**142**	**326.5**			

Source: Prepared by JET with several data sources

Summary of IRP



Generation 2041	MW
Wind/solar	959.59
Fossil fuel thermal	597.37
Hydro	36.2
Biomass	20.1
Waste to Energy	18.1
Total	**1631.36**
VRE	**58.8%**

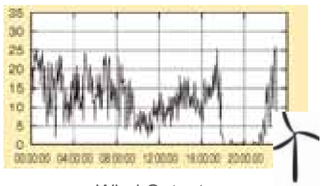
Unit Type	Overnight 2018 Capital Cost ($/kW)	2018 average estimated Variable cost ($/MWh)[1]	2018 Fixed Operating and Maintenance ($/kW)
New Capacity only; existing capacity is modeled at contracted rates			
Natural Gas Combined Cycle	1600	92.0	
Natural Gas Combustion Turbine	800	134.0	
Medium Speed Reciprocating Engine burning Natural Gas	1400	92.0	
Wind	Real, Levelized cost including capital, variable and fixed O&M and excluding profit = $105.8/MWh		
Solar	Real, Levelized cost including capital, variable and fixed O&M and excluding profit = $78.2/MWh		
Hydro	Real, Levelized cost including capital, variable and fixed O&M and excluding profit = $102/MWh		
Waste to Energy[2]	7200	9.3	
Biomass[2]	3837	5.6	

Source: Integrated Resource Plan Feb 2020

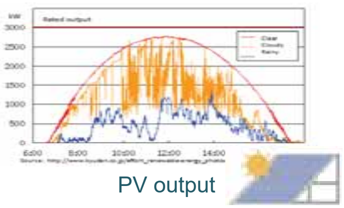
Year	Generation GWh	RE GWh	RE Portfolio
2030	5,453	1,913	35.1%
2037	5,939	2,435	41.0%

- Cost for control and grid stabilization is not included in Wind & PV
- It needs to identify yearly VRE introduction to assess grid stability

Characteristics of VRE



Wind Output


PV output

Wind
- Unpredictable generation output change
- produce ramps according to weather condition
- Depending on geographic areas, fluctuation comes at once if it installed in the same valley

PV
- No output in night-time and rainy day
- Large fluctuation in tropical climate (likely to change 80% in a minute)

Both (VRE):
- It does not always generate when needed. **Load-supply matching** is an issue
- Time coincidence of VRE, there can be times when there is too much supply. Curtailment of VRE is necessary **→energy storage/control cost need to be considered.**

Caribbean Islands:
- Lower cost than tariff →rapid private investment
- Limited area for transmission
- Frequent change of weather condition
- Limited stable RE (hydropower/geothermal)

Challenges for
- **Cost for stability** : who covers?
- Technical and regulatory matters

RE: Grid Stability Issue with VRE in Jamaica

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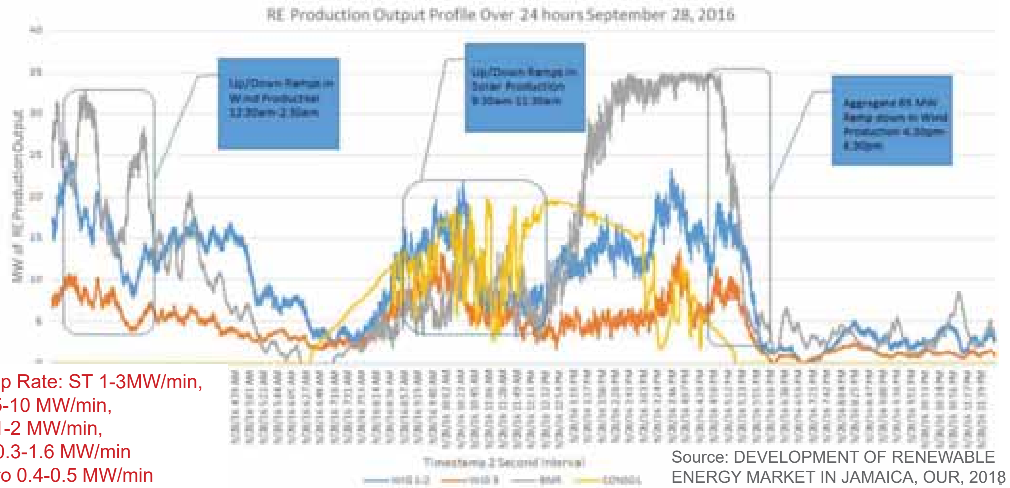
Grid Stability issues due to significant VRE fluctuation

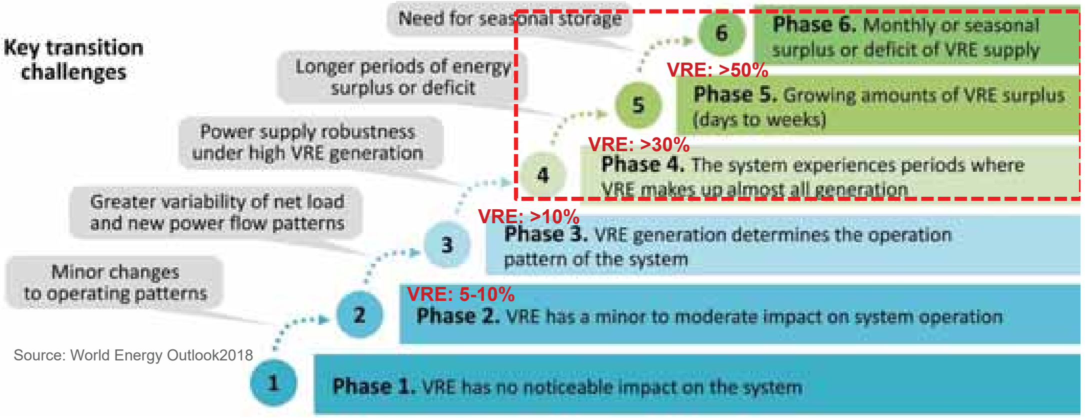
- Limitation of generating units, unable to ramp fast to counter rapid variations in VRE
- Adverse effect on Heat Rate (Efficiency) and increase of production cost
- Part-load operation of generating units, increasing emissions and reducing operating life of equipment
- Impacts System reliability, security, stability and power quality



Ramp Rate: ST 1-3MW/min,
GT 5-10 MW/min,
CC 1-2 MW/min,
DG 0.3-1.6 MW/min
Hydro 0.4-0.5 MW/min

Source: DEVELOPMENT OF RENEWABLE ENERGY MARKET IN JAMAICA, OUR, 2018

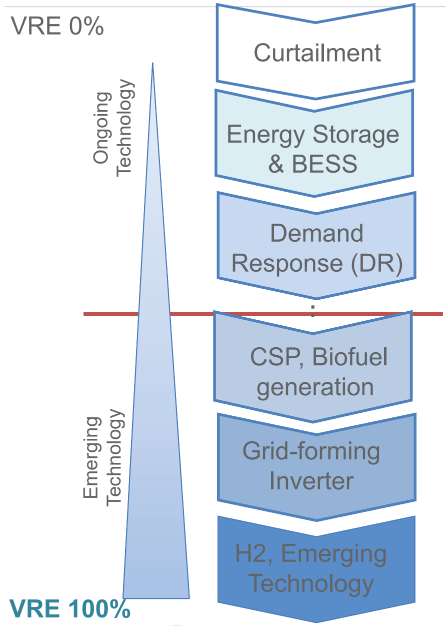
Transition Changes of RE Penetration



Source: World Energy Outlook2018

Phase-3	Increased level of uncertainty and variability by higher share of VRE. System flexibility is important for integrating VRE to in the supply-demand balance.
Phase-4	VRE provides majority of electricity. It **requires advanced technical options** to ensure system stability, causing **changes in operational/regulatory approaches.**
Phase-5	VRE output exceeds power demand. The demand is entirely supplied by VRE and further VRE additions face the of **substantial curtailment.**
Phase-6	Determined by a surplus or deficit of VRE supply on seasonal or inter-annual timescales. This drives a possible need for seasonal storage and use of **synthetic fuels or hydrogen**

Arrangement toward 100% RE



Voltage and frequency Stabilization

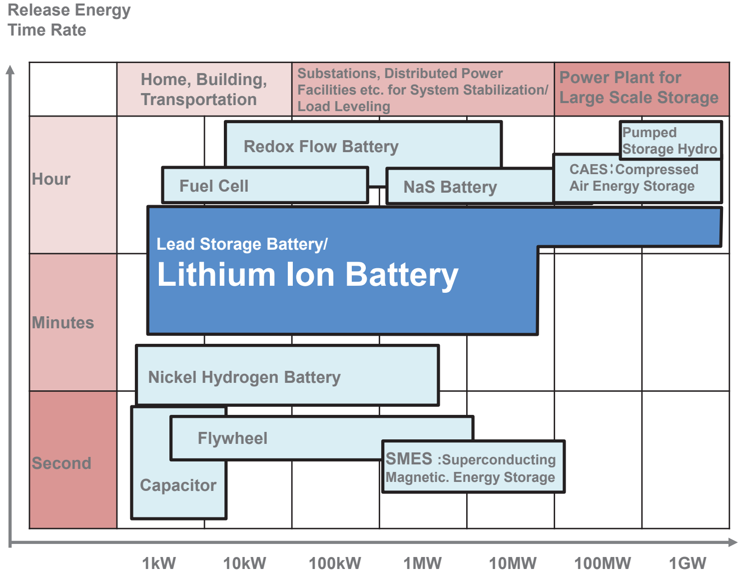
- Curtailment of VRE energy in PCS to make grid stables, smart inverter
- **Governor Free (GF), Economic Load Dispatch (ELD), Load Frequency Control (LFC)**
- **Energy storage: Battery, flywheel**
- **Synchronous condenser, Statcom**
- EV charging time shift
- Demand side management
- Regulatory framework change, **review of grid code**

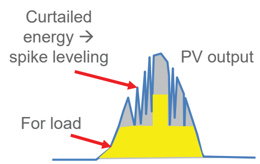
Insufficient Inertia, Synchronizing Force

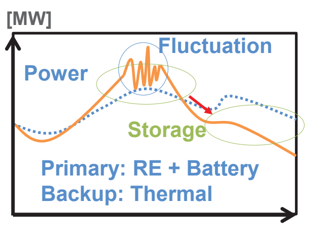
- **Battery-Motor generator set**
- **Biofuel (diesel, jet) for DG**
- CSP (Concentrated Solar Thermal Power)
- Gravitational Power
- **Grid forming Inverter**
- H2 generation from RE by electrolysis
- Seasonal large scale storage

Battery and Energy Storage

Positioning for Energy Storage Technology

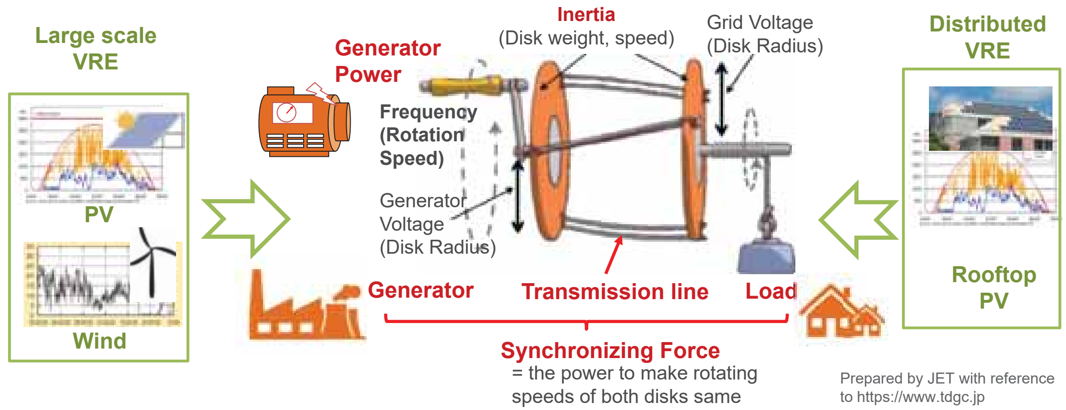






Source: NEDO Renewable Energy Technology White Paper Chapter 9

Inertia and Synchronizing Force with RE



Inertia: The force to keep the rotation of disk when load is changed
Synchronizing Force: The force to keep rotation speed of disks. It keeps back to the same rotation when generation power and load is varied, without entangling.

Fluctuation of large scale VRE affects to generator at generation side and load side
→ **Inertia and Synchronizing Force need to be enhanced for grid with large VRE**

Agenda for Workshop for Grid Stability with Large RE Penetration

Date/time: 13:00-15:00 12 Oct2022
Venue: MSET/ Online

(Tentative Schedule)

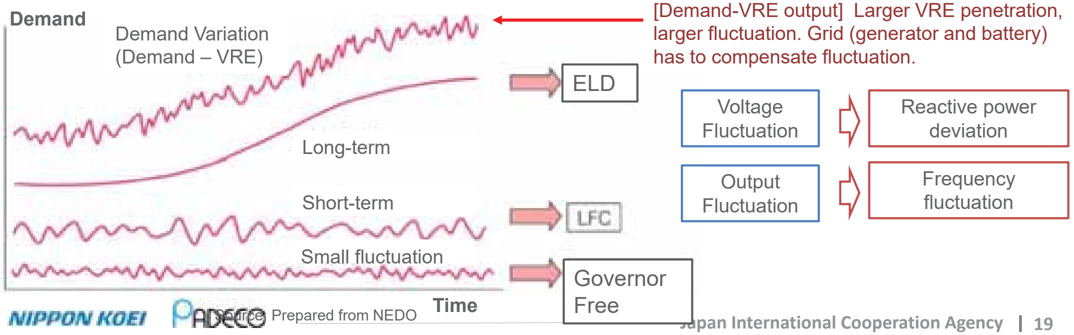
13:00-13:10 Opening Remarks and Introduction
13:10-13:30 RE target in Jamaica and Challenges
13:30-14:00 Monitoring of Grid: simple power flow analysis, demand-supply balance
14:00-14:30 Grid Stability: analysis method, tools, recommendation for grid code
14:30-15:00 Discussion

Seminar on Grid Stability with Large RE (3-days, Nov 2022)

Day	Title	Objective	Details
Day-1	Basics of Power System Engineering for Grid Stability Simulation (optional)	To review basic principal and necessary formula for conducting load flow analysis	1. What is Power System?: Three-phase AC, Single line network description 2. Per Unit Method: 3. Modeling of Power System Equipment: Tr.Line Transformer, Generator & Load 4. Active Power & Frequency: Frequency control, Area requirement 5. Reactive Power & Voltage: P-V Curve, Reactive power resource 6. Practice of Modeling of Grid
Day-2	Basics and Exercise for Load Flow Analysis	To understand the principal and method for Load Flow Analysis , DC Flow Method, and conduct exercise with the software "Microgrid/VPP Designer"	1. Overview of Load Flow Analysis: Purpose, Methods, Modeling of grid 2. Newton-Raphson Method: Theory, Characteristics 3. DC Flow Method: Theory, Simple method to solve load flow manually 4. Exercise of DC Flow Method, 5. Practice on Microgrid/VPP Designer 6. Load Flow Analysis & Evaluation of sample Grid
Day-3	Analysis of Grid Stability and LFC/ELD	To understand the method of grid stability analysis, with Steady State Stability, Transient Stability Equal Area Criterion, LFC (Load Frequency Control) and ELD (Economic Load Dispatching)	1. Overview of Stability: Definition, Methods, Swing equation 2. Stability Model: Simplified grid model, Equivalent circuit of synchronous generator 3. Equal Area Criterion: Theory, Simple method to solve stability manually 4. Available Transmission Capacity & Spinning Reserve 5. Exercise of Equal Area Criterion, 6. Practice on Mircogrid/VPP Designer and LFC/ELD 7. Stability Analysis, Evaluation of Barbados Grid

Grid Stabilization: GF, LFC, ELD

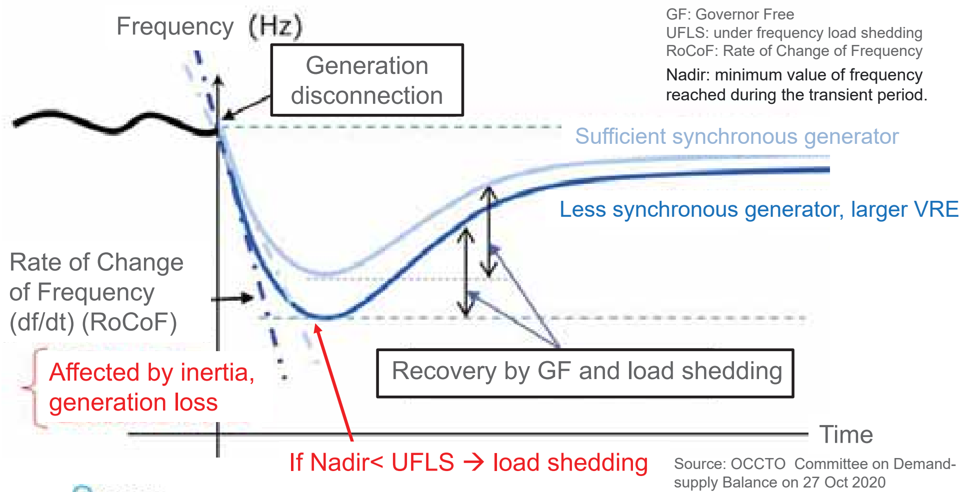
Control Type	Frequency	Description
Governor Free (GF)	Within one minute	Generator detects rotation fluctuation and automatically controls rotation so that frequency is kept at suitable level
Load Frequency Control (LFC)	Minutes-ten minutes	This involves the sensing of the bus bar frequency and compares with the tie line power frequency. The difference of the signal is given to speed changer of generator, so that the frequency of the tie line is maintained as const
Economic Load Dispatch (ELD)	More than ten minutes (preparatory setting)	Most economical load distribution between a number of generator units is considered with different heat late at each load range. Optimum operation of generators at each generating station at various station load levels (unit commitment) are settled.



Source: Prepared from NEDO

Inertia and Synchronizing Force with RE

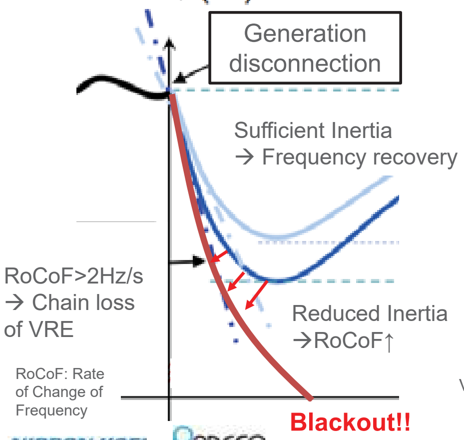
Synchronous generator: The power source establishes voltage and frequency with reactive power, and combines with generators by synchronizing force
VRE/BESS with inverter: DC converted to AC. There is no rotation, no synchronizing force. It monitors grid AC voltage and wave and adjust accordingly → no contribution for stability

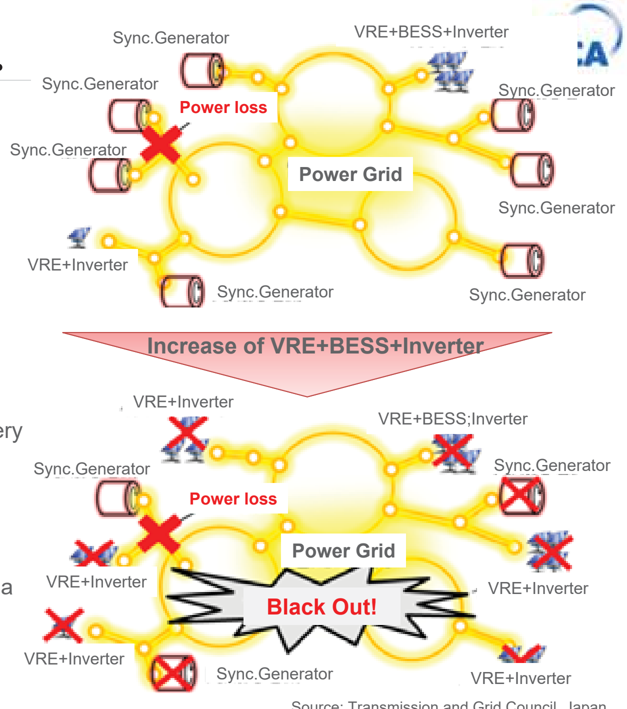


Source: OCCTO Committee on Demand-supply Balance on 27 Oct 2020

Black-out when insufficient Sync. Gen.

If synchronous generator is reduced and inertial is not sufficient, power loss
→ Frequency drop, with no recovery
→ Chain reaction of loss of VRE
→ **Black out**





Source: Transmission and Grid Council, Japan

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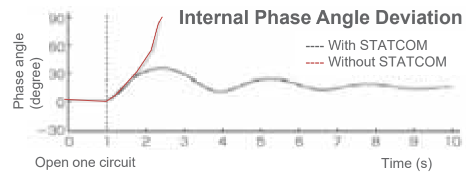
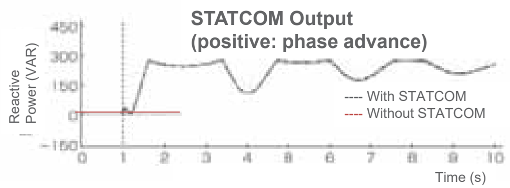
SCO and STATCOM for Reactive Power

SCO (Synchronous Condenser) :
SCO is DC-excited synchronous machine (large rotating generators) whose shaft is not attached to any driving equipment. Though changing field excitation, SCO adjusts reactive power and provides reactive power at the time of voltage drop.

https://energy-shift.com/news/af737655-0462-4655-81ae-b17d86b5784d

STATCOM (STATic synchronous COMpensator) :
For compensation of reactive power, it generates/absorbs reactive power, and stabilize voltage continuously at high speed by self-commutated inverter.





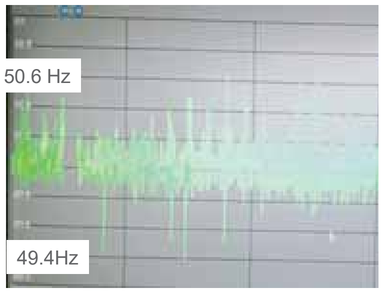
Source: Enhancement of Steady−State Stability and Suppression of Over−Voltage using 450MVA GCT−STATCOM, Mitsubishi Denki Giho, pp.52-55, Vol.87, No.11, 2013.

https://www.hitachi.co.jp/products/energy/STATCOM/about/index.html

Consideration for Larger VRE/BESS Penetration

- Increased application of PV and Wind :
  - Is Battery sufficient measurement?
  - To what extent can utility scale PV and wind be operated without affect on grid power quality?
  - How much can a feeder accommodate distributed PV and BESS?

- Planning with **grid simulation** is necessary.
  - Load flow analysis
  - Stability analysis
- Grid code needs to be checked for condition of grid connection of VRE and BESS



Example of frequency fluctuation with VRE

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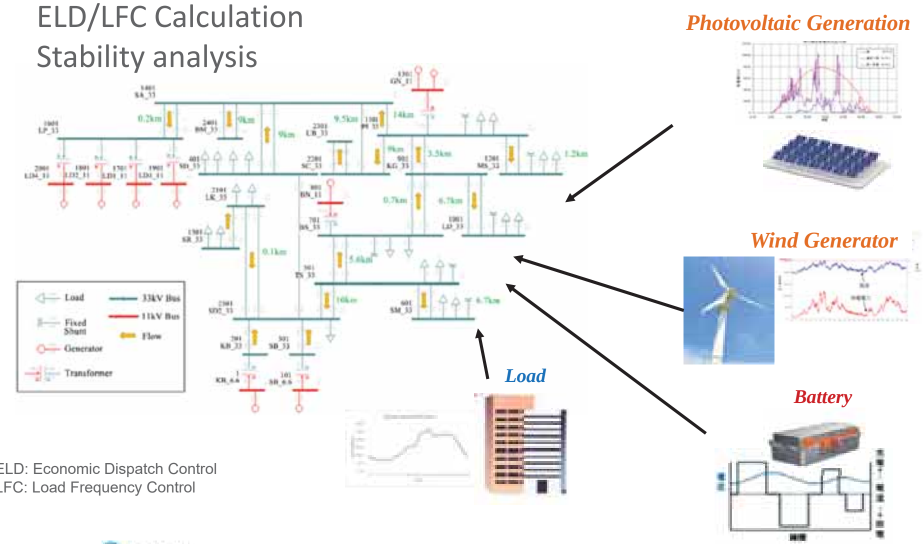
Grid Stability Simulation

- Simulation of National Grid Model based on asset data
- Analysis of Issues and Solutions
- ELD/LFC Calculation
- Stability analysis



ELD: Economic Dispatch Control
LFC: Load Frequency Control

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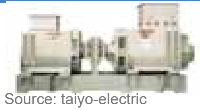
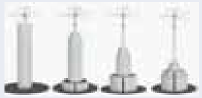
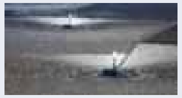
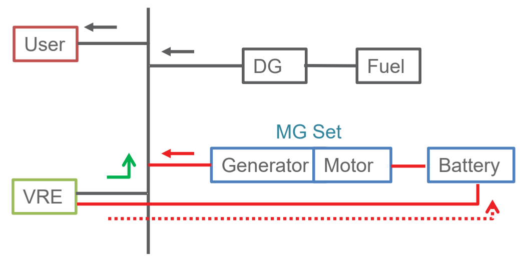
Emerging technology for large RE with Grid stabilization : Generation with Inertia and Synchronous Power

Type of Technology		Advantage	Develop stage
 Source: taiyo-electric	Motor generator (MG)	- Energy in battery provides synchronization and inertia - Small scale supply, for micro grid	- Used as frequency conversion - Commercial operation
 energyvault.com/gravity	Gravity Storage Battery	- Gravity of recycled Concrete block 35ton/nos - Provides inertia - Half cost of Li-ion battery	Pre-commercial, 35 MWh, 4MW per tower η=85% 52.5GW planned in USA
 /www.nedo.go.jp/news/press/AA5_100756.html	CAES (Compressed air energy storage)	- Compressed high pressure air - (Liquid air may be developed) - Provides inertia	-demonstration by NEDO - 900 MW in California - η=70-80%
 electrek.co/	CSP (concentrating solar power) Solar thermal	- With turbine, provides inertia and synchronization - Cost decrease expected, higher efficiency than PV, η=50%	- Commercial operation at Ivanpah392MW 22 bil USD - Heat storage (molten solt, etc) under development
 Source: CIGRE	Grid-forming inverter	- Dynamic active/reactive power, FRT, frequency control, inertia - Applicable to existing PV - (Smart Inv: FRT, VRT, voltage support)	- Under development - (Smart inverter by IEEE1547, Mandatory in Hawai)

Option For 100% RE: Battery Motor Generator set (MG Set)

Hateruma Island: Southern most island in Japan
- Area : 12.73 km2 , Population 527, hh 272 (2016)
- Peak power: 770 kW (2016)
- Generation: DG (Bunkar-A, total 1,250kW)
- Wind (245kW✕2, total 490kW)
- Lead-acid Batt (600kW/1,500kWh)
- **MG Set: Rated 300 kW**



Wind generator

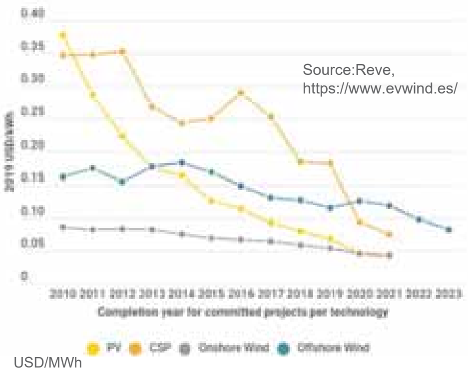
Photo: https://www.kankyo-business.jp/news/011605.php

MG set is driven by battery charged from VRE and provides power with inertia → possible method to achieve 100% RE with inertia

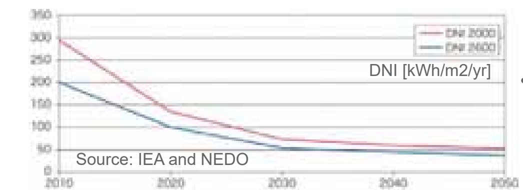
https://www.okiden.co.jp/shared/pdf/news_release/2017/180328.pdf

Option for 100% RE: CSP

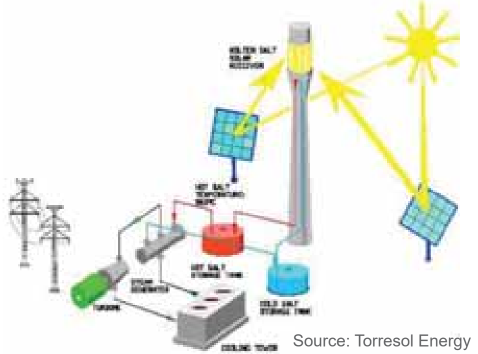
Concentrating Solar Thermal Power (CSP)



USD/MWh



- Rapid cost reduction (47% in 2010-2019)
- Combination with molten-salt heat storage
- Inertial power can be supplied



Source: Torresol Energy

- DNI (Direct normal irradiation)
  - Barbados: 1600-2000 kWh/m²/yr
  - St Kitts&Nevis:1600-2300 kWh/m²/yr
  - Jamaica: 1300-2200 kWh/m²/yr

Example of Grid Code

Country	UK	Ireland	Germany	Japan
Grid Code	The Grid Code	EirGrid Grid Code	Technical Connection Rules fore MV	Grid Code
Regulator	Ofgen (regulator)	TSO	VDE (Association)	OCCTO
Main Items of Grid Code	- Frequency and time for operation continue - Active power increase/ decrease at the time of frequency increase/ decrease - Active power Droop according to frequency change rate - Voltage, harmonic wave, flicker at nodes - FRT requirement at the time of voltage drop - Reactive power supply - Black start and Protection of grid and generators	- Frequency and time for operation continue - Active power decrease/ Increase at the time of frequency increase/ decrease - Governor control rate - FRT requirement at the time of voltage drop - Reactive power supply - Speed of power increase/ decrease with load dispatch order - Lower limit of load - Spinning reserve requirement	-Frequency and voltage that need continuous operation -Active power increase/ decrease at the time of frequency increase/ decrease - FRT requirement at the time of voltage drop - Reactive power supply at the time of voltage change - Active power limit at the time of large voltage change - Protection of grid and generators	(under preparation)

OCCTO: Organization for Cross-regional Coordination of Transmission Operators, Japan
FRT: Fault Ride Through

Appendix

Resilience for RE

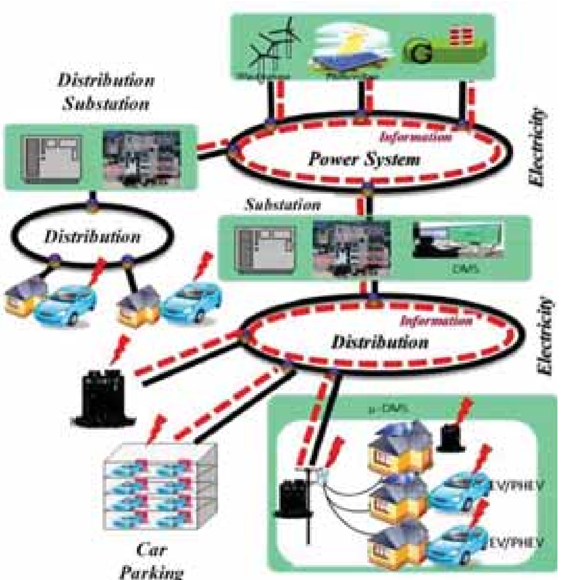
23 Aug 2018 Awaji, Japan
https://www.sankei.com/west/news/180828/wst1808280043-n1.html
600 kW, Fallen at 25.6m/s wind while 60m/s design
- Additional moment due to Excess of high speed
- Missing control power supply

9 Sep 2019 Kanto, Japan
@kadowaki_kozo
Damage of roof-top structure by high speed wind

26 Jul 2019 Himeji, Japan
https://www.dailyshincho.jp/article/2018/07260800/?photo=1
Landslide by a heavy rain

For enhancement of resilience:
- ✓ Design Standard with higher rank hurricane
- ✓ Autonomous Micro-grid
- ✓ Fast recovery with GIS and Asset management

Microgrid Concept

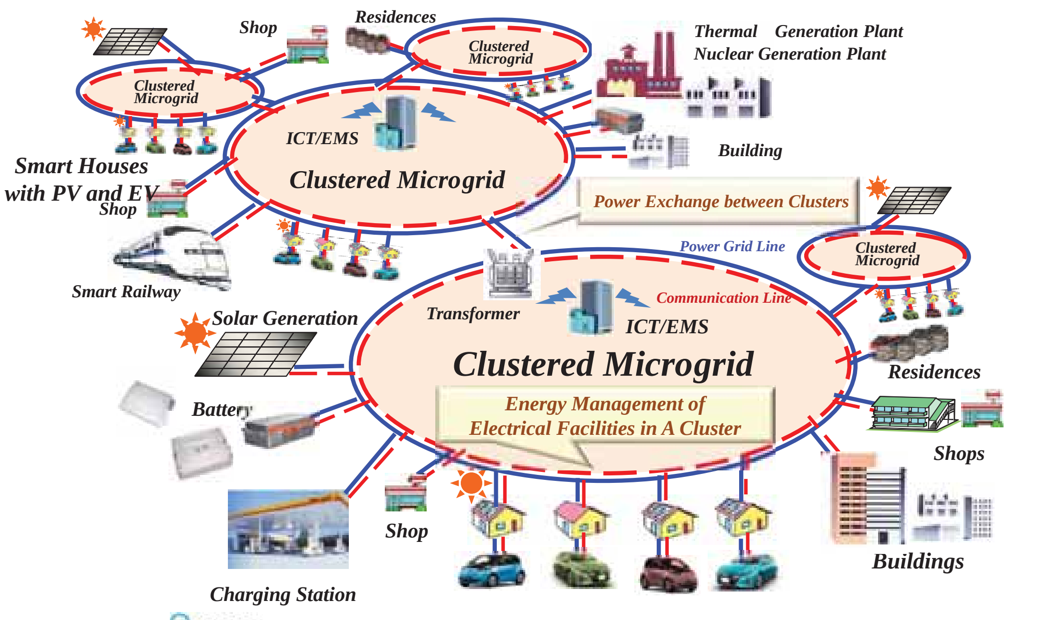


Source: Smart City Development and Recent trend in Electric Power Network, Waseda Univ.

Concept of Micro-grid

- ✓ Respective Micro-grid is connected each other, and each Micro-grid can work independently
- ✓ Local energy production for local consumption
  - ✓ Generation: PV, wind, biomass, DG, GT, battery, etc.
  - ✓ Demand: industry, commercial, home, EV, etc.
- ✓ No transmission → loss saving
- ✓ With IoT, control system, EMS, demand response, smart meters
- ✓ Enhance resiliency

Microgrid for Resilient System
-- Autonomous Micro Grid



Microgrid Planning

1	**Discussion with transmission operator about affect on outside Microgrid**	Confirm emergency recovery method and affect on adjacent area. Consider discuss about switching microgrid to master grid, and responsibility for the affect on adjacent areas.
2	**Plan for system structure of Microgrid with distribution operator**	Consider protection and control method considering supply and demand and capacity of generator, and operation at the time of emergency (load shedding, control method, etc.). Discuss about schedule, design, selection of equipment.
3	**Estimation of load and demand at normal and abnormal condition in Microgrid**	Plan load equipment, specification, and estimate demand at normal and abnormal condition, from data as much as accurate by each feeder. Confirm with drawing and diagram.
4	**New system installation/enhancement for facility requirement for RE and supply-load balancing**	Plan RE facility and energy storage based on power demand and supply, and consider necessary enhancement considering fluctuation and output instability.
5	**System requirement and legal confirmation for inside and outside Microgrid**	Review relevant regulation and rules including grid code for connection to transmission line and consider necessary system modification. Operation method at the time of emergency recovery and minimizing its time needs to be discussed.
6	**Based on above, finalization of system configuration and specification for whole Microgrid**	Based on above study and supply-load balance, determine the system configuration and specification of each equipment considering operation and communication. EMS development might be necessary.

Grid Stability-1: for Future Grid under Penetration of RE in Jamaica

JICA Expert Team, Nippon Koei Co., Ltd.

Why Grid Stability

- Responsibility of IBR(Inverter Based Resources) is faster than that of synchronous generator.
- The output of IBR can be controlled quickly.
- IBR has less or no inertia than synchronous generator.

↓

- Increase or add inertia function to IBR
  - Grid Forming Inverter
- Increase generator with large inertia.
  - Resources provided by Synchronous generators

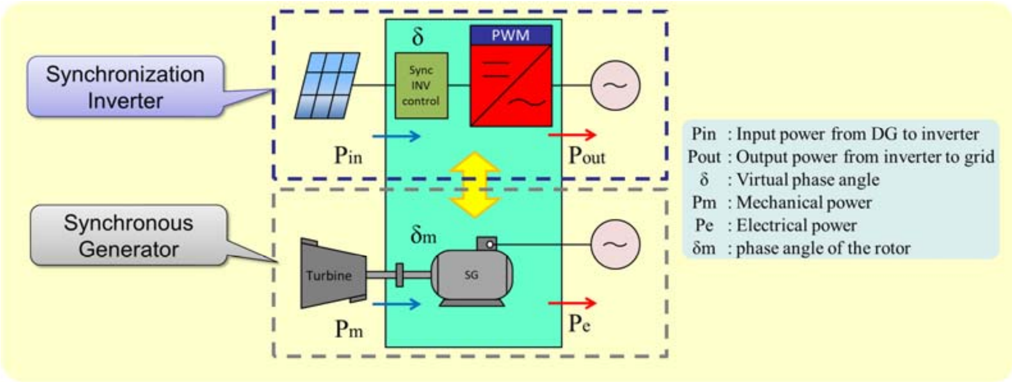
Keywords for Grid Stability

- **Virtual Inertia**
  - Grid Forming Inverter vs Grid Following Inverter
  - EV(Electric Vehicle) for V2G(Vehicle to Grid)
  - Virtual Power Plant
  - DR(Demand Response)
- Evaluation Index of Stability
  - **SCR**(Short Circuit Ratio)
  - **ATC**(Available Transmission Capacity)
  - **Spinning Reserve**
    - **Pilferage may decrease spinning reserve.**
- **Grid Code** from the Viewpoint of Stability
- **Microgrid**: One Solution for Stability
  - Decrease Power Flow of Utility Transmission Lines

IBR(Inverter Based Resources) Types

- Grid Following Inverter
  - Current Source Inverter
  - Control output current as adjusting voltage to grid's
- Grid Forming Inverter
  - Voltage Source Inverter
  - Virtual Synchronous Generator
  - Control output voltage and its frequency as adjusting power to grid's
  - Supply Virtual Inertia to Grid
  - Source: PV, WT(Wind Turbine), EV(Electric Vehicle), Battery

Concept of Virtual Inertia



Source: M. Kawai, Y. Sakai, H. Sugiyama, H. Taoka "Frequency Improvement of a Power System with a Distributed Generator using Synchronization Inverter," 2015 International Symposium on Smart Electric Distribution Systems and Technologies (EDST), CIGRE SC C6 Colloquium, Sep. 2015.

Control Algorithm for Virtual Inertia

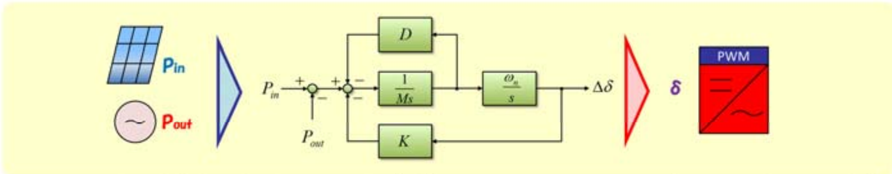
The control method of Synchronization Inverter is expressed by the swing equation.
This equation is added damping term and synchronizing power term.

$$\frac{M}{\omega_n}\frac{d^2\delta_m}{dt^2} + \frac{D}{\omega_n}\frac{d\delta_m}{dt} + K\delta_m = P_m - P_e$$

This swing equation of the Synchronization Inverter is solved for virtual phase angle δ.

The transfer function of voltage value

$$\delta = \frac{\frac{1}{M}\omega_n}{s^2 + \frac{D}{M}s + \frac{K}{M}\omega_n}(P_{in} - P_{out})$$



Source: M. Kawai, Y. Sakai, H. Sugiyama, H. Taoka "Frequency Improvement of a Power System with a Distributed Generator using Synchronization Inverter," 2015 International Symposium on Smart Electric Distribution Systems and Technologies (EDST), CIGRE SC C6 Colloquium, Sep. 2015.

SCR(Short Circuit Ratio)

- SCR is the factor to be considered for grid stability.
- SCR=AC System Capacity/Rated IBR Capacity
  - SCR>3 -------- High SCR, Stable
  - 3>SCR>2 ----- Low SCR
  - 2>SCR -------- Very Low SCR
- Discussed in IEEE Std 1204-1997(R2003)
  - IEEE Guide for Planning DC Links Terminating at AC Locations Having Low Short-Circuit Capacities
  - Recognized by ANSI(American National Standards Institute

Sources for High SCR Grid

- V2G(Vehicle to Grid) of EV(Electric Vehicle)
- BESS(Battery Energy Source System)
  - Battery with control circuits
- Biofuel Generator
- Solar Thermal Generator

  and
- Renewable Energy Resources (PV, WT) with Grid Forming Inverter
- These resources can supply inertia to grid.

ATC(Available Transmission Capacity)

- Transmission capacity needs to be calculated to see whether RE can be transmitted from source location to demand place.
- Power Equation
  - $P = \frac{V_i V_j}{X} \sin\delta$
- Synchronizing Force
  - $\frac{dP}{d\delta} = \frac{V_i V_j}{X} \cos\delta$
- Available Transmission Capacity from Heat Capacity Limit

$$P_{loss} = R * \left(\frac{V_i}{X}\right)^2 < P_{\mathrm{LOSSMAX}}$$

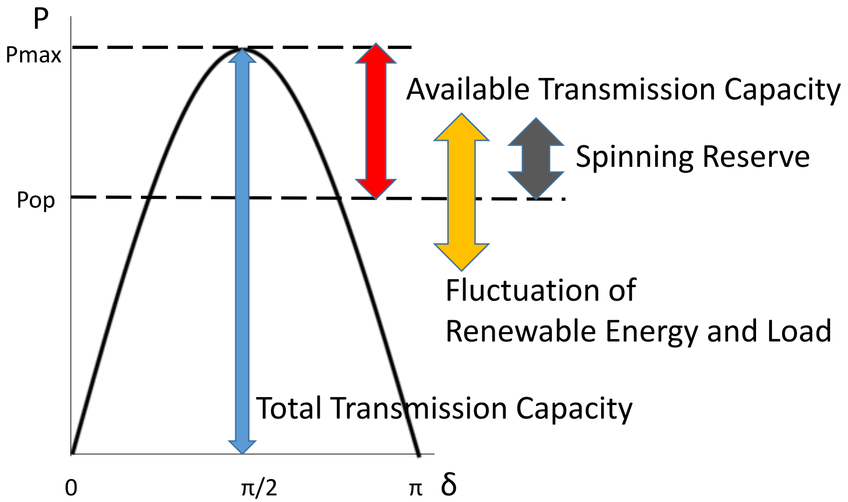
- Available Transmission Capacity from Transient Stability

$$P = \frac{V_i V_j}{X} \boldsymbol{\sin\delta} \rightarrow P_{\mathrm{ATC}} = \frac{V_i V_j}{X} - P_{\mathrm{OP}}$$

Spinning Reserve

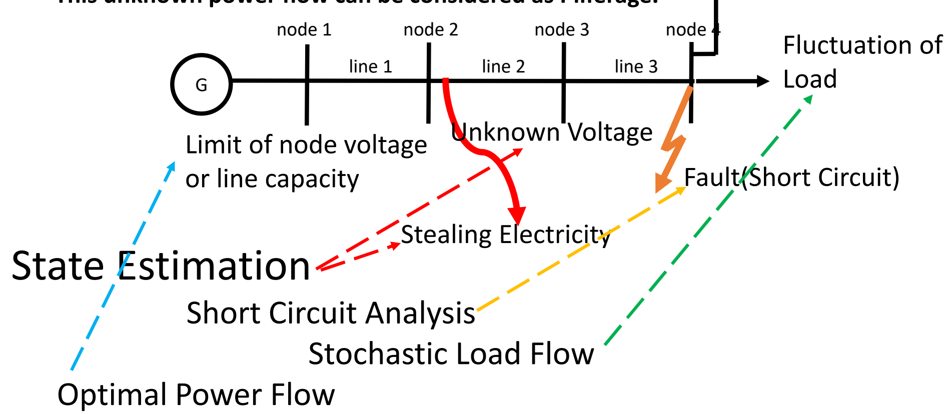
- In order to get electrical power under abnormal condition of grid, spinning reserve should be kept even if RE is installed. (under discussion)
- Spinning reserve should be more than mixed fluctuation of load and renewable energy.
  -> RE, EV and Battery with inertia is required for large RE penetration.
- Best Energy Mix
  -> Energy mix of several resources will be helpful for improving grid stability.
- RE Sources for Spinning Reserve: EV, Battery, Biofuel or Diesel Generator, etc.

Available Transmission Capacity & Spinning Reserve



Applications of Load Flow Analysis

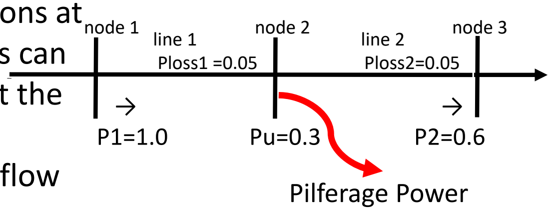
- Load Flow Analysis
  - Calculate voltages, voltage angles, real power and reactive power
- **State Estimation**
  - **Estimate unknown power flow through load flow analysis**
  - **This unknown power flow can be considered as Pilferage.**

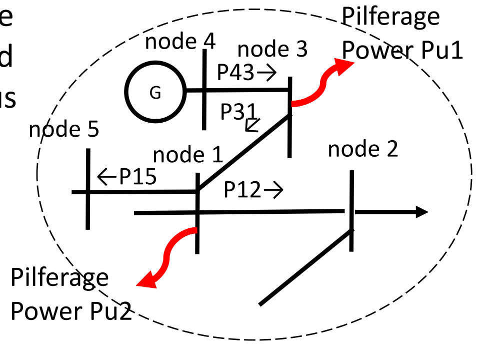


Example of State Estimation for Multi Point Pilferage

If there are multi point pilferage, we have to consider multiple conditions at the same time. Load flow analysis can provide answer for all pilferage at the same time using simultaneous equations of load flow. This load flow analysis is called state estimation.

For example, in a lower figure, pilferage power Pu1 and Pu2 cannot be obtained independently. It requires simultaneous equations which include conditions of node 1, 2,3 ,4 ,5, respectively.





For example, Power flow of pilferage can be formulated as P43=P31+Pu1, P31=P15+P12-Pu2. Line flow is described by quadratic equations of voltage. Then they are set up as simultaneous quadratic equations.

Purpose of State Estimation

- Bad data detection and repairing by Energy Management System
  - USA, EU, Japan, etc.
  - Find trouble of metering
  - Proposed by Dr. Schweppe(1970)
- Finding and possible countermeasures for pilferage by Distribution Management System
  - Middle-East Area Case in 1980's
  - Long transmission line in desert
- To check consumption of customers who do not allow meter reader person (ex. gang) to read proper meter
  - Japanese Utility's Case from 1970's
  - Automatic Meter Reading -> Smart Meter
- Control of Renewable Energy
  - Prediction and control output of RE

Finding and possible countermeasures for Pilferage

- Metering System and its Analysis
  - Server of Metering Data is located in Control Center, Substation
- Registration of Customers
  - Registration office calculate and check total capacity.
- Over Current Relay which works on Maximum Capacity of Registered Customers
  - Customers may have some problems in the limitation of electricity.
- Warning based on State Estimation
  - Evidence of calculated data from state estimation

Frequency and Voltage Control

- Frequency Control
  - Frequency Ride Through
  - Governor Control in Generation Side(PV, WT)
  - Load Frequency Control through Control Center/EMS
- Voltage Control
  - Voltage Ride Through
  - DVS(Dynamic Voltage Support) by Reactive Power in Generation Side (PV)

Recommendation for Grid Code

- The following items will be required from Grid Stability:
  - Virtual Inertia for IBR(Inverter Based Resources)
  - High SCR of Grid
  - Spinning Reserve from EV, Battery, etc.
- RE with these functions is key technology for grid stability.

Grid Code in EU and USA

- RfG(Requirements for Generators) : Grid Code in EU
  - The relevant TSO（Transmission System Operator）shall have the right to specify that power park modules [of type C and D, i.e. more than 10MW] be capable of providing synthetic inertia during very fast frequency deviations.
- IEEE P2800 : Grid Code in USA
  - IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Electric Power Systems

Category	Boundaries
Type A	800W to 1MW and connected below 110kV
Type B	1MW to 10MW and connected below 110kV
Type C	10MW to 50MW and connected below 110kV
Type D	50MW or connected at 110kV or above.

Grid Code Committee in Japan

Under discussion now

- Short Term Target:2023/4
  - Criterion for Generator
- Middle Term Target:2025/4
  - Voltage Ride Through
- Long Term Target:2030/4
  - Inertia Market
  - RoCoF (Rate of Change of Frequency)
  - Virtual Inertia
  - Stability
  - Black Start

Operating State of Power System

- Operated Generation Power is to be normally 60～70% of total generation capacity.
- The fluctuation of load is 10～20%, if load prediction is operated well.
- The magnitude of fluctuation of renewable energy(PV and WT) will be total capacity of renewable energy.
- The fluctuation of generation power will be up to sum of the fluctuation of load and renewable energy.

Operating State of Power System and Spinning Reserve

- If total demand of grid becomes up to 90% over of rated capacity of grid,
  - Spinning reserve will be decreased.
  - Synchronizing force will be very small or negative, not to be returned to stable state.

- Spinning reserve should be more than magnitude of mixed fluctuation of load and renewable energy.

➢ RE, EV and Battery which can provide inertia is required for large RE penetration.

➢ Energy mix of several resources will be helpful for improving grid stability.

➢ Pilferage may decrease spinning reserve.

Grid Stability-2: Overview of analysis method and tools

JICA Expert Team, Nippon Koei Co., Ltd.

Load Flow Analysis

- Gauss-Seidel Method
  - Iterative method to get approximate solution
- Newton-Raphson Method
  - Using Jacobian matrix to get approximate solution
- Fast Decoupled Method
  - Use relationship between active power and angle and relationship between reactive power and voltage
- DC Flow Method(manual calculation)
  - Use relationship between active power and angle in the way to solve DC circuit equations

Load Flow Analysis

Necessary items to consider Load flow Analysis
Buses are categorized to the following 3 types.

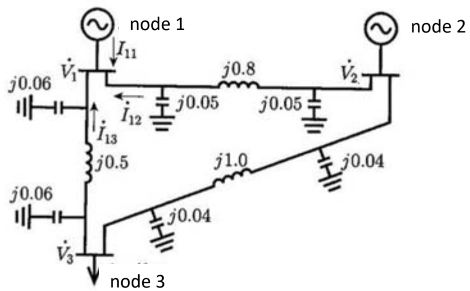
- Slack (Swing) Bus
  - The magnitude and phase angle of the voltage are specified.
  - This bus makes up the difference between the scheduled loads and generated power that are caused by the losses in the network.
- P-V Buses (Generator Buses)
  - The real power and voltage magnitude are specified.
  - The phase angles of the voltages and the reactive power are to be determined.
- P-Q Buses (Load Buses)
  - The active and reactive powers are specified.
  - The magnitude and the phase angle of the bus voltages are unknown.

Node Admittance Matrix

$$\begin{bmatrix} \dot{I}_1 \\ \dot{I}_2 \\ \vdots \\ \dot{I}_N \end{bmatrix} = \begin{bmatrix} \dot{Y}_{11} & \dot{Y}_{12} & \cdots & \dot{Y}_{1N} \\ \dot{Y}_{21} & \dot{Y}_{22} & \cdots & \dot{Y}_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \dot{Y}_{N1} & \dot{Y}_{N2} & \cdots & \dot{Y}_{NN} \end{bmatrix} \begin{bmatrix} \dot{V}_1 \\ \dot{V}_2 \\ \vdots \\ \dot{V}_N \end{bmatrix}$$

Describe Network Structure

Y= 1/(R+JωL) ＋jωC
R:Resistance
C:Capacitance
L: Inductance

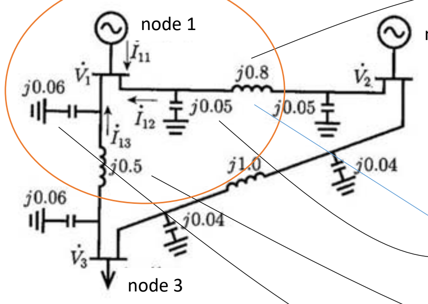


- Calculation example of power flow in 3 nodes network

V1,,,Vn: Node(Bus) Voltage
I1,,,In: Btanch(Line) Current
Yij: Admitance between earch node

Figure is cited from
M.Kato & H.Taoka, “Fundamental Power System Engineering,” Suurikogaku-sha, 2011.

Node Admittance Matrix



Driving Point Admittance

$$\dot{Y}_{11} = j0.05 + j0.06 + \frac{1}{j0.8} + \frac{1}{j0.5} = -j3.14$$

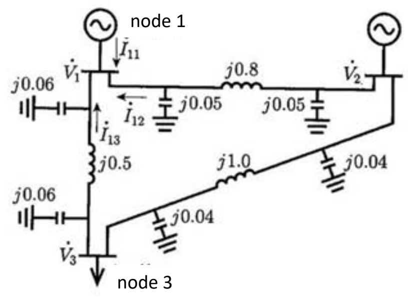
- Y11,Y22,Y33:
  - Driving Point Admittance
- Y12,Y21,Y13,Y31,Y23,Y32:
  - Transfer Admittance

Transfer Admittance

$$\dot{Y}_{12} = \dot{Y}_{21} = -\frac{1}{j0.8} = j1.25$$

Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Node Admittance Matrix



$$\dot{Y}_{11} = j0.05 + j0.06 + \frac{1}{j0.8} + \frac{1}{j0.5} = -j3.14$$

$$\dot{Y}_{22} = j0.05 + j0.04 + \frac{1}{j0.8} + \frac{1}{j1.0} = -j2.16$$

$$\dot{Y}_{33} = j0.04 + j0.06 + \frac{1}{j1.0} + \frac{1}{j0.5} = -j2.9$$

$$\dot{Y}_{12} = \dot{Y}_{21} = -\frac{1}{j0.8} = j1.25$$

$$\dot{Y}_{13} = \dot{Y}_{31} = -\frac{1}{j0.5} = j2.0$$

$$\dot{Y}_{23} = \dot{Y}_{32} = -\frac{1}{j1.0} = j1.0$$

- Y_{11},Y_{22},Y_{33}:
  - Driving Point Admittance
- Y_{12},Y_{21},Y_{13},Y_{31},Y_{23},Y_{32}:
  - Transfer Admittance

$$\boldsymbol{Y} = \begin{bmatrix} -j3.14 & j1.25 & j2.0 \\ j1.25 & -j2.16 & j1.0 \\ j2.0 & j1.0 & -j2.9 \end{bmatrix}$$

Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Power Equation

- Voltage and current of node k are described as following equations in complex value.
  - $V_k = e_k + j f_k$, $V_m = e_m + j f_m$
  - $I_k = Y_{km} V_{km}$
- Power Equation of node k is described using Node Admittance Matrix.

$$P_k + jQ_k = \dot{I}_k^* \dot{V}_k = \sum_{m=1}^{N} \dot{Y}_{km}^* \dot{V}_m^* \dot{V}_k$$

$$P_{ks} = \mathrm{Re}\left\{\sum_{m=1}^{N} \dot{Y}_{km}^*(e_m + jf_m)^*(e_k + jf_k)\right\}$$

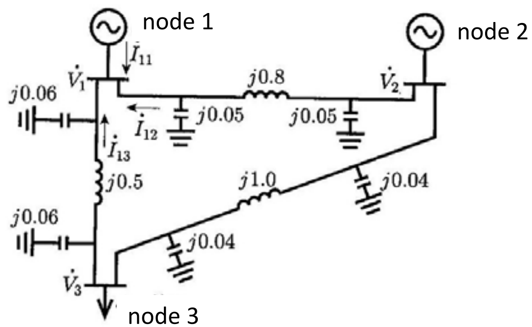
$$Q_{ks} = \mathrm{Im}\left\{\sum_{m=1}^{N} \dot{Y}_{km}^*(e_m + jf_m)^*(e_k + jf_k)\right\}$$

$$V_{ks}^2 = e_k^2 + f_k^2$$

Vi: Node(Bus) Voltage
Ii: Branch(Line) Current
Yij: Admittance between each node
Pi: Node(Bus) Active Power
Qi: Node(Bus) Reactive Power

Power Flow Equation
(Example of 3 nodes network)

Make a Power Flow Equations for each nodes



$$\begin{aligned} P_{2s} = \mathrm{Re}\{&(j1.25)^*(e_1 + jf_1)^*(e_2 + jf_2) \\ &+ (-j2.16)^*(e_2 + jf_2)^*(e_2 + jf_2) \\ &+ (j1.0)^*(e_3 + jf_3)^*(e_2 + jf_2)\} \\ = {}& 1.25e_1 f_2 - 1.25 e_2 f_1 + e_3 f_2 - e_2 f_3 \end{aligned}$$

$$V_{2s}^2 = e_2^2 + f_2^2$$

$$\begin{aligned} P_{3s} = \mathrm{Re}\{&(j2.0)^*(e_1 + jf_1)^*(e_3 + jf_3) \\ &+ (j1.0)^*(e_2 + jf_2)^*(e_3 + jf_3) \\ &+ (-j2.9)^*(e_3 + jf_3)^*(e_3 + jf_3)\} \\ = {}& 2.0e_1 f_3 - 2.0 e_3 f_1 + e_2 f_3 - e_3 f_2 \end{aligned}$$

$$\begin{aligned} Q_{3s} = \mathrm{Im}\{&(j2.0)^*(e_1 + jf_1)^*(e_3 + jf_3) \\ &+ (j1.0)^*(e_2 + jf_2)^*(e_3 + jf_3) \\ &+ (-j2.9)^*(e_3 + jf_3)^*(e_3 + jf_3)\} \\ = {}& 2.9e_3^2 + 2.9f_3^2 - 2.0e_1 e_3 - 2.0 f_1 f_3 - e_2 e_3 - f_2 f_3 \end{aligned}$$

node 1: Slack Bus
node 2: PV Bus
node 3: PQ Bus

$$e_1 = V_{1s}, \quad f_1 = 0$$

Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Newton Raphson Method

- Here we describe numerical theory of Newton Raphson Method
- Equation to be solved is one dimensional equation y=f(x).

1. First, for i=0, assume x(i) to a certain value (ex. 1.0).
2. Calculate $$\Delta x^{(i)} = -\frac{f(x^{(i)})}{f'(x^{(i)})}$$
3. Calculate $$x^{(i+1)} = x^{(i)} - \frac{f(x^{(i)})}{f'(x^{(i)})}$$
4. Repeat 2 and 3, until Δx(i)<ε,
   where ε is a accuracy (ex. 0.001).
1. Get answer of x

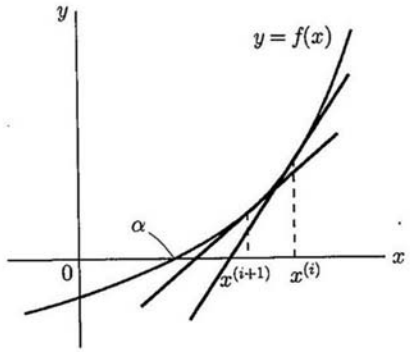


Figure is cited from
M.Kato & H.Taoka, “Fundamental Power System Engineering,” Suurikogaku-sha, 2011.

Newton-Raphson Method

1. Set Node Voltage to 1.0
2. Calculate Jacobian Matrix using modified Voltage (1.0 at first)
3. Calculate ΔP, ΔQ and $\Delta|V|^2$
4. Solve voltage difference ε of each Voltage by eq.(1)
5. Calculate new Voltage by eq.(2)
6. Repeat 2-6 until differences of Voltage are smaller than a certain value

eq.(1)

$$\begin{bmatrix} \Delta P_2 \\ \Delta|\dot V_2|^2 \\ \Delta P_3 \\ \Delta Q_3 \end{bmatrix} = - \begin{bmatrix} \frac{\partial P_2}{\partial e_2} & \frac{\partial P_2}{\partial f_2} & \frac{\partial P_2}{\partial e_3} & \frac{\partial P_2}{\partial f_3} \\ \frac{\partial |\dot V_2|^2}{\partial e_2} & \frac{\partial |\dot V_2|^2}{\partial f_2} & \frac{\partial |\dot V_2|^2}{\partial e_3} & \frac{\partial |\dot V_2|^2}{\partial f_3} \\ \frac{\partial P_3}{\partial e_2} & \frac{\partial P_3}{\partial f_2} & \frac{\partial P_3}{\partial e_3} & \frac{\partial P_3}{\partial f_3} \\ \frac{\partial Q_3}{\partial e_2} & \frac{\partial Q_3}{\partial f_2} & \frac{\partial Q_3}{\partial e_3} & \frac{\partial Q_3}{\partial f_3} \end{bmatrix} \begin{bmatrix} \varepsilon_1^{(i)} \\ \varepsilon_2^{(i)} \\ \varepsilon_3^{(i)} \\ \varepsilon_4^{(i)} \end{bmatrix}$$

eq.(2)

$$\begin{bmatrix} e_2^{(i+1)} \\ f_2^{(i+1)} \\ e_3^{(i+1)} \\ f_3^{(i+1)} \end{bmatrix} = \begin{bmatrix} e_2^{(i)} \\ f_2^{(i)} \\ e_3^{(i)} \\ f_3^{(i)} \end{bmatrix} + \begin{bmatrix} \varepsilon_1^{(i)} \\ \varepsilon_2^{(i)} \\ \varepsilon_3^{(i)} \\ \varepsilon_4^{(i)} \end{bmatrix}$$

DC Flow Method

- Simplified Load Flow Calculation of Transmission Line
- Set all node voltage to 1.0
- Set all resistance of transmission line to 0.0
- Solve relationship equation below between power and voltage angle for each node

$$P_r = \frac{\delta}{X}$$

δ : Phase Difference of voltages between both side of a transmission line
X : Transmission line inductance
Pr : Active power that flows in a transmission line

DC Flow Method

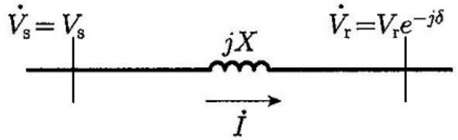
Manual method to calculate power flow.
Easy to calculate in manual.

δ : Phase Difference of voltages Vs, Vr between both side of a transmission line
X : Transmission line inductance
Pr, Qr : Active power that flows through a transmission line

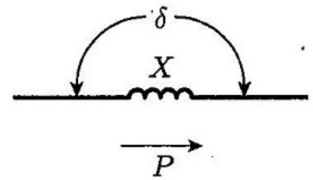
$$\begin{aligned} P_r + jQ_r &= V_r e^{-j\delta} \dot I^* \\ &= V_r e^{-j\delta} \left(\frac{V_s - V_r e^{-j\delta}}{jX} \right)^* \\ &= \frac{V_s V_r e^{-j\delta} - V_r^2}{-jX} \\ &= \frac{V_s V_r}{X} \sin\delta + j \frac{V_s V_r \cos\delta - V_r^2}{X} \end{aligned}$$

$$P_r = \frac{V_s V_r}{X} \sin\delta$$

$$P_r = \frac{\delta}{X}$$

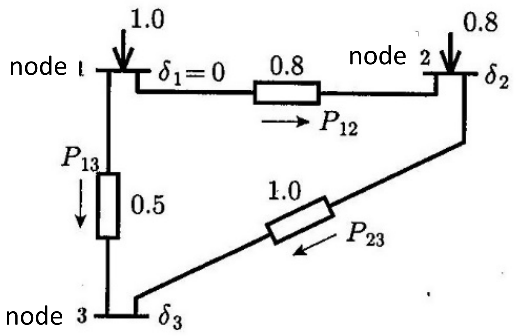


Simplified and Similar to DC circuit solution



Figures are cited from
M.Kato & H.Taoka, “Fundamental Power System Engineering,” Suurikogaku-sha, 2011.

DC Flow Method
(Example of 3 nodes network)



$$1.0 = \frac{0-\delta_2}{0.8} + \frac{0-\delta_3}{0.5}$$

$$0.8 = \frac{\delta_2-0}{0.8} + \frac{\delta_2-\delta_3}{1.0}$$

$$\delta_2 = 0.104$$

$$\delta_3 = -0.565$$

$$P_{12} = \frac{0-0.104}{0.8} = -0.130$$

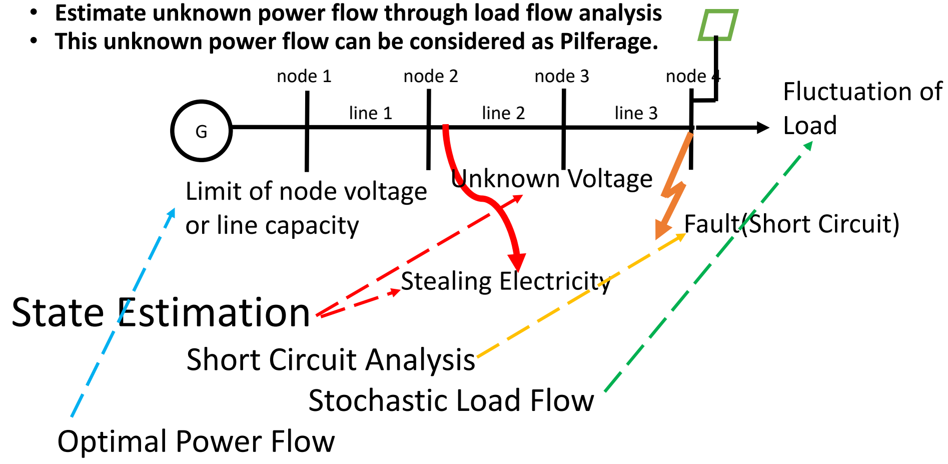
$$P_{13} = \frac{0-0.565}{0.5} = 1.13$$

$$P_{23} = \frac{0.104+0.565}{1.0} = 0.669$$

Per Unit Method:
Rated or base voltage and power in grid are set to 1.0

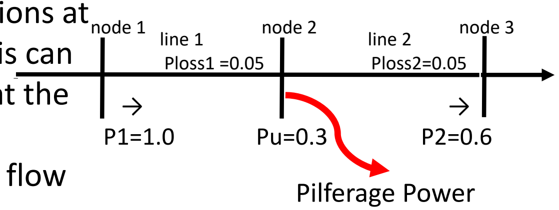
Applications of Load Flow Analysis

- Load Flow Analysis
  - Calculate voltages, voltage angles, real power and reactive power
- **State Estimation**
  - **Estimate unknown power flow through load flow analysis**
  - **This unknown power flow can be considered as Pilferage.**



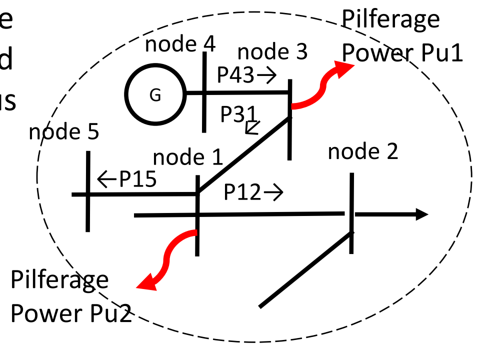
Example of State Estimation for Multi Point Pilferage

If there are multi point pilferage, we have to consider multiple conditions at the same time. Load flow analysis can provide answer for all pilferage at the same time using simultaneous equations of load flow. This load flow analysis is called state estimation.

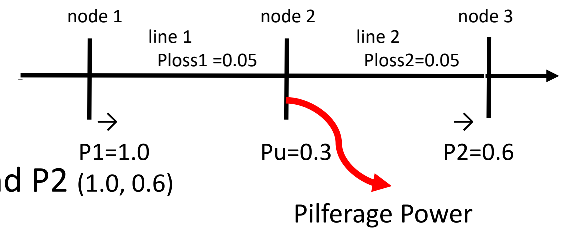


For example, in a lower figure, pilferage power Pu1 and Pu2 cannot be obtained independently. It requires simultaneous equations which include conditions of node 1, 2,3 ,4 ,5, respectively.

For example, Power flow of pilferage can be formulated as P43=P31+Pu1, P31=P15+P12-Pu2.
Line flow is described by quadratic equations of voltage. Then they are set up as simultaneous quadratic equations.



Example of State Estimation for One Point Pilferage

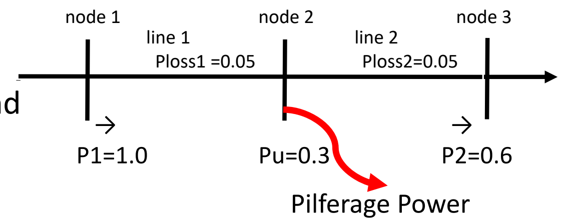


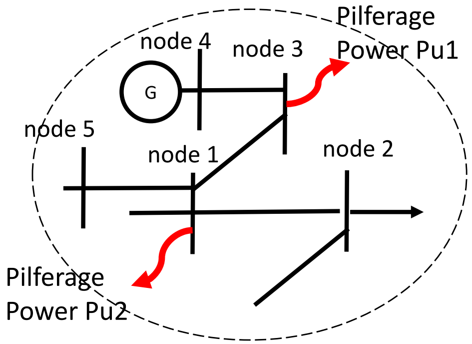
1. Input **Known** Power P1 and P2 (1.0, 0.6)
   - Get data by meter
2. Calculate **Loss** Ploss1 and Ploss2 (0.05, 0.05)
   - Calculate from line impedance and voltage of node1 and node 2
3. Calculate **Pilferage** Power Pu
   - Pu=P1-P2 –(Ploss1+Ploss2)
     =1.0-0.6-(0.05+0.05)=0.3

P1: Active power from node 1 to node 2
P2: Active power from node 2 to node 3
Ploss1: Loss power of line 1
Ploss2: Loss power of line 2
Pu: Pilferage power

Example of State Estimation for Multi Point Pilferage

1. Input **Known** Power (active and reactive power of transmission line, injection from generator and load) and **Known** Voltage and Current at Nodes (magnitude and phase angle)
2. Estimate **Unknown** Voltage by State Estimation (magnitude and phase angle)
3. Calculate Power **Loss and Flow** of Transmission Line and Nodes
4. Output **Pilferage** Power





Purpose of State Estimation

- Bad data detection and repairing by Energy Management System
  - USA, EU, Japan, etc.
  - Find trouble of metering
  - Proposed by Dr. Schweppe(1970)
- Finding and possible countermeasures for pilferage by Distribution Management System
  - Middle-East Area Case in 1980's
  - Long transmission line in desert
- To check consumption of customers who do not allow meter reader person (ex. gang) to read proper meter
  - Japanese Utility's Case from 1970's
  - Automatic Meter Reading -> Smart Meter
- Control of Renewable Energy
  - Prediction and control output of RE

Stability Analysis

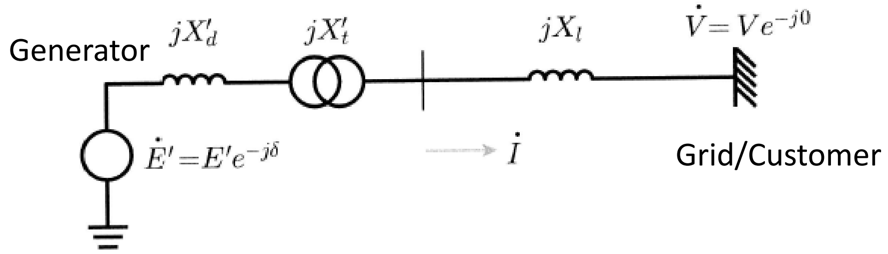
- Equal Area Criterion (Manual calculation)
  - Simplified Stability Calculation
- Transient Stability Program (Simulation Software)
  - Electro-Mechanical Transient Stability
    - Root Mean Square Value Calculation
    - PSS/E, ETAP, CYME, DigSILENT,,,
  - Electro-Magnetic Transient Stability
    - Instantaneous Value Calculation
    - EMTP, EMTDC, PSCAD,,,

Stability Analysis -Swing Equation-

M: Inertia capacity

- $M\ d^2\delta/dt^2 = P_m - P_e = \Delta P$
  - This equation describes relationship between power and frequency.
  - Power will swing according to disturbances caused by unbalance between generation power and consuming load.
- P_m: Generation Power
  - Synchronous Generator: Controllable
  - Renewable Energy Generator:
    Uncontrollable? -> Control,,,
    Uncertainty? -> Predict,,,
- P_e: Load
  - Customer: Uncertainty-> Predict,,,
  - Fault: Uncertainty, Unpredictable (Of course)

Simplified Grid Model



P-δ Equation

$$P = \frac{\dot{V}E'}{X}\sin\delta$$

$$P + jQ = \dot{V}\dot{I}^*$$

$$= \dot{V}\left\{\frac{E'e^{-j\delta} - \dot{V}}{j(X'_d + X_t + X_l)}\right\}^*$$

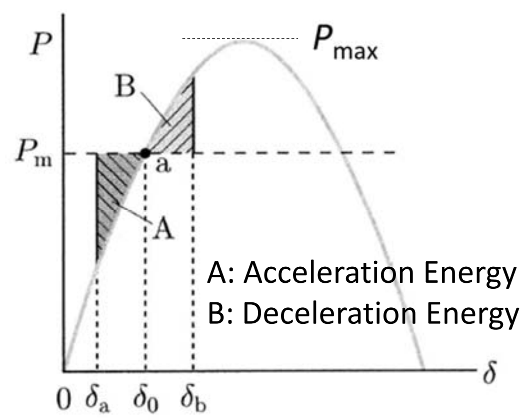
$$= \frac{\dot{V}E'}{X'_d + X_t + X_l}\sin\delta + j\frac{\dot{V}E'\cos\delta - \dot{V}^2}{X'_d + X_t + X_l}$$

$$X = X'_d + X_t + X_l$$

Equal Area Criterion for Stability Analysis

- $P = \frac{V_i V_j}{X} sin\delta$
  Uncertainty of Pm
  It will be caused by load and renewable energy.
- $\frac{dP}{d\delta} = \frac{V_i V_j}{X} cos\delta$
  Synchronizing Force
  Gradient of Power Curve
  If Pm reaches to Pmax, synchronizing force will be lost.

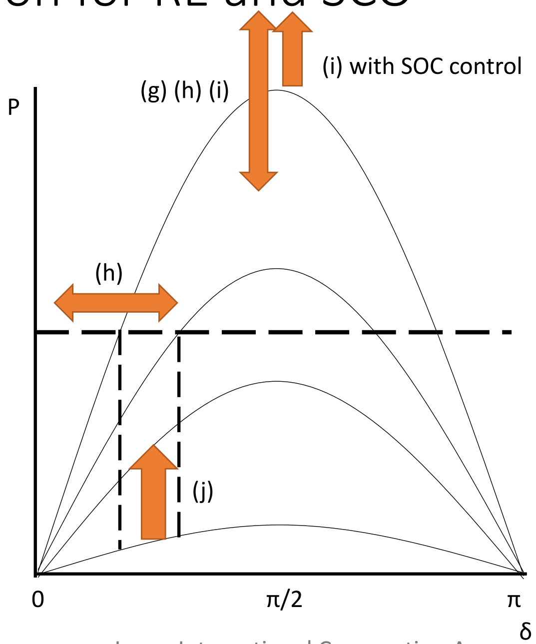
*P*max=>ATC



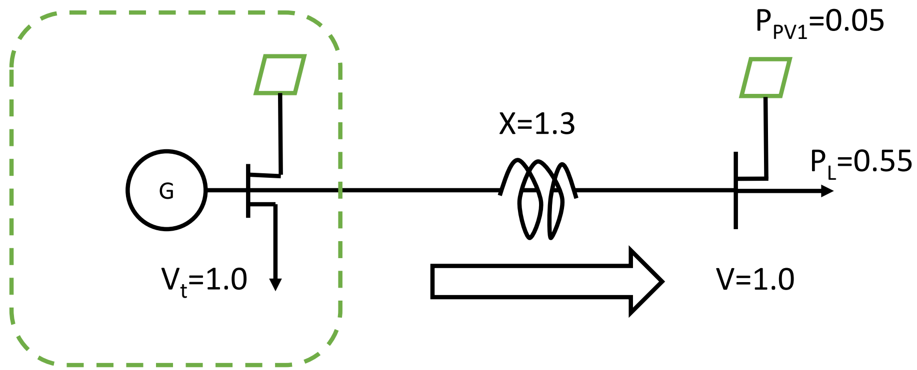
A: Acceleration Energy
B: Deceleration Energy

Equal Area Criterion for RE and SCO

(g) Photovoltaics
Change Pmax
(h) Wind Power
Change Pmax and Phase
(i) Battery
Change Pmax
(j) SCO
(Synchronous Condenser)
Change P during fault



Power System Model (Example)

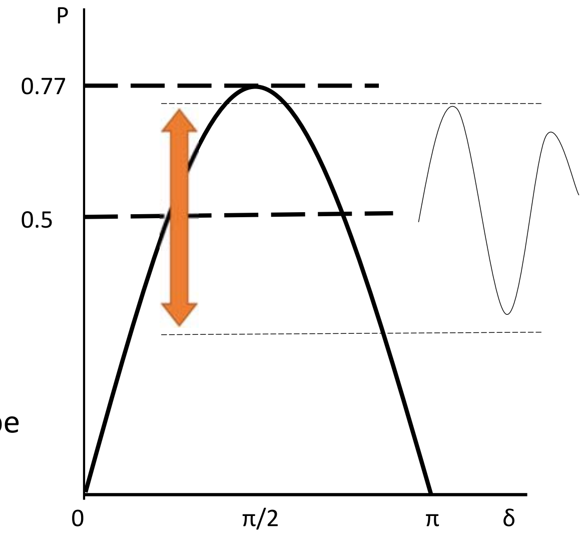


Treat as one generator

DC Flow Method: P=δ/X
0.55-0.55=δ/1.3
δ=0.65rad=37deg

P-δ Curve and Stability Evaluation

- $P_{max}=1*1/1.3=0.77$
- Pop=0.5
- (a) Currently $\Delta P_{RE}= 0.15$
  -> Stable
- (b) If $\Delta P_{RE}> 0.27$
  -> Unstable
- SCR=Pop/ΔP_{RE} should be over 3
  =(a) 3.33 -> Stable
  =(b) 1.85 -> Unstable
- ATC=0.27
- Spinning Reserve should be more than ΔP_{RE}
  =0.15



Technical Cooperation to Promote Energy Efficiency in Caribbean Countries

1st Seminar on Grid Stability and Large RE in Jamaica

List of Participants

SN	Name	Organization
1	Brain Richardson	MSET
2	Horace Buckley	MSET
3	Steve Dixon	MSET
4	Todd Johnson	MSET
5	Cedric Wilson	OUR
6	Craig Rattray	OUR
7	Sashana Miler	OUR
8	Wiunston Robotham	OUR
9	Dwayne Dyer	SJPC
10	Chase Lvey	JPS
11	David Clarke	JPS
12	Dhario Reid	JPS
13	Dweight Reid	JPS
14	Errington Case	JPS
15	Jodie Bowes Morrison	JPS
16	Ramon Lewis	JPS
17	Sheveena Haye	JPS
18	Shogo Otani	JPS
19	Takuya Kokawa	JPS
20	Keisuke Harada	JPS
21	Andre Lindsay	
22	Daniel Tomlinson	
23	Duane Smith	
24	Dweight Richards	
25	K Cowan	
26	Kirk Gilpin	
27	Mark Chambers	
28	Omar Stewart	
29	S Davis	
30	Terrie Brown	
31	Yeno	
32	Yuka Nakagawa	JET
33	Hisao Taoka	JET
34	Kevin Douglas	JET
35	Mitsuyoshi Kawasaki	JICA

Technical Cooperation to Promote Energy Efficiency in Caribbean Countries

1st Seminar on Grid Stability and Large RE in Jamaica Date: 12 Oct 2022

Feedback Form

Title and Organization	Please provide your opinion what is the challenges for 49% target renewable energy penetration in Jamaica.	Please input questions that you would like to know more details in the next seminar components.	Would you like to take basic course for power system engineering (outline of university course) as Day-1in the next seminar?	Please input what is the best finding during the seminar, and your other comment if any.
Senior Engineer - JPS	49% VRE energy penetration will mean much higher instantaneous (MW) VRE penetration and this will require new methods for all areas of grid design and operation.	How to calculate minimum inertia for grid stability.	No.	ATC and VRE integration.
Office of Utilities Regulation	Appropriate coordination and cooperation will be needed by all stakeholders and consumers.	None	No	Inverter Based Resources
Senior Power System Engineer - JPS	Clearer policy guidelines needed	More advice on mitigating pilferage	Yes	Grid Forming Inverter vs Grid Following Inverter
Transmission and Distribution Expert - Ministry of Science, Energy and Technology	With proper planning is achievable by 2030.	BESS is a new technology and therefore more emphasis is needed	No	Grid stability with increasing VRE
Principal Director, Energy - Ministry of Science, Energy & Technology	N/A			
Jamaica Public Service Company Limited	Hike in electricity price for stable power.			
Chief Technical Director - Energy	Achievable but some significant risks remain if not planned properly	Based on Jamaica's grid and generation composition, what is the optimal and realistic renewable penetration that can be achieved to keep the lights on?	Yes	The outline about virtual inertia and the impacts of pilferage on spinning reserves
JPS, Government and Regulatory Relations	The short time to achieve the target, the investment required to be made and most important, the tariff change to back that investment	Has the increase in RE penetration begun to affect the momentary interruption (MAIFI) index for customers in Japan in any way? Has the increase in RE+ storage led to more businesses and households leaving the grid and self generating? Is the increase in RE penetration so far helping or hurting electricity price in Japan? Is pumped storage considered an economically viable technology option for Japan and what are the challenges? Are waste to Energy projects price competitive in Japan or do they require special government subsidy support or concessions of any kind to be viable?	Yes	Very informative seminar. It has been very useful is addressing some of the challenges relating to power quality and intermittency from increasing amounts of RE on the grid.

Technical Cooperation to Promote
Energy Efficiency in Caribbean Countries

2nd Seminar on Grid Stability and Large RE In Jamaica

30 Nov 2022

Nippon Koei Co., Ltd.
PADECO Co., Ltd.

Agenda

- 10:00-10:05 Opening Remarks
- 10:05-10:15 S1-1. Project Outline, RE and Microgrid Concept
- 10:15-10:30 S1-2. Review and Feedback of 1st seminar
- 10:30-11:00 S1-3. Why Grid Stability is necessary
- 11:00-11:30 S2. Grid Modelling for Jamaica
- 11:30-12:00 S3. Basics of Power System Engineering for Grid Stability Simulation

(Lunch Break)

- 13:00-13:50 S4. Load Flow Analysis and its Evaluation
- 13:50-14:40 S5. Transient Stability Analysis and Evaluation of Stability
- 14:40-15:00 S6. State Estimation for Multi-point Pilferage
- 15:00-15:30 S7. Discussion for future grid and RE in Jamaica

Session No. 1

1. **Project Outline**
2. RE and Microgrid Concept
3. Review and Feedback of 1st seminar
4. Why Grid Stability is necessary

Project Outline and Schedule

1	2	3	4	5	6	7	8	9	10	11	12	13	…						32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	–
Phase 1 (Baseline Survey)						Phase 2 (Technical Transfer)																													
Year 2019									Year 2020				…						Year 2021		Year 2022												Year 2023		
4	5	6	7	8	9	10	11	12	1	2	3	4	…	…	…	…	…	…	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3

Output 1
The basic information is confirmed for the capacity building for the introduction of RE

→ **Output 3**
The human and institution capacity are enhanced for the mass introduction of RE

Output 2
The basic information is confirmed for the capacity building for the promotion of EE

→ **Output 4**
The human and institution capacity are enhanced for the promotion of EE

RE and Grid Stability activity is to:
- introduce micro-grid concept in one of the agreed areas and develop modelling based on existing grid data.
- introduce computer modelling for grid analysis and examine issues associated with a large penetration of VRE
- propose the way to enhance resiliency
- consider and propose the necessary technologies for achieving the RE goals, including grid stabilization,
- consider and propose additional policy legal system for achieving RE goals
- prepare necessary training plan
- provide recommendations on design of the policy/ legal system

Overall Schedule and objective

Team	Country	2022 Oct	Nov	Dec	2023 Jan	Feb	Mar	Apr
RE	Barbados							
	St.Kits&Nevis							
	Jamaica	☆	☆		☆		☆	
EE	Barbados							
	St.Kits&Nevis							
	Jamaica							

Training in Japan

- RE&Grid Team and EE team visit Jamaica on spot alternately.
- 1st Seminar on Grid Stability and RE on 12 Oct 2022
- **2nd Seminar on Grid Stability and RE on 30 Nov 2022**

  Objective:
  - To discuss challenges and solutions for future Jamaica Grid with RE penetration
  - To share knowledge about grid stability and simulation for future optimum grid planning
- 3rd Seminar on Grid Stability and RE in late Jan 2023 (proposed 23-27 Jan 2021)
- Final Joint Coordinating Committee (JCC) in March 2023

Summary: Jamaica

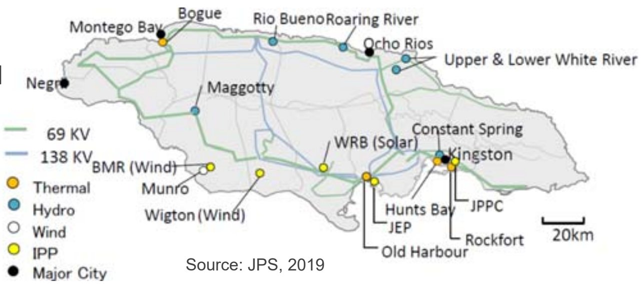
*1 JPS Annual Report 2021 *2 IRP Feb 2020
*3 Interview to JPS *4 Transmission Code

Item	Description	Project Activities
Energy Efficiency	• Energy Source: Oil (53%) , Electricity (37%) • Peak Demand: 654.5MW (2018)→622MW (2021)*1 • Generated 4356 GWh (2018)→4,303 GWh (2021)*1 • 1833 kWh/customer/yr, 0.34 USc/kWh (2021)*1 • Peak Period: 6:30pm – 8:30pm	Priority 1: BEMS Priority 2: Mini split AC with inverter Priority 3: LED
Renewable Energy	• RE target 33% by 2030, 49% by 2037 *2 • Hydro 28.6 MW, VRE 175 MW (PV utility 53+ distributed 20-40MW , wind 102MW) *2, RE 15% of grid	Recommendation for 50% RE target Micro-grid concept study Introduction of asset management
Grid Stabilization	• >50.5Hz:0.5sec, <49.5 Hz: 20 sec, <48Hz:0.5 sec *4 • RE Fluctuation affects gird stability*3 • JPS 21.5MW/16.6MWh Li BESS +3MW 16.5MWs flywheels	
O&M of Thermal Power Generation	• Thermal power plant: total 20 units including IPP • Installed Capacity: Total 1036.5MW including GTCC in Old Harbour P/S (190MW) • Heat rate 11,330(2017)→9,392 (2022) kj/kWh *1 • Predictive Maintenance: Considering to apply	-

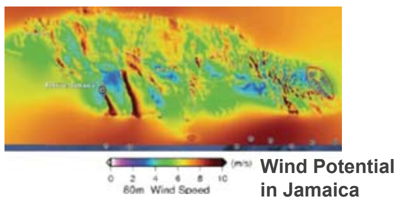
RE Status in Jamaica

Challenges for RE & Grid:

- ✓ Increasing RE capacity >15%. Grid stability and power cut issue
  - ✓ Feeder cut at 49.5 Hz
- ✓ System losses 26.3%(2018) →28.3%(2021)
- ✓ Large number of distributed PV, available database?
- ✓ Wind & PV potential unevenly distributed →less smoothing



Source: JPS, 2019



Wind Potential in Jamaica

Source: Sustainable Energy Roadmap 2013

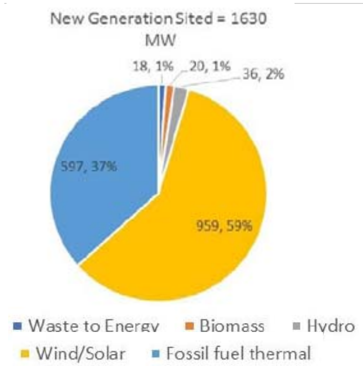
VRE Projects in Jamica

Location/Project		Capacity MW	Generation GWh estimated	Year	Tariff USc/kWh	Investment mil USD
Wigton I	Wind	20.7	52	2004	10.21	26
Wigton II	Wind	18	47	2010	10.723	45
Wigton III	Wind	24	63	2016	13.4	46.5
Munro	Wind	3	10.5	2010	(JPS)	
BMR Wind	Wind	36.3	120	2016	12.9	90
Content Solar (WRB)	PV	20	34	2016	18.8	65
Independent roof-top	PV	20?			--	
Eight River (EREC)	PV	33.1		2019	8.5	
Wigton IV	Wind	34		?		
VRE under operation		**142**	**326.5**			

Source: Prepared by JET with several data sources

Summary of IRP-1

IRP-2 is being prepared and values below will be modified in IRP-2.



Generation 2041	MW
Wind/solar	959.59
Fossil fuel thermal	597.37
Hydro	36.2
Biomass	20.1
Waste to Energy	18.1
Total	**1631.36**
VRE	**58.8%**

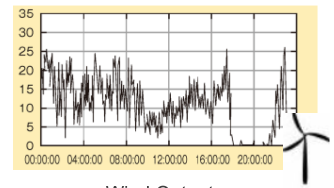
Unit Type	Overnight 2018 Capital Cost ($/kW)	2018 average estimated Variable cost ($/MWh)[1]	2018 Fixed Operating and Maintenance ($/kW)
New Capacity only; existing capacity is modeled at contracted rates			
Natural Gas Combined Cycle	1600	92.0	
Natural Gas Combustion Turbine	800	134.0	
Medium Speed Reciprocating Engine burning Natural Gas	1400	92.0	
Wind	Real, Levelized cost including capital, variable and fixed O&M and excluding profit = $105.8/MWh		
Solar	Real, Levelized cost including capital, variable and fixed O&M and excluding profit = $78.2/MWh		
Hydro	Real, Levelized cost including capital, variable and fixed O&M and excluding profit = $102/MWh		
Waste to Energy[2]	7200	9.3	
Biomass[3]	3837	5.6	

Source: Integrated Resource Plan Feb 2020

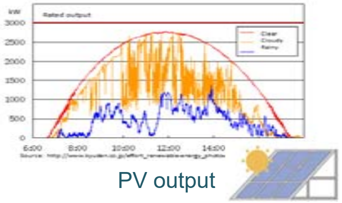
Year	Generation GWh	RE GWh	RE Portfolio
2030	5,453	1,913	35.1%
2037	5,939	2,435	41.0%

- Cost for control and grid stabilization is not included in Wind & PV
- It needs to identify yearly VRE introduction to assess grid stability

Characteristics of VRE



Wind Output



PV output

Wind
- Unpredictable generation output change
- produce ramps according to weather condition
- Depending on geographic areas, fluctuation comes at once if it installed in the same valley

PV
- No output in night-time and rainy day
- Large fluctuation in tropical climate (likely to change 80% in a minute)

Both (VRE):
- It does not always generate when needed. **Load-supply matching** is an issue
- Time coincidence of VRE, there can be times when there is too much supply. Curtailment of VRE is necessary **→energy storage/control cost need to be considered.**

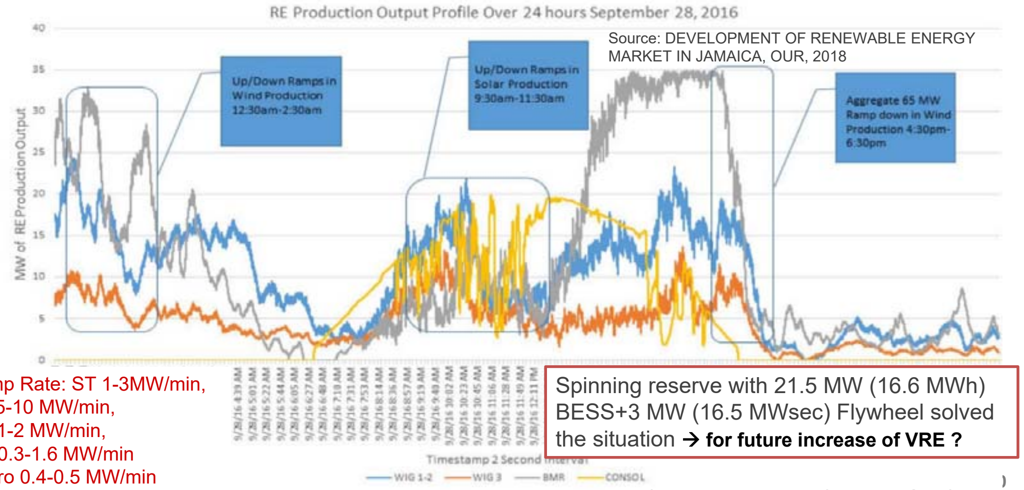
Caribbean Islands:
- Lower cost than tariff →rapid private investment
- Limited area for transmission
- Frequent change of weather condition
- Limited stable RE (hydropower/geothermal)

Challenges for
- **Cost for stability** : who covers?
- Technical and regulatory matters

RE: Grid Stability Issue with VRE in Jamaica

Grid Stability issues due to significant VRE fluctuation

- Limitation of generating units, unable to ramp fast to counter rapid variations in VRE
- Adverse effect on Heat Rate (Efficiency) and increase of production cost
- Part-load operation of generating units, increasing emissions and reducing operating life of equipment
- Impacts System reliability, security, stability and power quality

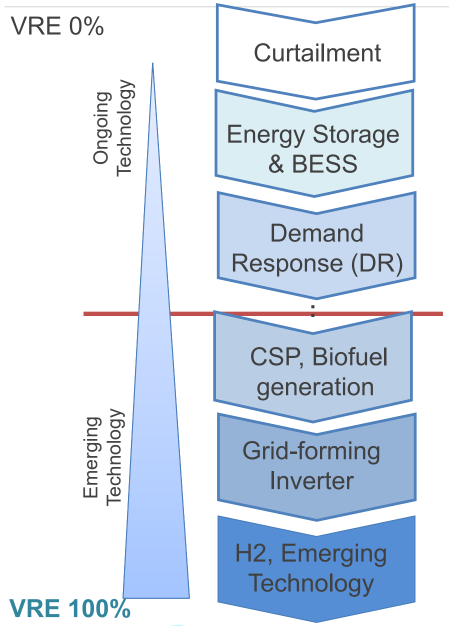


Source: DEVELOPMENT OF RENEWABLE ENERGY MARKET IN JAMAICA, OUR, 2018

Ramp Rate: ST 1-3MW/min,
GT 5-10 MW/min,
CC 1-2 MW/min,
DG 0.3-1.6 MW/min
Hydro 0.4-0.5 MW/min

Spinning reserve with 21.5 MW (16.6 MWh) BESS+3 MW (16.5 MWsec) Flywheel solved the situation **→ for future increase of VRE ?**

Arrangement toward 100% RE

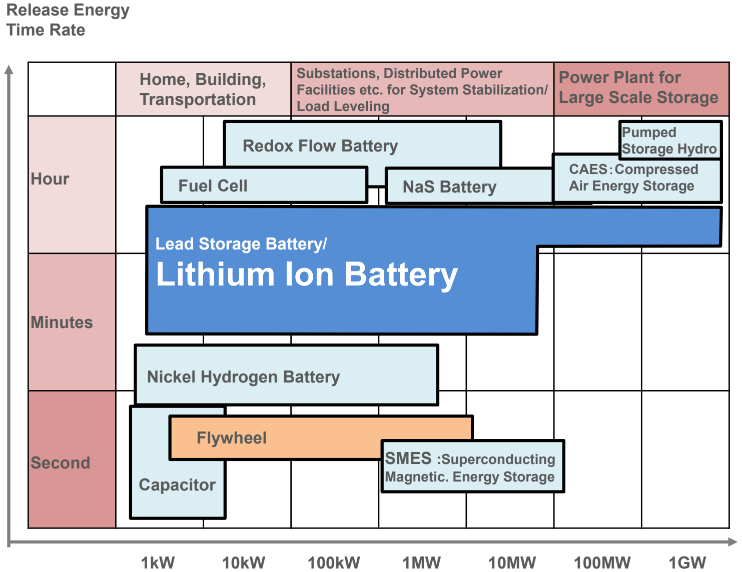


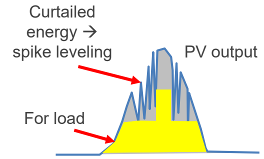
Voltage and frequency Stabilization
- Curtailment of VRE energy in PCS to make grid stables, smart inverter
- **Governor Free (GF), Economic Load Dispatch (ELD), Load Frequency Control (LFC)**
- **Energy storage: Battery, flywheel**
- **Synchronous condenser, Statcom**
- EV charging time shift
- Demand side management
- Regulatory framework change, **review of grid code**

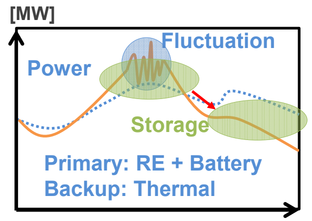
Insufficient Inertia, Synchronizing Force

- **Battery-Motor generator set**
- **Biofuel (diesel, jet) for DG**
- CSP (Concentrated Solar Thermal Power)
- Gravitational Power
- **Grid forming Inverter**
- H2 generation from RE by electrolysis
- Seasonal large scale storage

Battery and Energy Storage
Positioning for Energy Storage Technology

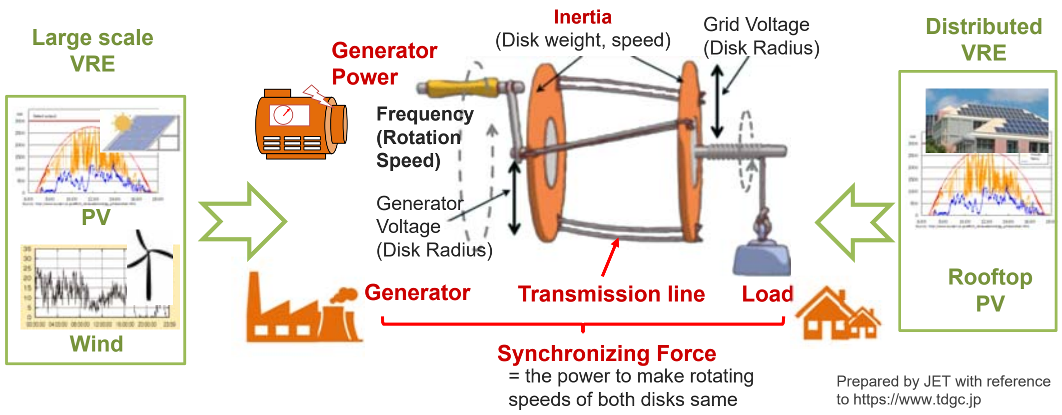






Source: NEDO Renewable Energy Technology White Paper Chapter 9

Inertia and Synchronizing Force with RE

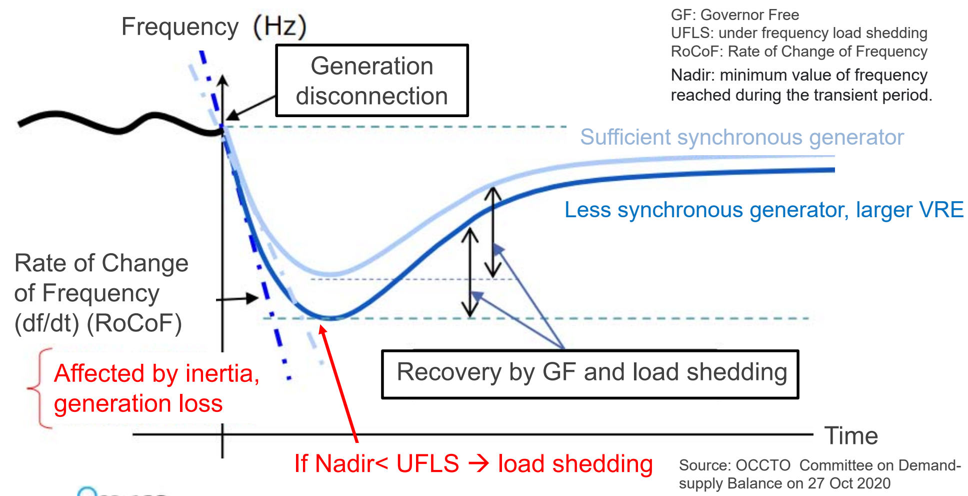


Inertia: The force to keep the rotation of disk when load is changed
Synchronizing Force: The force to keep rotation speed of disks. It keeps back to the same rotation when generation power and load is varied, without entangling.

Fluctuation of large scale VRE affects to generator at generation side and load side
→ Inertia and Synchronizing Force need to be enhanced for grid with large VRE

Inertia and Synchronizing Force with RE

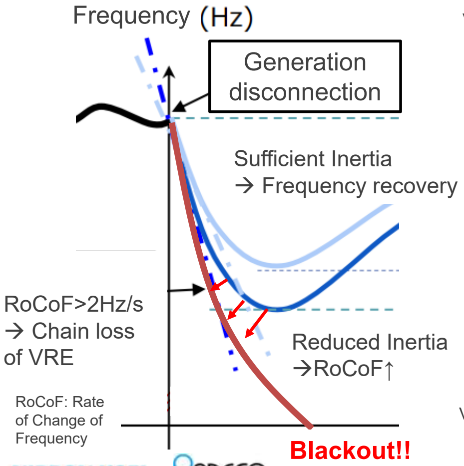
Synchronous generator: The power source establishes voltage and frequency with reactive power, and combines with generators by synchronizing force
VRE/BESS with inverter: DC converted to AC. There is no rotation, no synchronizing force. It monitors grid AC voltage and wave and adjust accordingly → no contribution for stability

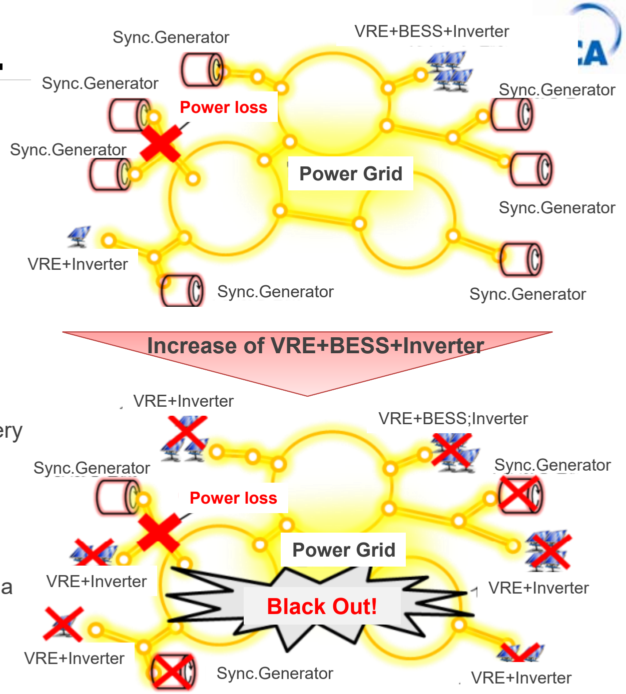


Source: OCCTO Committee on Demand-supply Balance on 27 Oct 2020

Black-out when insufficient Sync. Gen.

If synchronous generator is reduced and inertial is not sufficient, power loss
→ Frequency drop, with no recovery
→ Chain reaction of loss of VRE
→ **Black out**



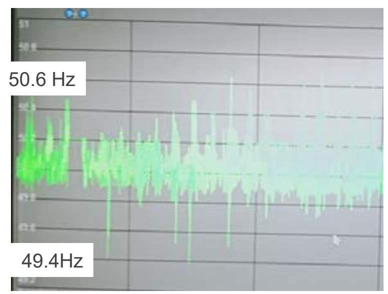


Source: Transmission and Grid Council, Japan

Consideration for Larger VRE/BESS Penetration

- Increased application of PV and Wind :
  - Is Battery sufficient measurement?
  - To what extent can utility scale PV and wind be operated without affect on grid power quality?
  - How much can a feeder accommodate distributed PV and BESS?

- Planning with **grid simulation** is necessary.
  - Load flow analysis
  - Stability analysis
- Grid code needs to be checked for condition of grid connection of VRE and BESS



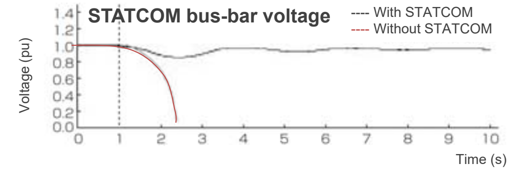
Example of frequency fluctuation with VRE

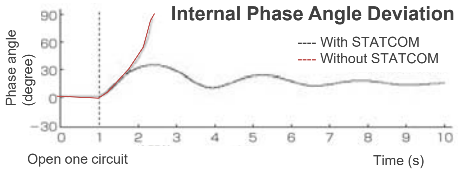
SCO and STATCOM for Reactive Power

SCO (Synchronous Condenser) :
SCO is DC-excited synchronous machine (large rotating generators) whose shaft is not attached to any driving equipment. Though changing field excitation, SCO adjusts reactive power and provides reactive power at the time of voltage drop.

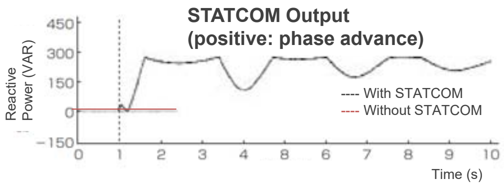
https://energy-shift.com/news/af737655-0462-4655-81ae-b17d86b5784d

STATCOM (STATic synchronous COMpensator) :
For compensation of reactive power, it generates/absorbs reactive power, and stabilize voltage continuously at high speed by self-commutated inverter.





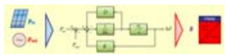
Source: Enhancement of Steady－State Stability and Suppression of Over－Voltage using 450MVA GCT－STATCOM, Mitsubishi Denki Giho, pp.52-55, Vol.87, No.11, 2013.



https://www.hitachi.co.jp/products/energy/STATCOM/about/index.html

Japan Inte

Emerging technology for large RE with Grid Stabilization : Generation with Inertia and Synchronous Power

Type of Technology		Advantage	Develop stage
 Source: taiyo-electric	Motor generator (MG)	- Energy in battery provides synchronization and inertia - Small scale supply, for micro grid	- Used as frequency conversion - Commercial operation
 energyvault.com/gravity	Gravity Storage Battery	- Gravity of recycled Concrete block 35ton/nos - Provides inertia - Half cost of Li-ion battery	Pre-commercial, 35 MWh, 4MW per tower η=85% 52.5GW planned in USA
 /www.nedo.go.jp/news/press/AA5_100756.html	CAES (Compressed air energy storage)	- Compressed high pressure air - (Liquid air may be developed) - Provides inertia	-demonstration by NEDO - 900 MW in California - η=70-80%
 electrek.co/	CSP (concentrating solar power) Solar thermal	- With turbine, provides inertia and synchronization - Cost decrease expected, higher efficiency than PV, η=50%	- Commercial operation at Ivanpah392MW 22 bil USD - Heat storage (molten solt, etc) under development
 Source: CIGRE	Grid-forming inverter	- Dynamic active/reactive power, FRT, frequency control, inertia - Applicable to existing PV - (Smart Inv: FRT, VRT, voltage support)	- Under development - (Smart inverter by IEEE1547, Mandatory in Hawai)

Example of Grid Code

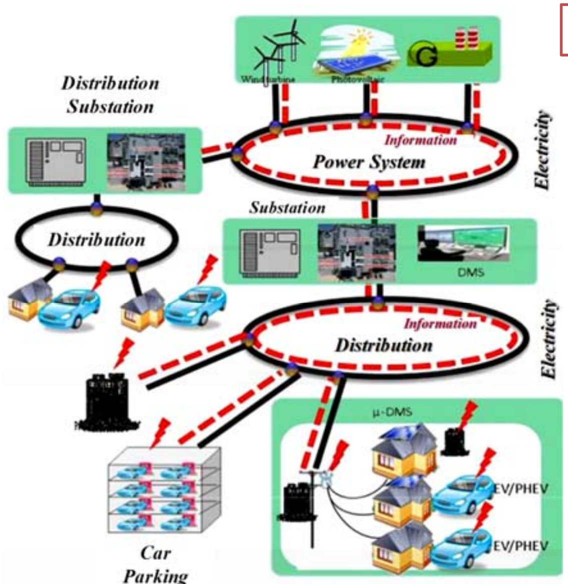
Country	UK	Ireland	Germany	Japan
Grid Code	The Grid Code	EirGrid Grid Code	Technical Connection Rules fore MV	Grid Code
Regulator	Ofgen (regulator)	TSO	VDE (Association)	OCCTO
Main Items of Grid Code	- Frequency and time for operation continue - Active power increase/ decrease at the time of frequency increase/ decrease - Active power Droop according to frequency change rate - Voltage, harmonic wave, flicker at nodes - FRT requirement at the time of voltage drop - Reactive power supply - Black start and Protection of grid and generators	- Frequency and time for operation continue - Active power decrease/ Increase at the time of frequency increase/ decrease - Governor control rate - FRT requirement at the time of voltage drop - Reactive power supply - Speed of power increase/ decrease with load dispatch order - Lower limit of load - Spinning reserve requirement	-Frequency and voltage that need continuous operation -Active power increase/ decrease at the time of frequency increase/ decrease - FRT requirement at the time of voltage drop - Reactive power supply at the time of voltage change - Active power limit at the time of large voltage change - Protection of grid and generators	(under preparation)

OCCTO: Organization for Cross-regional Coordination of Transmission Operators, Japan
FRT: Fault Ride Through

Session No. 1

1. Project Outline
2. **RE and Microgrid Concept**
3. Review and Feedback of 1st seminar
4. Why Grid Stability is necessary

Microgrid Concept

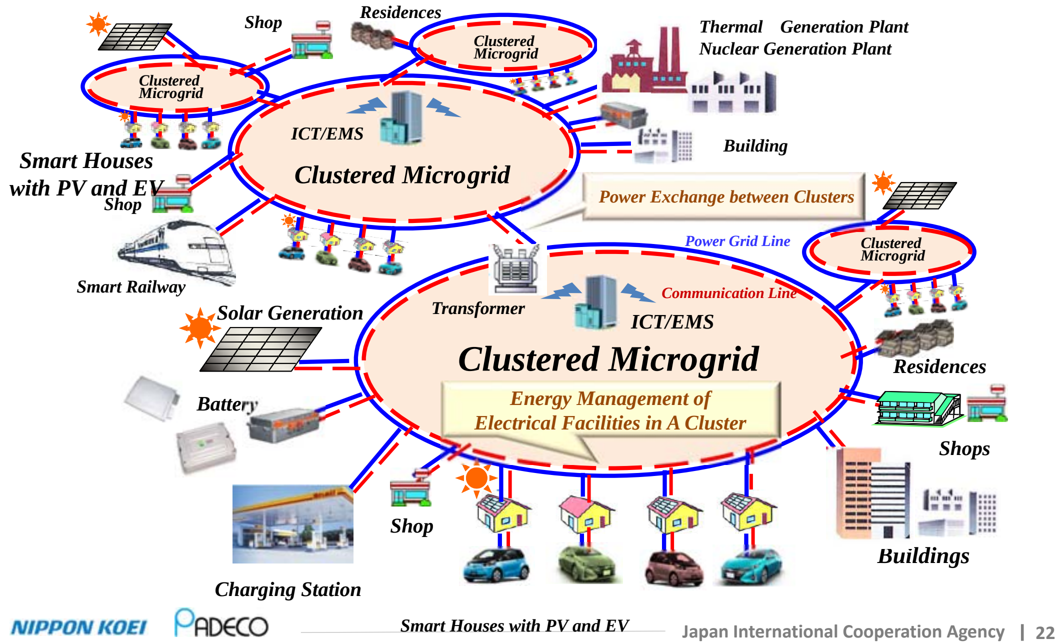


Concept of Micro-grid

- ✓ Respective Micro-grid is connected each other, and each Micro-grid can work independently
- ✓ Local energy production for local consumption
  - ✓ Generation: PV, wind, biomass, DG, GT, battery, etc.
  - ✓ Demand: industry, commercial, home, EV, etc.
- ✓ No transmission → loss saving
- ✓ With IoT, control system, EMS, demand response, smart meters
- ✓ Enhance resiliency

Source: Smart City Development and Recent trend in Electric Power Network, Waseda Univ.

Microgrid for Resilient System -- Autonomous Micro Grid



Resilience for RE

23 Aug 2018 Awaji, Japan
https://www.sankei.com/west/news/180828/wst1808280043-n1.html
600 kW, Fallen at 25.6m/s wind while 60m/s design
- Additional moment due to Excess of high speed
- Missing control power supply

9 Sep 2019 Kanto, Japan
@kadowaki_kozo
Damage of roof-top structure by high speed wind

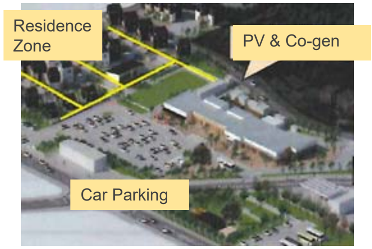
26 Jul 2019 Himeji, Japan
https://www.dailyshincho.jp/article/2018/07260800/?photo=1
Landslide by a heavy rain

For enhancement of resilience:
- ✓ Design Standard with higher rank hurricane
- ✓ **Autonomous Micro-grid**

Microgrid Planning

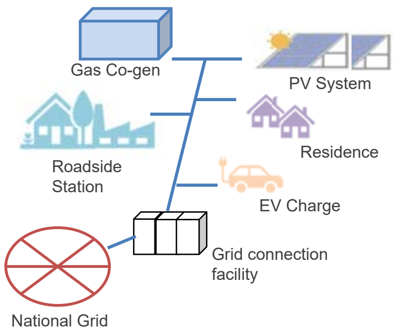
1. **Study for legal requirement of regulators considering affect on transmission line outside of Microgrid**
   - Legal requirement for microgrid by the regulatory authority
   - Method for emergency recovery, switching from microgrid to master grid, Affect on adjacent areas.
2. **Estimation of load and demand at normal and abnormal condition in Microgrid**
   - Estimate demand of daily curve, total demand of the day/week / year, at normal and abnormal condition,
   - data as much as accurate by each feeder.
3. **Plan for system structure of Microgrid in distribution lines based on demand**
   - Capacity of generator, and PV, design, selection of equipment.
   - Preparation for emergency (load shedding, control, etc.)
   - Protection and control method considering supply and demand
4. **New system installation/enhancement for stabilization facility requirement for RE and supply-load balancing**
   - Plan RE facility with energy storage based on power demand
   - Consider necessary stabilization equipment considering fluctuation and output instability.
5. **System requirement and legal confirmation for inside and outside Microgrid**
   - Review regulation and rules including grid code for connection to transmission line
   - Operation method at the time of emergency recovery and minimize outage
6. **Finalization of system configuration and specification for whole Microgrid**
   - Based on supply-load balance, finalize system configuration &Spec
   - Operation and EMS development, communication system

Microgrid Ex.-1: Mutsuzawa, Chiba, Japan



Mutsuzawa Road Side Station

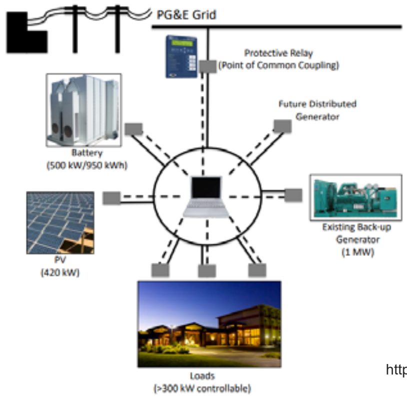
- Gas co-generation (80kWx2), PV system (20kW), Solar heating (37 kW) EV charger,
- Independent power supply for residence zone
- Thermal supply for hot spring by co-gen
- Microgrid area connected with grid
- Continuous supply during Typhoon (large scale regional power cut approx. 1 week) in Sep 2019
  - 1000 utilized power supply, shower, toilet for emergency
  - Regional Disaster-prevention facility
  - All power lines are underground



https://www.env.go.jp/press/files/jp/113284.pdf

Microgrid Ex.-2: Blue Lake Rancheria, CA, USA

- Humboldt County, natural disaster-prone coastal area
- Completed in Mar 2018
- Optimized operation with PV and BESS with back-up DG
- At emergency, independent operation with seamless switching of disconnection/connection of main grid
- Demand response with load shedding for less important load at the time of supply difficulty
- Microgrid controller (EMS) controls independent operation 25%, $170,000 of electricity saving in 2018



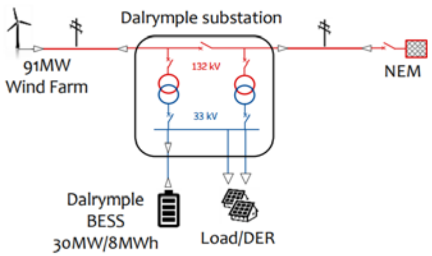
Component	Spec/details
Schedule	July 2015 – March 2018
Utility	PG&E
Generation	PV 420 kW and back up DG 1MW
Inverter	SMA TP30-TL-US10
BESS	500kW/950 kWh Tesla Powerpack
Control (EMS)	Siemens Spectrum Power TM MGMS
Project cost	USD6.32 million

https://bluelakerancheria-nsn.gov/wp-content/uploads/2018/11/BLR_Microgrid_FactSheet.pdf

Microgrid Ex.-3: South Australia Yorke Microgrid

https://www.electranet.com.au/new-battery-charged-and-ready-to-power-lower-yorke-peninsula/

- One circuit 132 kV line is connected to the area, which once had frequent outage and issue on reliability
- Autonomous microgrid, sifted to independent operation without outage, seamless islanding
- 91 MW Windfarm provides power
- BESS provides virtual inertia, reactive power compensation, and black start function
- System provides ancillary service with frequency adjustment



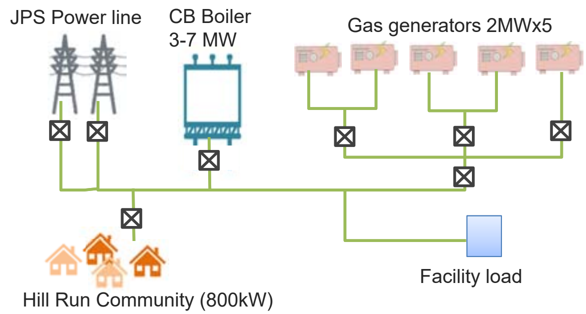
Grid Forming Energy Storage System addresses challenges of grids with high penetration of renewables (A case study), CIGRE, 2020

Items	Description
Utility	Electra Net
Area	Dalrymple, Lower Yorke, SA
Substation	Dairymple S/S 132/33 kV
Generation	91 MW Wind
BESS	30 MW/8MWh ABB
Project cost	30 mil AUD (of which 12 mil AUD is financed by ARENA)

Microgrid Ex.-4: Jamaica Caribbean Boiler-JPS

- Microgrid with Combined heat and power (CHP) generation plant and supply to community
- The exhaust heat converted into energy and improve efficiency
- improve its operational efficiency and reliability.
- 5 generators + CB boilers
- Provides power to Hill Run community
- 30% CO2 reduction by fuel switch from heavy oil to LNG

https://www.cvmtv.com/news/major-stories/jps-and-cb-group-collaborates-on-new-power-plant/



1. Project Outline
2. RE and Microgrid Concept
3. **Review and Feedback of 1st seminar**
4. Why Grid Stability is necessary

1. Feedbacks of the 1st seminar in 12 Oct 2022

	Question	Feedback
1	Please provide your opinion what is the challenges for 49% target renewable energy penetration in Jamaica	• Appropriate coordination and cooperation will be needed by all stakeholders and consumers. • With proper planning is achievable by 2023. • Achievable but some significant risks remain if not planned properly. • 49% VRE energy penetration will mean much higher instantaneous(MW) VRE penetration and this will require new methods for all areas of grid design and operation. • Hike in electricity price for stable power. • Clearer policy guidelines needed. • The short time to achieve the target, the investment required to be made and most important, the tariff change to back that investment.

	Question	Feedback
2	Please input questions that you would like to know more details in the next seminar components	• BESS is a new technology and emphasis is needed. • Based on Jamaica's grid and generation composition, what is the optimal and realistic renewable penetration that can be achieved to keep the lights on? • How to calculate minimum inertia for grid stability. • More advice on mitigating pilferage • Has the increase in RE penetration begun to affect the momentary interruption(MAIFI) index for customers in Japan in any way? • Has the increase in RE+storage led to more businesses and households leaving the grid and self generating?

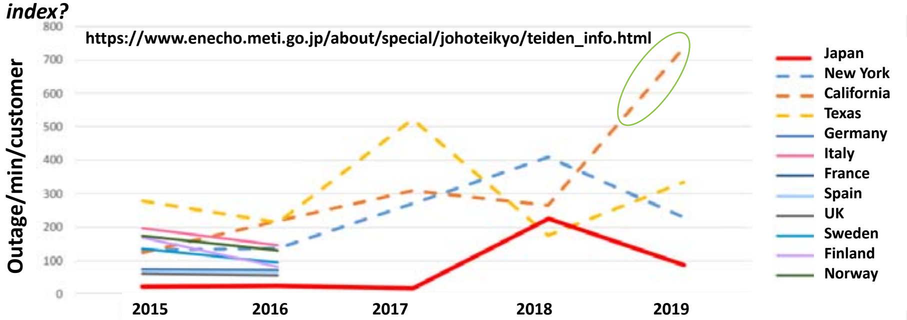
	Question	Feedback
2	Please input questions that you would like to know more details in the next seminar components	• Is the increase in RE penetration so far helping or hurting electricity price in Japan? • Is pumped storage considered an economically viable technology option for Japan and what are the challenges? • Are waste to Energy projects price competitive in Japan or do they require special government subsidy support or concessions to be viable?

To be explained today:

Optimal and reasonable VRE plan and grid model
System capacity and Inertia requirement
Grid Forming Inverter
Microgrid for mitigating pilferage

Outage trend and VRE affect on Outage

Has the increase in RE penetration begun to affect the momentary interruption(MAIFI) index?

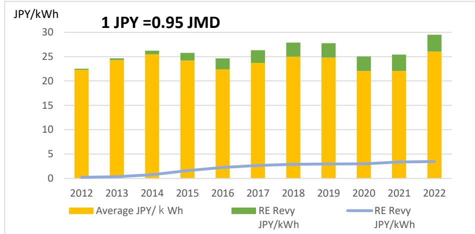


- At present, no momentary interruption is caused from large RE penetration
- In Japan, RE have not yet affect outage but sever weather like typhoon affected
- 28 Sep 2016 South Australia grid with50% Wind . Wind power is disconnected due to thunder and transmission damage → Blackout for 850,000 customer
- California (CAISO): 32%RE in 2019. 14-15 Aug 2020 Load Shedding due to large scale introduction of PV and halt of coal/gas power plant and heat wave in evening

https://ieei.or.jp/2020/09/yamamoto-blog200914/

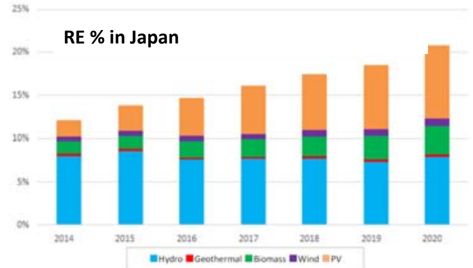
Power Tariff and RE Revy in Japan

Is the increase in RE penetration so far helping or hurting electricity price in Japan?



Power Tariff in Japan (JPY/kWh)

- VRE Percentage: approx. 10% in 2020
- RE Revy is approx. 10% in 2020
- 10% VRE in kWh base is 20-50 % of VRE capacity
- RE Revy (additional tariff/kWh for RE cost) is likely to be proportional to VRE percentage
- Future ??

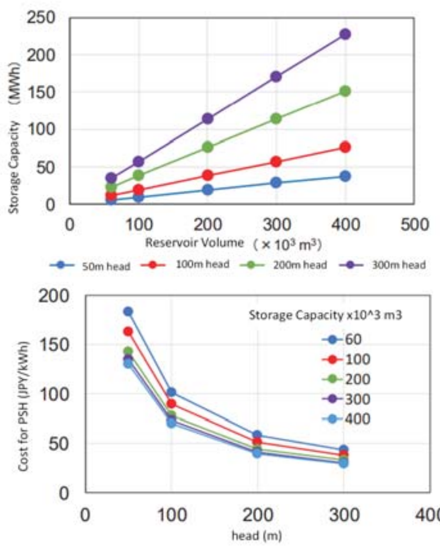


Power Tariff in Germany (Usc/kWh)

Prepared by JET from METI and Enetech data

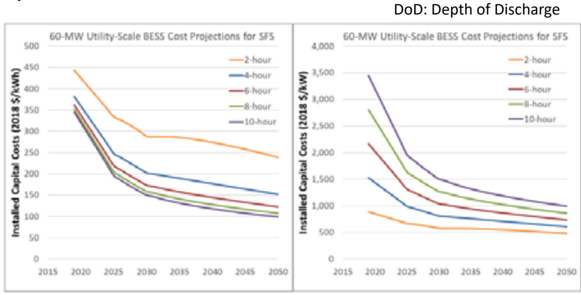
Pumped Storage vs Battery

Is pumped storage considered an economically viable technology option for Japan and what are the challenges?



- Challenges: Topology and water. Higher head, lower cost: 700USD/kWh@100m, 350USD/kWh@200m (100,000m3) .
- Long lead time, Environmental Impact Assessment
- Advanta40-50 years life, black start possible
- LiB : 350-450USD/MWh @2022 (for 60MW scale), Cycle: 5000-20,000 @DoD 80-90%

DoD: Depth of Discharge



Source Utility-Scale Battery Storage | Electricity | 2021 | ATB | NREL

Note: headrace 1500m is assumed for head 200m
Source: Potential Capacity and Cost of Pumped-Storage Power in Japan Strategy for Technology Development Proposal Paper for Policy Making and Governmental Action toward Low Carbon Societies, LCS-FY2018-PP-08, 2019

Waste to Energy

Are waste to Energy projects price competitive in Japan or do they require special government subsidy support or concessions to be viable?

- FIT for Waste-to-Energy: 17 JPY /kWh in Japan
- 9,000-250,000 JPY/kW additional power generation cost to waste treatment plant
- Cost is Depending on calorific value of feedstock, collection and separation of feedstock, etc.
- Not very stable output → low tariff purchased by power company
- Generally, policy initiative is necessary

https://www.maff.go.jp/j/study/other/recycle/pdf/7_11b.pdf

System Capacity and Inertia Requirement

- Inertia M has the relationship with RoCoF.
- In Japan, it is said that RoCoF should be less than 2[Hz/sec].
- If you have to keep stable for the drop of PV output, inertia requirement will be calculated using RoCoF.

1) R. Shikuma, D. Orihara, H. Kikusato, H. Taoka, A. Kaneno, Y. Hayashi, "Evaluation of Practical Inertia of Grid-Forming Inverter in Frequency variation under Load Trip," IEE Japan Power & Energy Symposium, No. 114, pp. 1-2-23, Sep., 2022.
2) R. Shigenobu, T. Takano, D. Orihara, T. Goda, "A basic Study on Specification Requirements for Virtual Synchronous Control in Inverters," IEE Japan Power & Energy Symposium, No. 206, pp. 3WEB5-21, Sep., 2021.

2nd Seminar on Grid Stability with Large RE in Jamaica

JICA Expert Team, Nippon Koei Co., Ltd.

Agenda

- 10:00-10:05 Opening Remarks
- 10:05-10:15 S1-1. Project Outline, RE and Microgrid Concept
- 10:15-10:30 S1-2. Review and Feedback of 1st seminar
- 10:30-11:00 S1-3. Why Grid Stability is necessary (Key of Grid Stability)
- 11:00-11:30 S2. Grid Modelling for Jamaica
- 11:30-12:00 S3. Basics of Power System Engineering for Grid Stability Simulation

(Lunch Break)

- 13:00-13:50 S4. Load Flow Analysis and its Evaluation
- 13:50-14:40 S5. Transient Stability Analysis and Evaluation of Stability
- 14:40-15:00 S6. State Estimation for Multi-point Pilferage
- 15:00-15:30 S7. Discussion for future grid and RE in Jamaica

Session No. 1

1. Project Outline
2. RE and Microgrid Concept
3. Review and Feedback of 1st seminar
4. Why Grid Stability is necessary

Why Grid Stability is necessary

- VRE connected through inverter. Most of PV and Wind Turbine are IBR (Inverter based resources)
- Response of IBR is faster than that of synchronous generator.
- IBR has less or no inertia compared to synchronous generator.
- The output of IBR changes according to the connected power resources such as sunshine or wind.
  - When IBR is connected to grid, IBR can not adjust output according to demand exactly. It requires support from other controllable power for the lack of power.

↓

- Increase or add inertia function to IBR for grid stability
  - Grid Forming Inverter
- Increase generators with large inertia for grid stability
  - Inertia Resources provided by
    Synchronous generators:
    Thermal Power, Hydro Power, Nuclear Power
    Renewable Synchronous generator:
    Biomass, Waste-to-Energy, CSP(Concentrated Solar Power)

Objective of Grid Stability Seminar

- To recognize possible issues and necessary examination items for future Jamaica grid with large VRE (variable renewable energy) penetration
- To share knowledge of basic of power system analysis to examine future grid challenges
- To discuss about innovation for power system for stable power supply with large VRE

Role of Us: Power System Engineers

- Supply stable electricity to all the customers without interruption
  - With avoiding power cut, outage or damage on equipment and power appliance
  - With no failures or minimize failures
  - By Minimize the influence of disturbance after faults
- Keep the quality of electricity with
  - Constant voltage
  - Constant frequency
  - Less distortion or harmonics

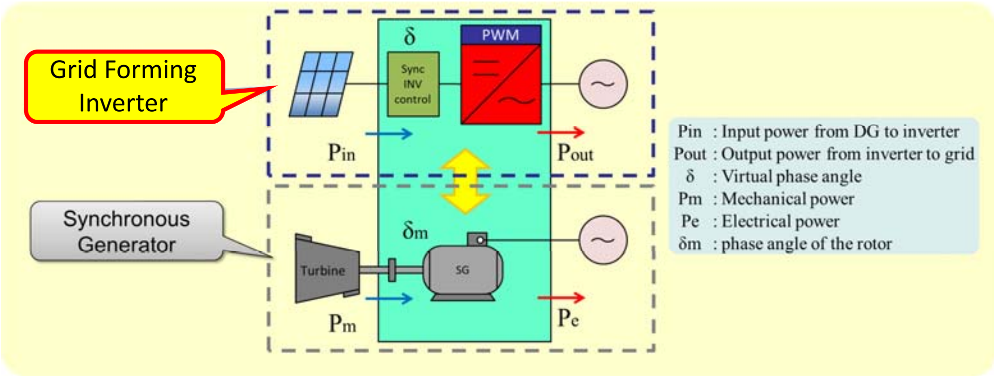
Simple Method of Grid Stability Evaluation

- For steady state stability
  - **Can large amount of RE be installed in the present/planned power system?**
  - Apply Load flow analysis:
    - If we reach at the normal load flow state, actual system is also considered to be stable.
    - From load flow results, adequacy of power flow of transmission line can be assessed. It is evaluated with the maximum capacity of transmission line.
- For transient state stability
  - **Is power system with large amount of RE stable or not, when instantaneous RE fluctuation happens?**
  - Apply Equal Area Criterion:
    - Power system stability under disturbance can be calculated by using acceleration and deceleration energy.
    - Available Transmission Capacity and Spinning Reserve can be calculated briefly.

Base for Evaluation of Grid Stability

- Resource of Virtual Inertia
  - **VRE with Grid Forming Inverter (1)**
  - EV(Electric Vehicle) with Grid Forming Inverter for V2G
  - Virtual Power Plant
- Evaluation Items of Stability
  - **SCR**(Short Circuit Ratio) (2)
  - **ATC**(Available Transmission Capacity) (3)
  - **Spinning Reserve (4)**
- Tools for Analyzing Grid Stability
  - Load Flow Analysis to check available condition
  - Stability Evaluation by EAC(Equal Area Criterion)
- **Microgrid** for Grid Stability
  - Decrease power supply of utility transmission lines
  - Monitor load flow by smart meter accurately
  - Pilferage location may be estimated through State Estimation

(1) Grid Forming Inverter for VRE



Source: M. Kawai, Y. Sakai, H. Sugiyama, H. Taoka "Frequency Improvement of a Power System with a Distributed Generator using Synchronization Inverter," 2015 International Symposium on Smart Electric Distribution Systems and Technologies (EDST), CIGRE SC C6 Colloquium, Sep. 2015.

Control Algorithm for Grid Forming Inverter

The control method of Grid Forming Inverter is expressed by the swing equation.
This equation is added damping term and synchronizing power term.

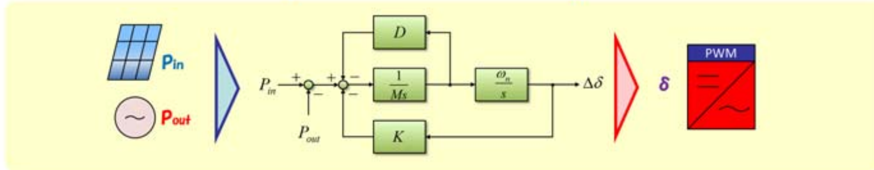
$$\frac{M}{\omega_n}\frac{d^2\delta_m}{dt^2}+\frac{D}{\omega_n}\frac{d\delta_m}{dt}+K\delta_m=P_m-P_e$$

This swing equation of the Grid Forming Inverter is solved for virtual phase angle δ.

The transfer function of voltage value

$$\delta=\frac{\frac{1}{M}\omega_n}{s^2+\frac{D}{M}s+\frac{K}{M}\omega_n}(P_{in}-P_{out})$$

M:Inertia
D:damping Factor
K:synchronizing Factor



Source: M. Kawai, Y. Sakai, H. Sugiyama, H. Taoka "Frequency Improvement of a Power System with a Distributed Generator using Synchronization Inverter," 2015 International Symposium on Smart Electric Distribution Systems and Technologies (EDST), CIGRE SC C6 Colloquium, Sep. 2015.

GFL(Grid Following Inverter) & GFM(Grid Forming Inverter)

- GFL(Grid Following Inverter)
  - Current Source Inverter
  - Control output current as adjusting voltage and frequency to grid
  - No supply of synchronizing force.
- GFM(Grid Forming Inverter)
  - Voltage Source Inverter
  - Virtual Synchronous Generator
  - Control output voltage and its frequency as adjusting power to grid's
  - Supply Virtual Inertia to Grid
  - Power resource: PV, WT(Wind Turbine), EV(Electric Vehicle), Battery

ref) "GC0137: Grid Code Modification Proposal Form"
- National Grid, UK, 25 Nov., 2021
- This grid code is the first one in the world that includes the requirement about Grid Forming Inverter.

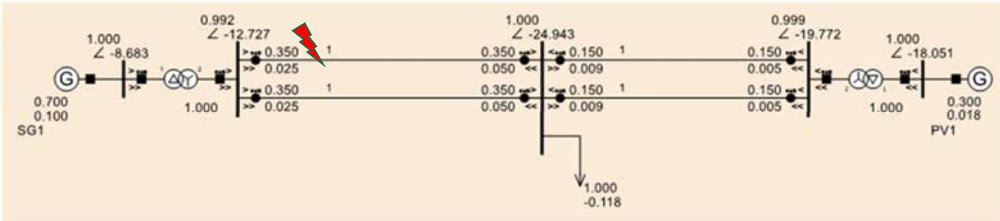
(2) SCR(Short Circuit Ratio)

- SCR is the factor to be considered in large RE penetration for grid stability.
- SCR=AC System Capacity/Rated IBR Capacity
  - SCR>3 -------- High SCR, Stable
  - 3>SCR>2 ----- Low SCR
    Small fluctuation continues.
  - 2>SCR -------- Very Low SCR
    Sensitivity of IBR to Grid goes high.
    Grid is unstable that may bring blackout.

ref) "IEEE Std 1204-1997(R2003)", IEEE, 2003
- IEEE Guide for Planning DC Links Terminating at AC Locations Having Low Short-Circuit Capacities
- Recognized by ANSI(American National Standards Institute

SCR(Short Circuit Ratio) Evaluation Model

- PV: Modelled by virtual low inertia synchronous generator
  - Inertia=0.1 (right side generator)
- SG: high inertia conventional synchronous generator model
  - Inertia=10.0 (left side generator)

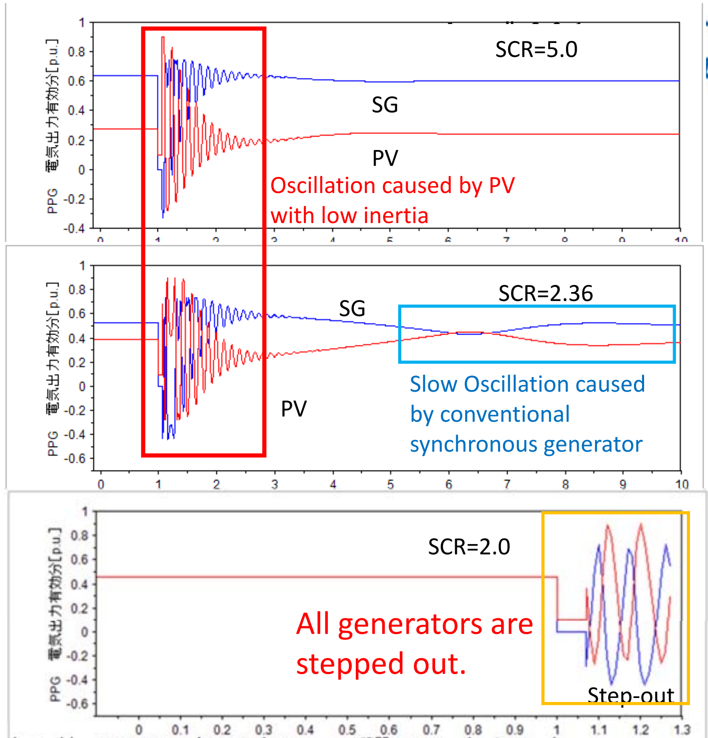


Calculated by CPATFree(CRIEP's Power System Analysis Tools

Difference of SCR value

Red: PV
(Low Inertia)
Blue: Synchronous Generator (SG)
(High Inertia)

70 msec 3 line ground fault by lightning at 1 of 2 circuit transmission line close to SG.



Calculated by CPATFree(CRIEP's Power System Analysis Tools

Sources for High SCR Grid

- Following resources can supply inertia to grid.
  - V2G(Vehicle to Grid) of EV(Electric Vehicle) with Grid Forming Inverter
  - BESS(Battery Energy Source System) with Grid Forming Inverter and SOC Control.
    - SOC Control is required to realize Grid Forming Inverter.
  - Biofuel Generator
  - Solar Thermal Generator
  - **Renewable Energy Resources (PV, WT) with Grid Forming Inverter**

(3) ATC(Available Transmission Capacity)

- Transmission capacity needs to be calculated to see whether RE can be transmitted from source location to demand place.
- Available Transmission Capacity from Heat Capacity Limit

$$P_{loss} = R * \left(\frac{V_i}{X}\right)^2 \quad < \quad P_{\mathrm{LOSSMAX}}$$

- Available Transmission Capacity from Transient Stability

$$P = \frac{V_i V_j}{X} \boldsymbol{sin\delta} \quad \rightarrow \quad P_{\mathrm{ATC}} = \frac{V_i V_j}{X} - P_{\mathrm{OP}}$$

R: Transmission line resistance
X: Transmission line inductance
V_i, V_j : Sending Voltage and Receiving voltage, 2)
P_{loss} : Transmission line loss by line Resistance R and line inductance.
$P_{LOSSMAX}$: Capacity Limit of transmission line
P_{ATC} : Available Transmission Capacity
P_{OP} : Operating Power

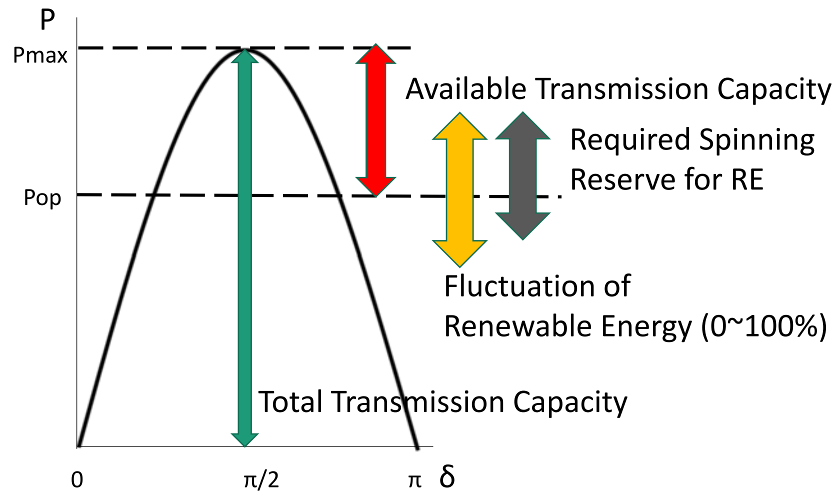
(4) Spinning Reserve

- In order to get electrical power under abnormal condition of grid, spinning reserve should be kept even if VRE is installed.
- Spinning reserve should be more than total fluctuation of load and VRE.

  -> RE, EV and Battery **with inertia** is required for large RE penetration.
- Best Energy Mix

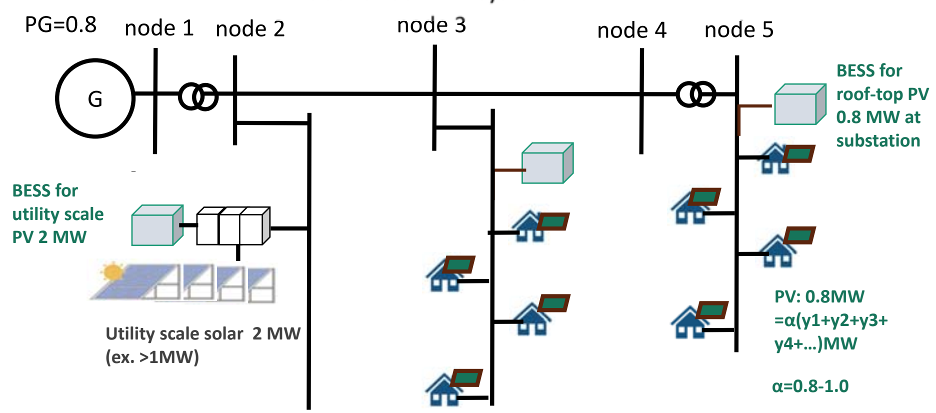
  -> Energy mix of several resources is highly recommended for improving grid stability.
- **RE Sources for Spinning Reserve**
  - **EV, Battery, Fly Wheel -> Short period, Quick response**
  - **Biofuel or Diesel Generator -> Long period, Slow response**

Available Transmission Capacity & Spinning Reserve



Where to add storage? How much storage for VRE?

BESS had better to be set to substations where place BESS at a nearby substation with other PVs.
If the capacity of PV system is large, BESS had better to be set close to PV system.



Evaluation of VRE Installation

- **To know how much we can install PV or WT in a particular power line**
  - **Load Flow Analysis**
  - If you get the answer of load flow such as node voltage and transmission line power, this case is stable.
  - If you cannot get the solution, that case cannot be in real.
- **To know whether RE installed grid is stable**
  - Search operating point through **Equal Area Criterion**
- **To know how much we can install RE**
  - Estimate ATC(Available Transmission Capacity) by **Equal Area Criterion**
- **To know how much spinning reserve is necessary**
  - Maximum capacity of RE

Capacity Guideline for VRE

- The amount of PV output should be under **ATC(Available Transmission Capacity)** in transmission line.
- Maximum PV output should be covered by other generators for the case of its ramping by weather change. The capacity of generators to cope with the ramping in the grid is of **Spinning Reserve**.
- PV fluctuation can be covered by **smoothing effect** if PV systems are installed at different locations among wide area.
- RE with Grid Following Inverter should be **less than 30%** as described in the guideline* about **SCR(Short Circuit Ratio)**.

*IEEE Std 1204-1997(R2003)

Session No. 2
Grid Modelling for Jamaica

<Current>

- Total Demand in Jamaica: 650MW
- VRE(PV & WT): 175MW
- Distributed PV is 20~40MW

215MW -> 33% of Demand
It is Stability Limit in terms of SCR

- HESS 24.5MW: BESS 21.5MW(16.6MWh) + FW 3MW(16.5MWs)
  -> to avoid the influence of fluctuation of PV output and demand
- Utility scale PV is located at Content solar and Eight River, wind turbine is 5 places (Wigton I, II, III, Munro, and BMR).

- VRE with GFL: Limit is 215MW
- VRE with GFM: VRE over 215MW should be operated by GFM.
- Battery: BESS 1MW*4h / VRE 3MW
  = 4MWh*215/3 = 286MWh (Expected Value)

Cost of RE and Stabilization

PV: US$ 570,000~720,000/MW

SCO(Synchronous Condenser):

US$ 140,000~220,000/MVA（20~30% of PV）

Battery： US$ 400,000/MWh (BESS 1MW*4h / VRE 3MW)

For PV:1MW, SCO(Synchronous Condenser):1MVar, Battery:1.33MWh

PV: US$ 700,000/MW

SCO(Synchronous Condenser): US$ 200,000/MVA

Battery: US$ 400,000/MWh*1.33

(1.33=BESS 1MW*4h / VRE 3MW : Expected Value)

Total: US$ 1,432,000

Cost of RE and Stabilization

PV: US$ 570,000~714,000/MW

SCO(Synchronous Condenser):

US$ 140,000~220,000/MVA（20~30% of PV）

Battery： US$ 400,000/MWh

For PV:215MW(=650*0.3),

SCO(Synchronous Condenser):43MVar, Battery: 215MWh

PV: US$ 700,000/MW*215MW

SCO(Synchronous Condenser): US$ 200,000/MVA*215MW

Battery: US$ 400,000/MWh*1.33*215MW

Total: US$ 1,432,000*215 = 308,000,000

Cost Comparison of Reactive Power Generating Equipment and Sources

Reactive Power Generating Equipment's and Sources	Investment Cost		
	Capital Cost (per kVAR)	*Operating Cost*	*Opportunity Cost*
Capacitors/Reactors	$10-30	Very Low	No
Synchronous Generators	Difficult to separate	High	Yes
STATCOM	$50-100	Moderate	No
Static VAR compensators	$40-100	Moderate	No
Synchronous condensers	$10-40	High	No

Famous O. Igbinovia, Ghaeth Fandi, Zdenek Müller, Jan Švec, Josef Tlusty,
"Cost implication and reactive power generating potential of the synchronous condenser"
2016 2nd International Conference on Intelligent Green Building and Smart Grid (IGBSG)

Cost Benefit Comparison between Capacitors and Synchronous Condensers

Costs and Benefits ($/year)	Capacitor Banks (5.0 MVAR)	Small Generator Retrofitted to Synchronous Condenser (5.0 MVAR)
Capital Cost	$22,000	$50,000
Technology Life Time	10 years	20 years
Preventive Maintenance Cost	$6,000	$3,500
Cost of Voltage Regulator Maintenance	$6,600	$3,300
Annual Cost in Present Value	$14,800	$9,300

Famous O. Igbinovia, Ghaeth Fandi, Zdenek Müller, Jan Švec, Josef Tlusty,
"Cost implication and reactive power generating potential of the synchronous condenser"
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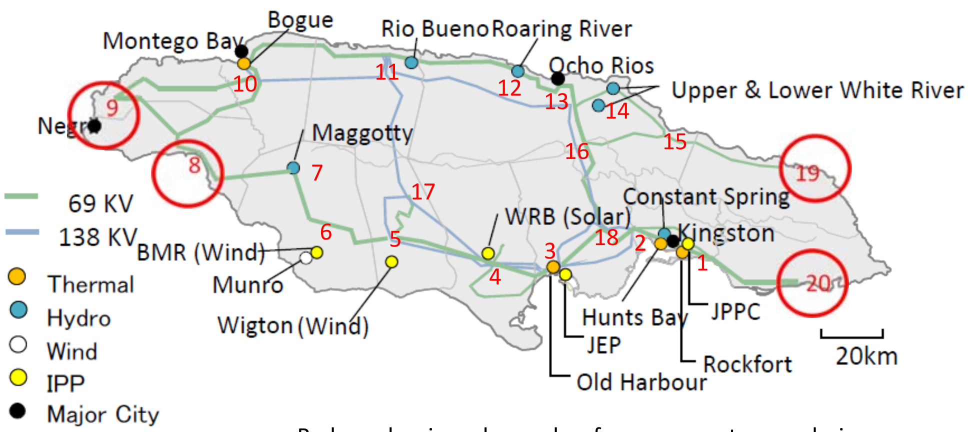
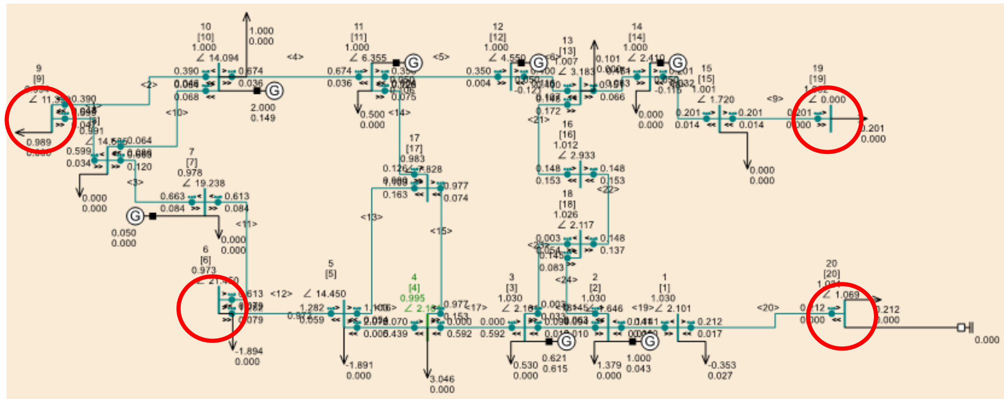
Grid of Jamaica



Red number is node number for power system analysis. Voltages of nodes in red circle became low in the load flow analysis.

* Map is from the presentation document of JPS(Jamaica Power Sector) on May 27, 2019.

Load Flow Analysis of Jamaica Grid



Calculated by CPATFree(CRIEP's Power System Analysis Tools)

Condition of Grid

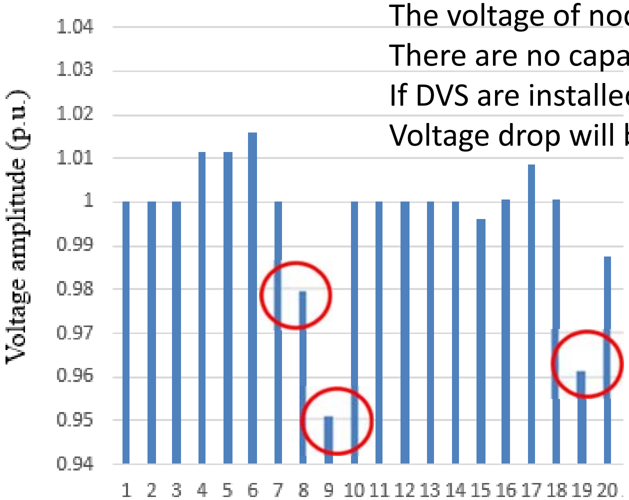
- Thermal Generator stations are located in the middle and west area of Jamaica.
- Load is spent mainly in the west and east area of Jamaica.
- Hydro power stations in the north area contribute to keep voltage among west area and east area
- JPS has taken measures against voltage drop by using DVS(Dynamic Voltage Support) function, which controls voltages changing power factor, Battery, Fly wheel and compensators.

Grid Code for Frequency and Voltage

- Frequency
  - Normal condition : 49.5~50.5Hz
  - Contingency condition: 48.0 ~ 52.5Hz
- Voltage:
  - normal condition -> ±5%
  - contingency condition -> ±10%
  - Voltage between +5% and +10% shall not be last longer than 15 minutes unless abnormal conditions prevail.
- In the following simulation, value of voltages are described in Per Unit value.
- In Per Unit description, 1.0 of value means rated value such as 69.0kV. Voltage should be between 0.95 and 1.05 in normal condition.

Load Flow Analysis by Microgrid Designer

The voltage of node 8, 9 and 19 are low.
There are no capacitance at nodes.
If DVS are installed into inverter for VRE,
Voltage drop will be less than this simulation.



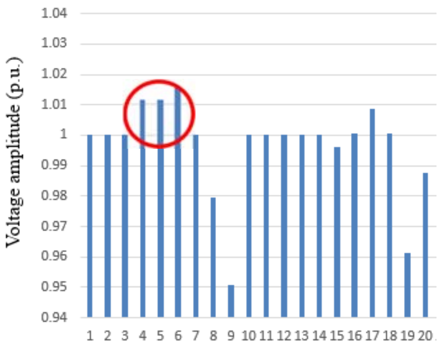
Calculated by Microgrid Designer

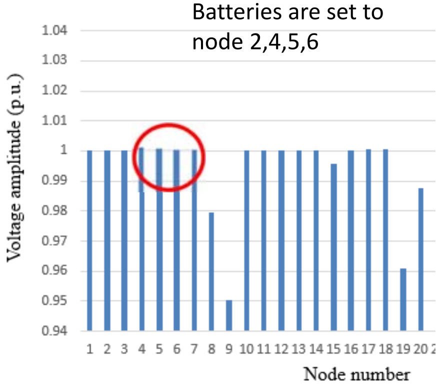
Location of Batteries

- For WT(Wind Turbine Generator)
  - The capacity of WT is large comparing with other RE.
  - In case utility scale WT is installed in the future, BESS had better to be set close to WT.
- For PV system
  - 1/3~1/2 of total PV capacity are assumed as rooftop PV.
  - The BESS for distributer PV systems should be placed at upstream substation to which those distributed PVs are connected.
  - If the capacity of PV system is large, BESS had better to be set close to PV system.

Load Flow Analysis (Battery) by Microgrid Designer

Batteries are set to node 2,4,5,6





Effect of Battery

without Battery in end nodes | with Battery in end nodes

Batteries are located at nodes in which PVs are installed.
The capacity of battery is et as the same as PV at the node.

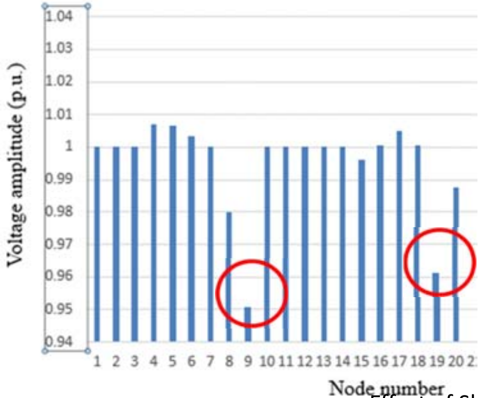
Calculated by Microgrid Designer

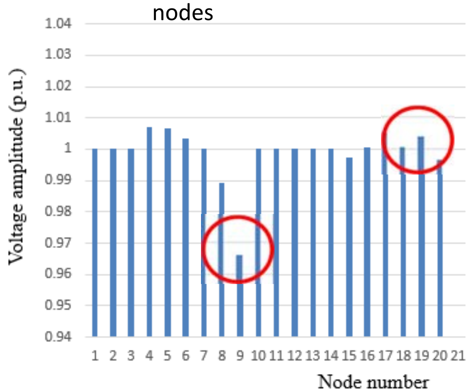
Location of Compensators

- Compensators include SC(Shunt Capacitor), SCO(Synchronous Generator), SVC and STATCOM(Static Var Compensator), and other FACTS(Flexible AC Transmission System) equipment.
- Resources with GFL(Grid Following) Inverter
  - GFL controls node current as current source to follow but does not control node voltage.
  - In order to keep voltage of load node as normal amplitude, a compensator should be installed at substation upstream of the VRE resources connected through GFL in general.
  - The capacity of the compensator should be the same as consuming reactive power of node.
- Resources with GFM(Grid Forming) Inverter
  - It does not require compensators, because GFM inverter is a voltage source inverter and can keep voltage as operation value.

Load Flow Analysis (Shunt Capacitor) by Microgrid Designer

SC's are set to the same nodes





Effect of Shunt Capacitor

without SC in end nodes | with SC in end nodes

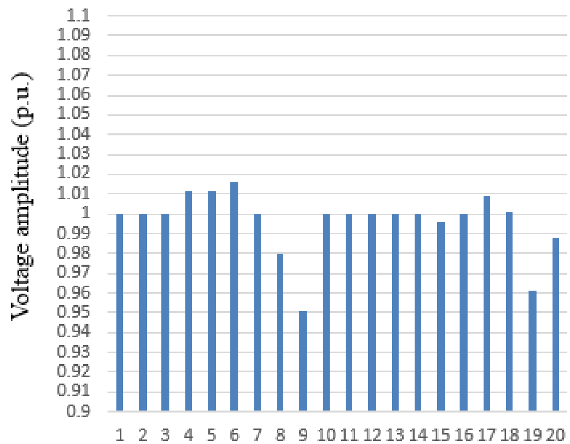
Shunt Capacitors are located at nodes in which PVs are installed.
The capacity of Shunt Capacitor is 0.1 pu, that means that 10% reactive power is provided at node.

Calculated by Microgrid Designer

Grid Modelling for Jamaica - Case 1 -

Capacity Base 24% RE

- Total Demand: 650MW
- PV & WT: 158MW
  (Rated output)
  PV: node 4 -- 57MW
  (WRB & Eight River)
  WT: node 5 (Wigton)
  node 6 (BMR & Munro)
  -- 101MW
- Any measures such as compensators are not included in this simulation.



Calculated by Microgrid Designer

Grid Modelling for Jamaica - Case 2 -

Capacity Base 30% RE

- Total Demand: 650MW
- PV & WT: 195MW

  PV: node 4 -- 57MW

  (WRB & Eight River)

  WT: node 5 (Wigton)

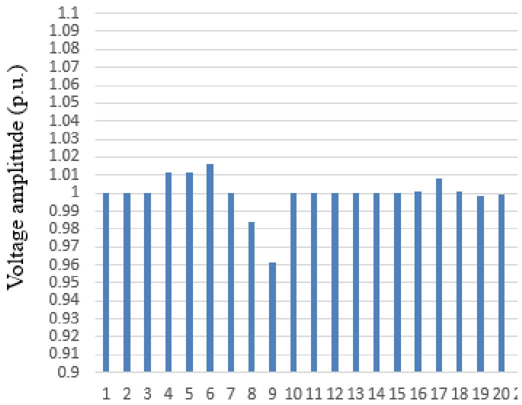
  node 6 (BMR & Munro)

  -- 101MW

  PV: node 9, 19, 20

  -- 19*3=37MW

- Any measures such as compensators are not included in this simulation.



Calculated by Microgrid Designer

Grid Modelling for Jamaica - Case 3 -

Capacity Base 40% RE

- Total Demand: 650MW
- PV & WT: 260MW

  PV: node 4 -- 57MW

  (WRB & Eight River)

  WT: node 5 (Wigton)

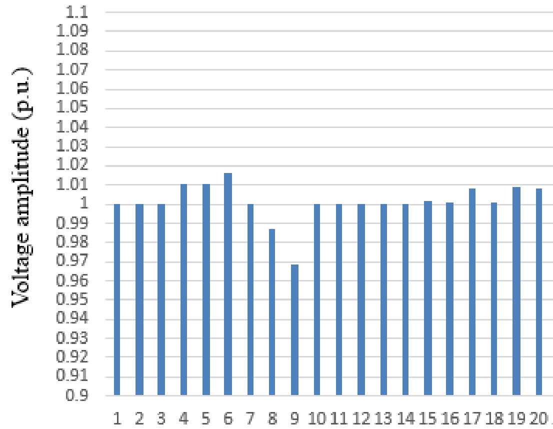
  node 6 (BMR & Munro)

  -- 101MW

  PV: node 9, 19, 20

  -- 34*3=102MW

- Any measures such as compensators are not included in this simulation.



Calculated by Microgrid Designer

Grid Modelling for Jamaica - Case 4 -

Capacity Base 50% RE

- Total Demand: 650MW
- PV & WT: 325MW

  (Rated output)

  PV: node 4 -- 57MW

  (WRB & Eight River)

  WT: node 5 (Wigton)

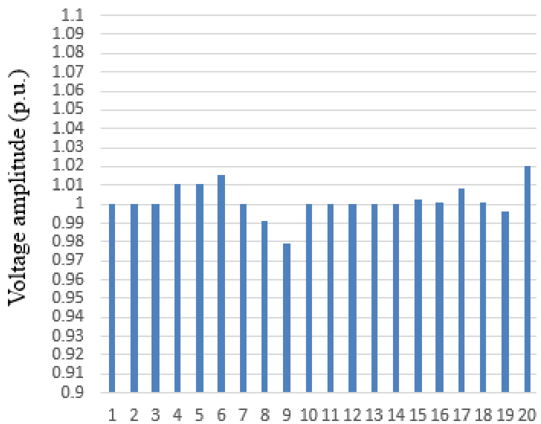
  node 6 (BMR & Munro)

  -- 101MW

  PV: node 9, 19, 20

  -- 56*3=168MW

- Any measures such as compensators are not included in this simulation.



Calculated by Microgrid Designer

Grid Modelling for Jamaica - Case 5 -

Capacity Base 50% RE

- Total Demand: 650MW
- PV & WT: 325MW

  (Rated output)

  PV: node 4 -- 57MW

  (WRB & Eight River)

  WT: node 5 (Wigton)

  node 6 (BMR & Munro)

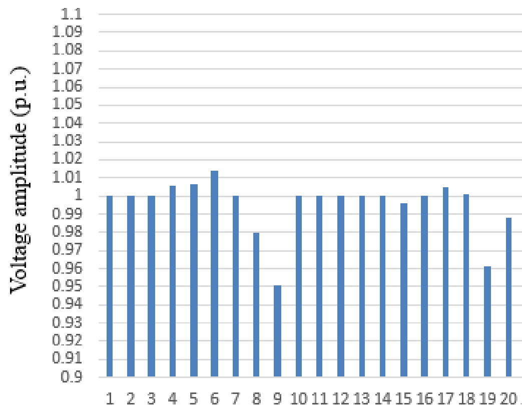
  -- 101MW

  PV: node 9, 19, 20

  -- 56*3=168MW

  BESS: node 4,9,19,20

  -- the same capacity of PV



Calculated by Microgrid Designer

Grid Modelling for Jamaica - Case 6 -

Capacity Base 50% RE

- Total Demand: 650MW
- PV & WT: 325MW

  (Rated output)

  PV: node 4 -- 57MW

  (WRB & Eight River)

  WT: node 5 (Wigton)

  node 6 (BMR & Munro)

  -- 101MW

  PV: node 9, 19, 20

  -- 56*3=168MW

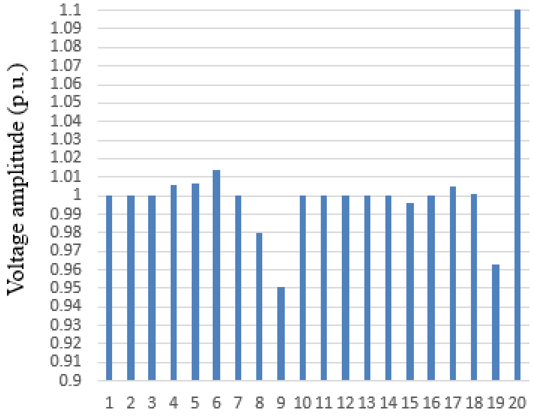
  BESS: node 4,9,19,20

  -- the same capacity of PV

  Shunt Capacitor: node 4,9,19,20

  -- 0.002S for each node

  (S=1/Ω)



Calculated by Microgrid Designer

Session No. 3 Basics of Power System Engineering for Grid Stability Simulation

1. Per Unit Method

   Definition, Example

2. Modeling of Power System Equipment

   Transmission line, Transformer, Generator, Load

3. Active Power & Frequency

   Frequency control, Area requirement

4. Reactive Power & Voltage

   P-V Curve, Reactive power source

1. Per Unit Method

- Normalize impedances and quantities across different voltage levels to a common base in a power system
- Simplify calculations without considering voltage levels and capacity of equipment

- Rated capacity of equipment to 1.0
  - Equipment(ex. Generator): Rated Capacity of each equipment
  - Grid: Grid Capacity or Total Generation

    (need not to set to maximum amount of capacity)
- Rated voltage to 1.0
  - Each Transmission Line can be set to 1.0

Per Unit Value & Actual Value

- Normalize a value to one that is based on unit number 1.0
- For each equipment
  - Rated capacity -> 1.0
  - Rated voltage -> 1.0
- For grid
  - Total capacity of grid -> 1.0
  - Rated voltage of transmission line -> 1.0

$$\dot{V} = \dot{Z}\dot{I}$$

$$\dot{V}_p = \frac{\dot{V}}{V_{base}}, \quad \dot{I}_p = \frac{\dot{I}}{I_{base}}, \quad \dot{Z}_p = \frac{\dot{Z}}{Z_{base}}$$

$$V_{base} = I_{base} Z_{base}$$

$$\frac{\dot{V}}{V_{base}} = \frac{\dot{I}}{I_{base}} \frac{\dot{Z}}{Z_{base}}$$

$$\dot{V}_p = \dot{I}_p \dot{Z}_p$$

$$(VA)_{base} = V_{base} I_{base}$$

$$Y_{base} = \frac{1}{Z_{base}}$$

V: Voltage, I: Current, Z: Impedance
Vbase: Base Voltage, Ibase: Base Current
Zbase: Base Impedance, Ybase: Base Admittance
(VA)base: Base Apparent Power
Vp: Per Unit Voltage, Ip: Per Unit Current
Zp: Per Unit Impedance

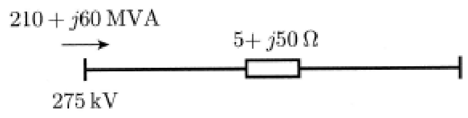
Example of Conversion to Per Unit

(1) Calculate Base Value

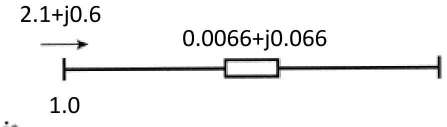
Vbase=275kV

(VA)base=100MVA

$$Z_{\mathrm{Ybase}} = \frac{(275 \times 10^3)^2}{100 \times 10^6} = 756\ \Omega$$



(2) Change Actual Value to Per Unit Value



$$\dot{Z}_{\mathrm{p}} = \frac{5 + j50}{756} = 0.0066 + j0.066$$

$$2.1 + j0.6 = 1.0 I_{\mathrm{p}}^*$$

$$\dot{I}_{\mathrm{p}} = 2.1 - j0.6$$

$$\dot{S}_{\mathrm{sp}} = \dot{V}_{\mathrm{sp}} \dot{I}_{\mathrm{p}}^*$$

$$\dot{V}_{\mathrm{rp}} = \dot{V}_{\mathrm{sp}} - \dot{I}_{\mathrm{p}} \dot{Z}_{\mathrm{p}} = 1.0 - (2.1 - j0.6)(0.0066 + j0.066) = 0.947 - j0.135$$

$$\dot{S}_{\mathrm{rp}} = \dot{V}_{\mathrm{rp}} \dot{I}_{\mathrm{p}}^* = (0.947 - j0.135)(2.1 + j0.6) = 2.07 + j0.285$$

$$\dot{S}_{\mathrm{r}} = (2.07 + j0.285)100\ \mathrm{MVA} = 207 + j28.5\ \mathrm{MVA}$$

$$\dot{V}_{\mathrm{r}} = (0.947 - j0.135)275\ \mathrm{kV} = 260 - j37.1\ \mathrm{kV}$$

$$|\dot{V}_{\mathrm{r}}| = 263\ \mathrm{kV}$$

Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Per Unit Base in Jamaica

- Vbase=69kV
- (VA)base=100MVA
- Ibase=100/69=1.45kA
- Zbase=Vbase^2/(VA)base=69^2/100=47.6Ω
  - R=0.05Ω/km, X=0.1Ω/km
  - Length =10km
  - Rpu=0.05x10/47.6=0.01
  - Xpu=0.1x10/47.6=0.021
  - Zpu=$\sqrt{0.01*0.01+0.021*0.021}$=0.023 => |Z|=0.023Ω

Vbase: Base Voltage
(VA)base: Base Apparent Power
Ibase: Base Current
Zbase: Base Impedance
Rbase: Base Resistance, Xbase: Base Reactance
Rpu: Resistance in Per Unit, Xpu: Reactance in Per Unit

Meaning of Per Unit

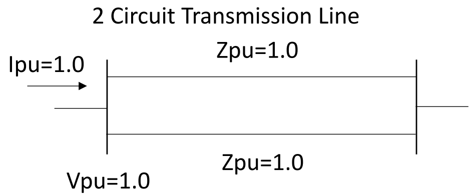
- Meaning of Per Unit:

1pu(|Z|=0.023Ω) impedance transmission line can send 1pu(100MVA) power by 1pu(69kV) voltage. Its current is 1pu(8.7kA).

This will be maximum or rated capacity of transmission line.

If transmission line has 2 circuits, its total impedance will be 0.5pu(0.0115Ω), and the maximum capacity will be twice(2pu:200MVA).

Vpu: Voltage in Per Unit
(VA)pu: Base Apparent Power in Per Unit
Ipu: Current in Per Unit
Zpu: Impedance in Per Unit
Rpu: Resistance in Per Unit
Xpu: Reactance in Per Unit

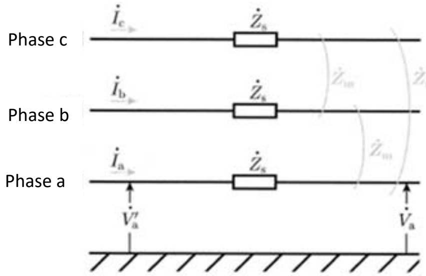


2. Modeling of Power System Equipment

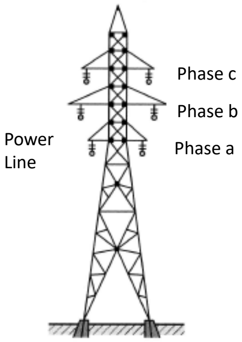
- Make it easy to analyze feature of power system equipment
- Modeling of Components of Power System
  - Transmission Line
  - Synchronous Generator
  - PV(Photovoltaic Generator)
  - WT(Wind Turbine Generator)
  - Load

Transmission Line

- In a 3-Phase balanced system, we may consider only positive phase circuit same as single phase circuit.



Ia, Ib, Ic: Phase Current
Zs: Line Impedance
Va', Va: Phase Voltage
(Sending Terminal Voltage, Receiving Terminal Voltage)

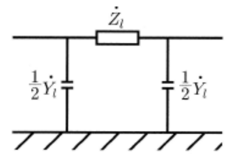


Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

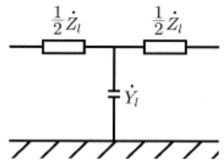
Equivalent Circuit of Transmission Line

Two types of Equivalent Circuit

- Π (pai) Model
  - Divide line admittance into sending node side and receiving node side
  - No need to add another node



- T (tee) Model
  - Divide line impedance into sending node side and receiving node side
  - Need to add another middle point node



- T model is easy to handle in analysis, because it is not necessary to add new node at the middle point of transmission line.

Zl: Impedance of Transmission Line
Yl: Admittance of Transmission Line

Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

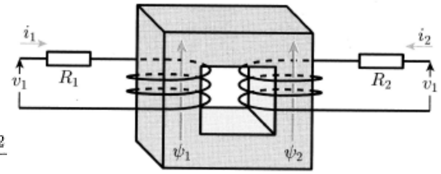
Transformer

- Mathematical equations of transformer

Φ1: primary side flux
Φ2: secondary side flux
L1: primary side self inductance
L2: secondary side self inductance
M1: primary side mutual inductance
M2: secondary side mutual inductance
Ω: angular velocity

$$\begin{cases} v_1 = i_1 R_1 + \dfrac{d\psi_1}{dt} \\ v_2 = i_2 R_2 + \dfrac{d\psi_2}{dt} \end{cases}$$

$$\begin{cases} \psi_1 = L_1 i_1 + M_{12} i_2 \\ \psi_2 = M_{21} i_1 + L_2 i_2 \end{cases} \qquad r = \frac{M_{12}}{L_2}$$



$$\begin{cases} \dot{V}_1 = \dot{I}_1 R_1 + j\omega(L_1 \dot{I}_1 + M_{12}\dot{I}_2) = (R_1 + j\omega L_1)\dot{I}_1 + j\omega M_{12}\dot{I}_2 \\ \dot{V}_2 = \dot{I}_2 R_2 + j\omega(M_{21}\dot{I}_1 + L_2\dot{I}_2) = j\omega M_{21}\dot{I}_1 + (R_2 + j\omega L_2)\dot{I}_2 \end{cases}$$

Magnetic circuit connects two electrical circuits through a transformer.

Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011

Equivalent Circuit of Transformer

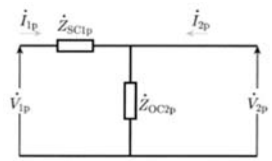
- Relationship of per unit base values

$$\frac{r\dot{I}_1}{I_{2\mathrm{base}}} = \frac{r\dot{I}_1}{rI_{1\mathrm{base}}} = \dot{I}_{1\mathrm{p}} \qquad rI_{1\mathrm{base}} = I_{2\mathrm{base}},\quad Z_{1\mathrm{base}} = r^2 Z_{2\mathrm{base}}$$

$$\frac{\dot{I}_2}{rI_{1\mathrm{base}}} = \frac{\dot{I}_2}{I_{2\mathrm{base}}} = \dot{I}_{2\mathrm{p}}, \quad \frac{r^2\dot{Z}_{\mathrm{OC2}}}{Z_{1\mathrm{base}}} = \frac{\dot{Z}_{\mathrm{OC2}}}{Z_{2\mathrm{base}}} = \dot{Z}_{\mathrm{OC2p}}$$

- Equivalent Circuit and Equation

$$\begin{cases} \dot{V}_{1\mathrm{p}} = \dot{I}_{1\mathrm{p}}\dot{Z}_{\mathrm{SC1p}} + (\dot{I}_{1\mathrm{p}} + \dot{I}_{2\mathrm{p}})\dot{Z}_{\mathrm{OC2p}} \\ \dot{V}_{2\mathrm{p}} = (\dot{I}_{1\mathrm{p}} + \dot{I}_{2\mathrm{p}})\dot{Z}_{\mathrm{OC2p}} \end{cases}$$



I1: Primary side Current, I2 secondary side Current, r: Transformer Ratio
I1base: Primary side Base Current, I2base: Secondary side Base Current
Z1base: Primary side Base Impedance, Z2base: Secondary side Base Impedance
V1p, V2p, I1p, I2p: Per Unit Voltage and Current of Primary, Secondary Circuit
Zsc1, Zsc1p: Short Circuit Impedance from Primary side and its per unit value
Zoc2, Zoc2p: Secondary side Open Circuit Impedance and its per unit value

Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Synchronous Generator (Steady State)

Induced Electromotive Force $\dot{E}_g = E_g e^{j\delta}$

$$P + jQ = \dot{V}_t \dot{I}_g^*$$
$$= V_t \left(\frac{E_g e^{j\delta} - V_t}{jX_g} \right)^*$$
$$= \frac{V_t E_g}{X_g} \sin\delta + j \left(\frac{V_t E_g}{X_g} \cos\delta - \frac{V_t^2}{X_g} \right)$$

$$P = \frac{V_t E_g}{X_g} \sin\delta$$
$$Q = \frac{V_t E_g}{X_g} \cos\delta - \frac{V_t^2}{X_g}$$

Vt: Terminal Voltage, Eg: Induced Electromotive Force
Xg: Armature Impedance, Ig: Armature Current
P: Active Power Output, Q: Reactive Power Output
δ: Internal Electromotive Force Angle
Po: Rated Active Power

Load (Consumer)

- Numerical Model
  - Constant Impedance (**Z**=R+jX)
  - Constant Power (**S**=P+jQ)
  - Constant Current (**I**=a+jb)
  - Easy to include into network equations of power system, because these parameters can be included into Node Admittance Matrix.

How to make a model of Renewable Energy Generator

- PV(Photovoltaic) & WT(Wind Turbine)
  - **Negative load model**
  - Maximum Power Point Control
  - **Follow the Voltage of Grid**
  - Model
    - Constant Current for GFL
    - Constant Voltage for GFM
  - -> similar model of
    Constant Current or Constant Impedance Load model
- Diesel Generator & Biofuel Generator & SCO(Synchronous Condenser)
  - **Synchronous Generator model**
  - Automatic Voltage Regulator -> Constant Voltage
  - Power System Stabilizer -> Control Active Power
  - Governor & Turbine -> Control Frequency
  - -> similar model of **synchronous generator**

3. Active Power & Frequency

- Difference of active power between generator output and load is proportional to frequency.
- Active power of synchronous generators decrease according to frequency.
- Load characteristic is mostly proportion to frequency, because load consists of inductance.
- Crossing point of generator and load characteristics is an operating point.

F0: No-load frequency
FN: Frequency under normal operation
GN: Power of synchronous generators under normal operation

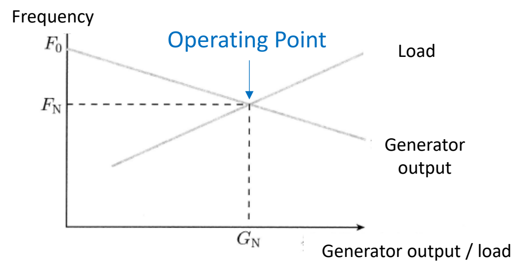


Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Frequency Control Scheme

- Frequency Control Scheme is categorized to 4 stages.

(1) Self-control of load

Quick response of Load according to its characteristics.

(2) Turbine Governor control (Governor Free)

Function of synchronous generator

Conventional inverter doesn't have this.

(3) Load Frequency Control

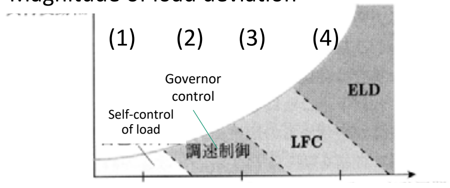
Feedback frequency and change generator outp according to PI (Proportional-Integral) control in EMS as the following equation:

ΔPG = (K1+K2/s)Δf

(4) Economic Load Dispatching

Select most cost effective generator among LFC generators

Magnitude of load deviation



EMS: Energy Management System
 -> operated in central control center
ΔPG: Generator Output Change
Δf: Frequency Change
K1: Proportional Gain
K2: Integral Gain

Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Power–Frequency Coefficients

- Power-Frequency Coefficients is a constant depending on the governor and load characteristics.

$$\%K_G = \frac{100}{F_0 - F_N}\ \%\mathrm{MW/Hz} \qquad \varepsilon = \frac{F_0 - F_N}{F_N} \times 100\,\%$$

$$\%K_G = \frac{100 \times 100}{\varepsilon \times F_N}\ \%\mathrm{MW/Hz}$$

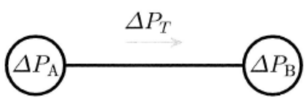
$$\Delta P + (\Delta G - \Delta L) = 0$$
$$\Delta P = (K_G + K_L)\Delta F$$

$$K = K_G + K_L\ [\mathrm{MW/Hz}]$$

F0: Rated Frequency
FN: Current Frequency
ΔG: Generator Output Change
ΔL: Load Change
ΔP: Chang of Power
ΔF: Change of Frequency
KG: Gain for Generator Output Change
KL: Gain for Load Change
K: Power-Frequency Coefficient

Power Systems Connected by a Tie-Line

- Two interconnected power systems



$$\Delta P_A = \Delta G_A - \Delta L_A$$
$$\Delta P_B = \Delta G_B - \Delta L_B$$

Area Requirement (supply and demand balance and tie line flow)

$$\Delta P_A = K_A \Delta F + \Delta P_T$$
$$\Delta P_B = K_B \Delta F - \Delta P_T$$

Frequency of Interconnected grids are collected as the following equations.

$$\begin{cases} \Delta F = \dfrac{\Delta P_A + \Delta P_B}{K_A + K_B} \\ \Delta P_T = \dfrac{K_B \Delta P_A - K_A \Delta P_B}{K_A + K_B} \end{cases}$$

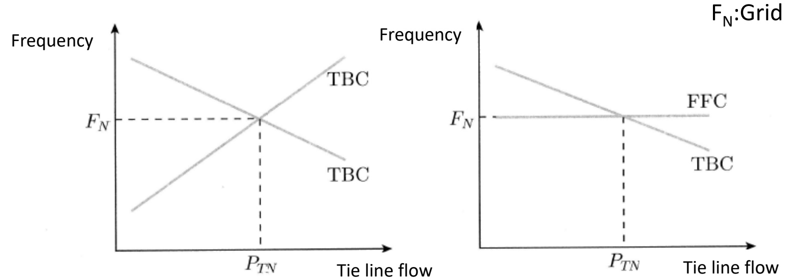
F0: Rated Frequency
F: Frequency of Interconnected Grid
ΔG: Generator Output Change
ΔL: Load Change
ΔP: Chang of Power
ΔF: Change of Frequency
KG: Gain for Generator Output Change
KL: Gain for Load Change
K: Power-Frequency Coefficient

Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Relationship between generator, load and frequency

- FFC: Flat Frequency Control
  - To keep frequency constant in a grid
- TBC: Tie Line Load Frequency Bias Control
  - To keep area requirement (supply and demand balance and tie line flow) zero in a grid

F_N:Grid Frequency



Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

LFC and ELD

- Load Frequency Control (LFC)
  - LFC control signal, that is output reference of generator, is set every 1 minutes as follows.

$$\Delta P = (-1/R) \times \Delta f$$

ΔP: Resulting Change of Power
R: Speed Regulation
Δf: Change of Frequency

- Economic Load Dispatching (ELD)
  - Equal λ method
  - λ=incremental fuel cost / capacity of generator
  - Comparing each λ of generator, select lowest generator every 5 minutes.

LFC & ELD Model in Microgrid Designer

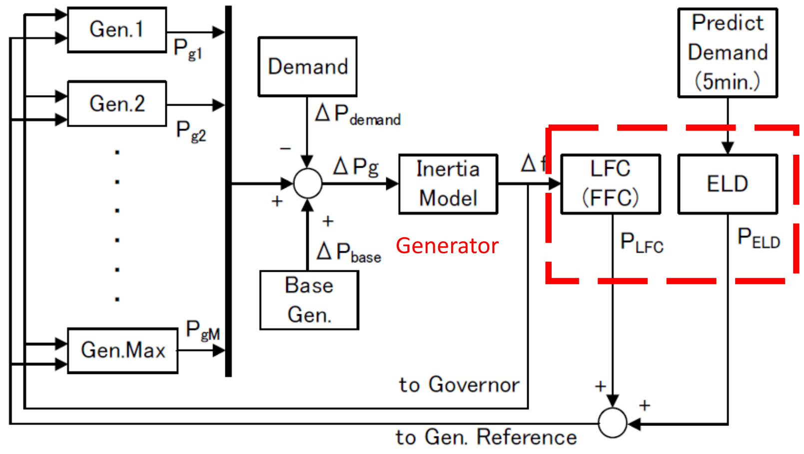
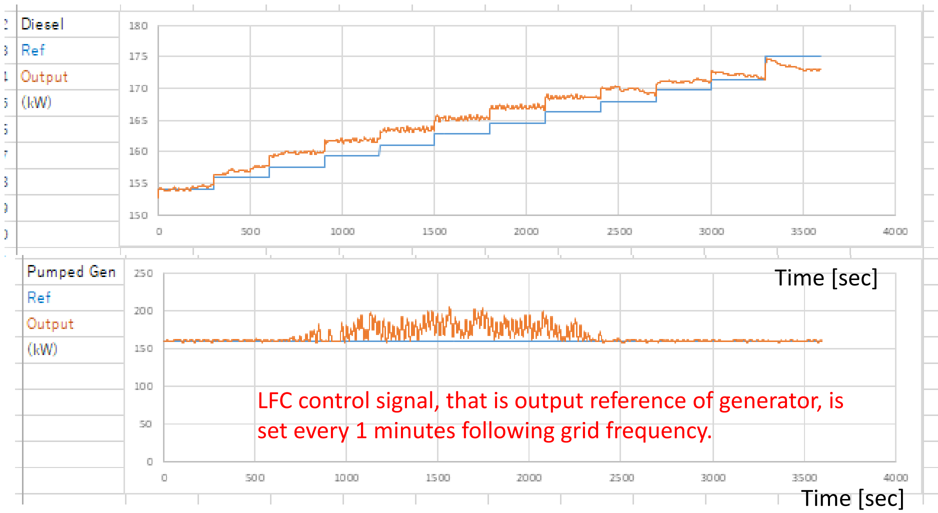


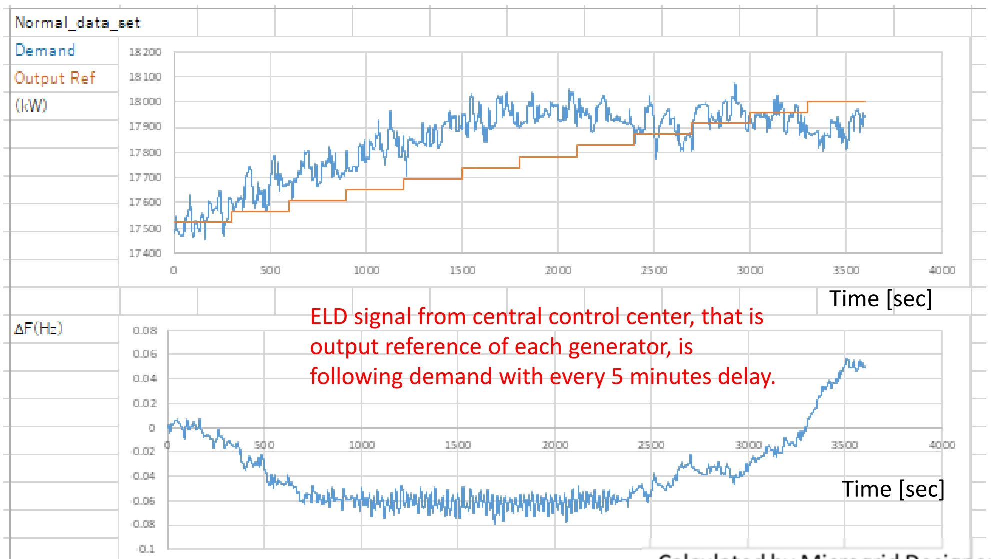
Figure is cited from MicroGrid Designer User and Technical Reference Manual

Generator Output - Result of LFC -



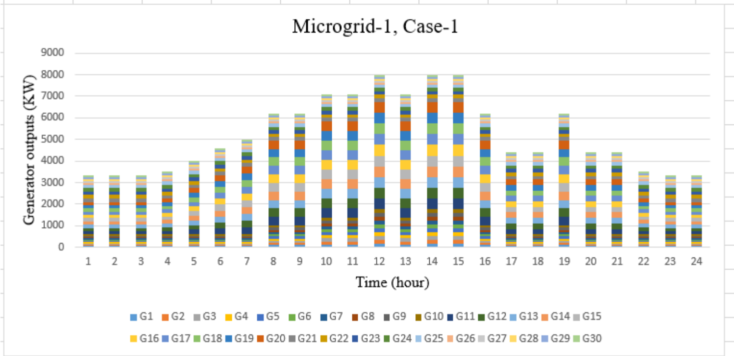
Calculated by Microgrid Designer

Demand and Frequency - Result of ELD -



Calculated by Microgrid Designer

Result of ELD in Microgrid Designer



Calculated by Microgrid Designer

4. Reactive Power & Voltage

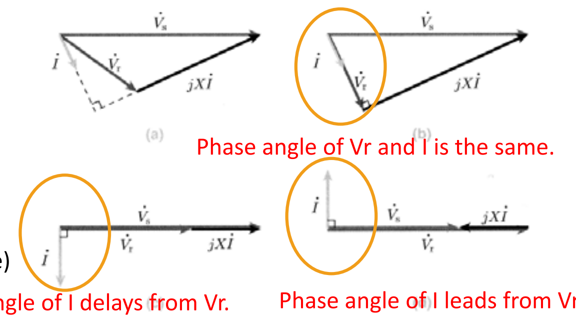
- Most of load consumes reactive power and the voltage of load node will be low.
- Reactive power should be provided or controlled to keep voltage as a set value.
- Providers of reactive power
  - Synchronous generator (SG)
  - Shunt Capacitor (SC)
  - Synchronous Condenser/Capacitor (SCO, RC: Rotary Condenser)
  - Static Var Compensator (SVC) Var means reactive power.
  - Static Var Compensator (STATCOM, Self-commutated Inverter)
  - Voltage Reactive Power Control (VQC)

Reactive Power & Voltage

- Relationship between Reactive Power and Voltage

$$\dot{V}_r = \dot{V}_s - jX\dot{I}$$

(a) Usual load
(b) Power factor=1
(c) Power factor=0,
Lagging load (only inductance)
(d) Power factor=0,
Leading load (only capacitance)

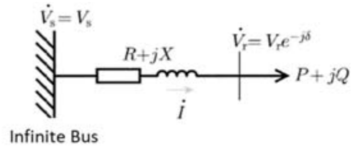


Vs: Sending Terminal Voltage, Vr: Receiving Terminal Voltage
I: Transmission Line Current
X: Transmission Line Impedance

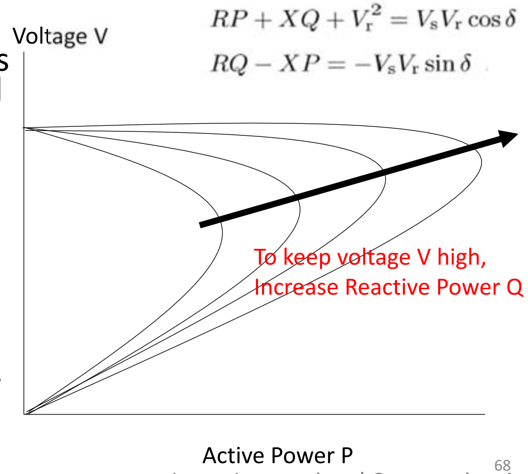
Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

P-V Curve & Q(Reactive Power)

- The equations describe a relationship of active power P and Voltage V according to the change of reactive power Q.
- If Reactive Power Q increases, voltage V will be up and active power P of load will increase.
- In order to keep voltage V as around set value, we should increase reactive power Q of load by adding reactive power resources such as Shunt Capacitor, Synchronous Condenser or Static Var Compensator (SVC, STATCOM) to the load node.
- Caution!!: Too much Q decreases node voltage V and causes blackout to grid.



$$RP + XQ + V_r^2 = V_s V_r \cos\delta$$
$$RQ - XP = -V_s V_r \sin\delta$$



Lunch Break

Session No. 4
Load Flow Analysis and its Evaluation

1. Overview of Load Flow Analysis
   Purpose, Methods, Modeling of grid
2. Newton-Raphson Method
   Theory, Characteristics
3. DC Flow Method
   Simple method to solve load flow manually
4. Load Flow Analysis and Evaluation

1. Overview of Load Flow Analysis

- Steady state analysis under small disturbance
- System is explained as linear model.
- Voltage, power, angle are constant at a certain time, and kept as the same value under small disturbance at a certain time.

-> Load Flow Analysis: Algebraic equations

-> Eigenvalue Analysis: Differential equations

Load Flow Analysis

- Node Admittance Matrix
  - Relationship between voltage and current for multiple nodes in a power system
- Power Equation
  - Relationship between active power, reactive power and voltage
- Load Flow Analysis
  - Conduct Steady state analysis of grid, and get the operating state.
  - A set of simultaneous non linear algebraic equations for voltage
  - The output is the voltage and phase angle, active and reactive power (both sides in each line), line losses and slack bus power
- DC Flow Method (manual calculation): Simplified analysis method of power and voltage in grid by setting each voltages as rated value and using scalar value
- Newton Raphson Method (computer calculation): Detailed analysis method of power and voltage using Jacobian matrix which describe sensitivity of power and voltage using vector value

Load Flow Analysis

Necessary items to consider Load flow Analysis

Buses are categorized to the following 3 types.

- Slack (Swing) Node
  - Node with largest capacity generator with constant voltage is generally selected.
  - Only the magnitude and phase angle of the voltage are specified.
  - This node supplements the difference between the scheduled loads and generated power that are caused by the losses in the network.
- P-V Nodes (Generator Nodes)
  - The active power P and voltage magnitude V are specified.
  - The phase angles of the voltages and the reactive power are to be determined.
- P-Q Nodes (Load Nodes or Substation Nodes)
  - The active and reactive powers P, Q are specified.
  - The magnitude and the phase angle of the bus voltages are unknown.

Node Admittance Matrix

$$\begin{bmatrix} \dot{I}_1 \\ \dot{I}_2 \\ \vdots \\ \dot{I}_N \end{bmatrix} = \begin{bmatrix} \dot{Y}_{11} & \dot{Y}_{12} & \cdots & \dot{Y}_{1N} \\ \dot{Y}_{21} & \dot{Y}_{22} & \cdots & \dot{Y}_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \dot{Y}_{N1} & \dot{Y}_{N2} & \cdots & \dot{Y}_{NN} \end{bmatrix} \begin{bmatrix} \dot{V}_1 \\ \dot{V}_2 \\ \vdots \\ \dot{V}_N \end{bmatrix}$$

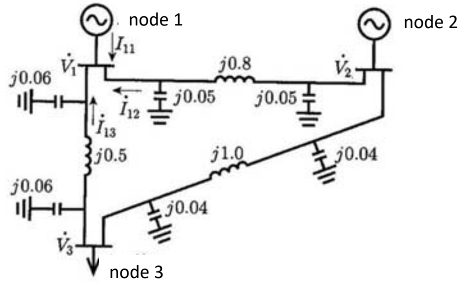
Describe Network Structure

Y= 1/(R+JωL) ＋jωC

R:Resistance

C:Capacitance

L: Inductance



- Calculation example of power flow in 3 nodes network

V1,,,Vn: Node(Bus) Voltage

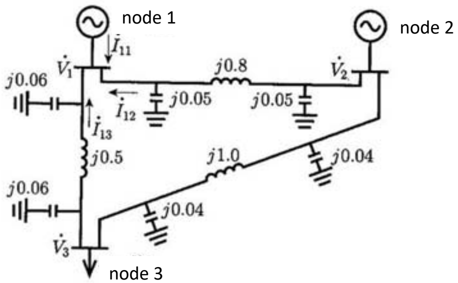
I1,,,In: Branch(Line) Current

Yij: Admittance between each node

Figure is cited from

M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Node Admittance Matrix



$$\dot{Y}_{11} = j0.05 + j0.06 + \frac{1}{j0.8} + \frac{1}{j0.5} = -j3.14$$

$$\dot{Y}_{22} = j0.05 + j0.04 + \frac{1}{j0.8} + \frac{1}{j1.0} = -j2.16$$

$$\dot{Y}_{33} = j0.04 + j0.06 + \frac{1}{j1.0} + \frac{1}{j0.5} = -j2.9$$

$$\dot{Y}_{12} = \dot{Y}_{21} = -\frac{1}{j0.8} = j1.25$$

$$\dot{Y}_{13} = \dot{Y}_{31} = -\frac{1}{j0.5} = j2.0$$

$$\dot{Y}_{23} = \dot{Y}_{32} = -\frac{1}{j1.0} = j1.0$$

$$\boldsymbol{Y} = \begin{bmatrix} -j3.14 & j1.25 & j2.0 \\ j1.25 & -j2.16 & j1.0 \\ j2.0 & j1.0 & -j2.9 \end{bmatrix}$$

- Y_{11}, Y_{22}, Y_{33}:
  - Driving Point Admittance
- $Y_{12}, Y_{21}, Y_{13}, Y_{31}, Y_{23}, Y_{32}$:
  - Transfer Admittance

Figure is cited from

M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Power Equation

- Voltage and current of node k are described as following equations in complex value.
  - $\mathbf{V}_k = e_k + j f_k$, $\mathbf{V}_m = e_m + j f_m$
  - $\mathbf{I}_k = \mathbf{Y}_{km} \mathbf{V}_{km}$
- Power Equation of node k is described using Node Admittance Matrix.

$$P_k + jQ_k = \dot{I}_k^* \dot{V}_k = \sum_{m=1}^{N} \dot{Y}_{km}^* \dot{V}_m^* \dot{V}_k$$

$$P_{ks} = \mathrm{Re}\left\{ \sum_{m=1}^{N} \dot{Y}_{km}^* (e_m + jf_m)^* (e_k + jf_k) \right\}$$

$$Q_{ks} = \mathrm{Im}\left\{ \sum_{m=1}^{N} \dot{Y}_{km}^* (e_m + jf_m)^* (e_k + jf_k) \right\}$$

$$V_{ks}^2 = e_k^2 + f_k^2$$

Vi: Node(Bus) Voltage

Ii: Branch(Line) Current

Yij: Admittance between each node

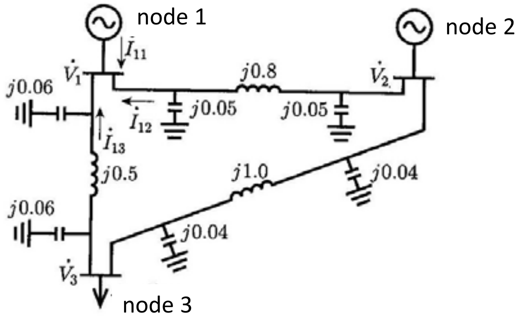
Pi: Node(Bus) Active Power

Qi: Node(Bus) Reactive Power

Power Equation (Example of 3 nodes network)

Power equation describes the way to calculate active power and reactive power using node voltages and node admittance matrix.

Left side value is specified value of power, and right side is a power equation for each node.



$$P_{2s} = \mathrm{Re}\{(j1.25)^*(e_1+jf_1)^*(e_2+jf_2) + (-j2.16)^*(e_2+jf_2)^*(e_2+jf_2) + (j1.0)^*(e_3+jf_3)^*(e_2+jf_2)\}$$
$$= 1.25e_1f_2 - 1.25e_2f_1 + e_3f_2 - e_2f_3$$
$$V_{2s}^2 = e_2^2 + f_2^2$$
$$P_{3s} = \mathrm{Re}\{(j2.0)^*(e_1+jf_1)^*(e_3+jf_3) + (j1.0)^*(e_2+jf_2)^*(e_3+jf_3) + (-j2.9)^*(e_3+jf_3)^*(e_3+jf_3)\}$$
$$= 2.0e_1f_3 - 2.0e_3f_1 + e_2f_3 - e_3f_2$$
$$Q_{3s} = \mathrm{Im}\{(j2.0)^*(e_1+jf_1)^*(e_3+jf_3) + (j1.0)^*(e_2+jf_2)^*(e_3+jf_3) + (-j2.9)^*(e_3+jf_3)^*(e_3+jf_3)\}$$
$$= 2.9e_3^2 + 2.9f_3^2 - 2.0e_1e_3 - 2.0f_1f_3 - e_2e_3 - f_2f_3$$
$$e_1 = V_{1s}, \quad f_1 = 0$$

In this grid, node 1 is set as slack node,
node 2 is set as P-V node,
and node 3 is set as P-Q node.

Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

2. Newton Raphson Method

- Newton Raphson Method is appropriate in computer simulation for large grid.
- This method is applied in Microgrid Designer, which is used in the analysis in this seminar.
- We can get the answer, even if load flow is heavy and difficult to get it by another methods.

Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Algorithm of Newton Raphson Method

Suppose y=f(x), we solve the value of x which satisfies equation f(x)=0.

1. First(i=0), assume x(i) to a certain value (ex. 1.0).
2. Calculate $\Delta x^{(i)} = -\dfrac{f(x^{(i)})}{f'(x^{(i)})}$
3. Calculate $x^{(i+1)} = x^{(i)} - \dfrac{f(x^{(i)})}{f'(x^{(i)})}$
4. Repeat 2 and 3, until Δx(i)<ε,
   where ε is a accuracy (ex. 0.001).
5. Get answer of x

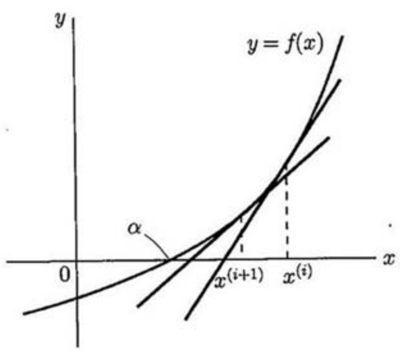


Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Newton-Raphson Method

Newton Raphson Method is applied to power equation as follows:

1. Set node voltage to 1.0
2. Calculate Jacobian Matrix using modified voltage (1.0 at first)
3. Calculate ΔP, ΔQ and Δ|V|^2
4. Solve voltage difference ε of each voltage by eq.(1)
5. Calculate new Voltage by eq.(2)
6. Repeat 2-6 until differences of voltage are smaller than a certain value

$$\begin{bmatrix} \Delta P_2 \\ \Delta|\dot{V}_2|^2 \\ \Delta P_3 \\ \Delta Q_3 \end{bmatrix} = - \begin{bmatrix} \frac{\partial P_2}{\partial e_2} & \frac{\partial P_2}{\partial f_2} & \frac{\partial P_2}{\partial e_3} & \frac{\partial P_2}{\partial f_3} \\ \frac{\partial |\dot{V}_2|^2}{\partial e_2} & \frac{\partial |\dot{V}_2|^2}{\partial f_2} & \frac{\partial |\dot{V}_2|^2}{\partial e_3} & \frac{\partial |\dot{V}_2|^2}{\partial f_3} \\ \frac{\partial P_3}{\partial e_2} & \frac{\partial P_3}{\partial f_2} & \frac{\partial P_3}{\partial e_3} & \frac{\partial P_3}{\partial f_3} \\ \frac{\partial Q_3}{\partial e_2} & \frac{\partial Q_3}{\partial f_2} & \frac{\partial Q_3}{\partial e_3} & \frac{\partial Q_3}{\partial f_3} \end{bmatrix} \begin{bmatrix} \varepsilon_1^{(i)} \\ \varepsilon_2^{(i)} \\ \varepsilon_3^{(i)} \\ \varepsilon_4^{(i)} \end{bmatrix}$$

eq.(1)

$$\begin{bmatrix} e_2^{(i+1)} \\ f_2^{(i+1)} \\ e_3^{(i+1)} \\ f_3^{(i+1)} \end{bmatrix} = \begin{bmatrix} e_2^{(i)} \\ f_2^{(i)} \\ e_3^{(i)} \\ f_3^{(i)} \end{bmatrix} + \begin{bmatrix} \varepsilon_1^{(i)} \\ \varepsilon_2^{(i)} \\ \varepsilon_3^{(i)} \\ \varepsilon_4^{(i)} \end{bmatrix}$$

eq.(2)

3. DC Flow Method

- Simplified Load Flow Method of Grid
- Set all node voltage to 1.0
- Set all resistance of transmission line to 0.0
- Solve relationship equation below between power and voltage angle for each node

$$P_r = \frac{\delta}{X}$$

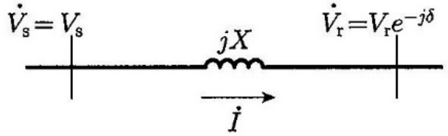
δ : Phase Difference of voltages between both side of a transmission line
X : Transmission line inductance
Pr : Active power that flows in a transmission line

DC Flow Method

Manual method to calculate load flow.
Easy to calculate in manual.

δ : Phase Difference of voltages Vs, Vr between both side of a transmission line
X : Transmission line inductance
Pr, Qr : Active power that flows through a transmission line

$$P_r + jQ_r = V_r e^{-j\delta}\dot{I}^* = V_r e^{-j\delta}\left(\frac{V_s - V_r e^{-j\delta}}{jX}\right)^* = \frac{V_s V_r e^{-j\delta} - V_r^2}{-jX} = \frac{V_s V_r}{X}\sin\delta + j\frac{V_s V_r\cos\delta - V_r^2}{X}$$

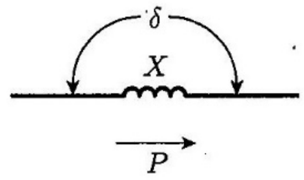


Simplified and Similar to DC circuit solution

$$P_r = \frac{V_s V_r}{X}\sin\delta$$

$$P_r = \frac{\delta}{X}$$

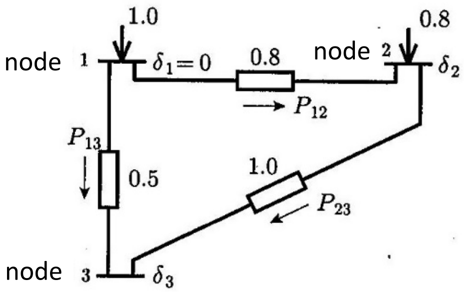
Approximate sinδ by δ



Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

DC Flow Method

(Example of 3 nodes network)



Power equation of each node

$$1.0 = \frac{0-\delta_2}{0.8} + \frac{0-\delta_3}{0.5}$$

$$0.8 = \frac{\delta_2 - 0}{0.8} + \frac{\delta_2 - \delta_3}{1.0}$$

$$\delta_2 = 0.104$$
$$\delta_3 = -0.565$$

Power flow of transmission line

$$P_{12} = \frac{0-0.104}{0.8} = -0.130$$

$$P_{13} = \frac{0-0.565}{0.5} = 1.13$$

$$P_{23} = \frac{0.104+0.565}{1.0} = 0.669$$

Solution of voltage angle

$$\delta_2 = 0.104$$
$$\delta_3 = -0.565$$

Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

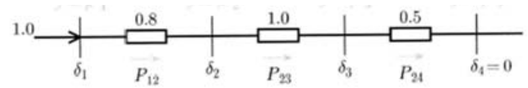
Example of DC Flow method

$$1.0 = \frac{\delta_1 - \delta_2}{0.8}$$

$$0 = \frac{\delta_2 - \delta_1}{0.8} + \frac{\delta_2 - \delta_3}{1.0}$$

$$0 = \frac{\delta_3 - \delta_2}{1.0} + \frac{\delta_3 - 0}{0.5}$$

node 1 node 2 node 3 node 4

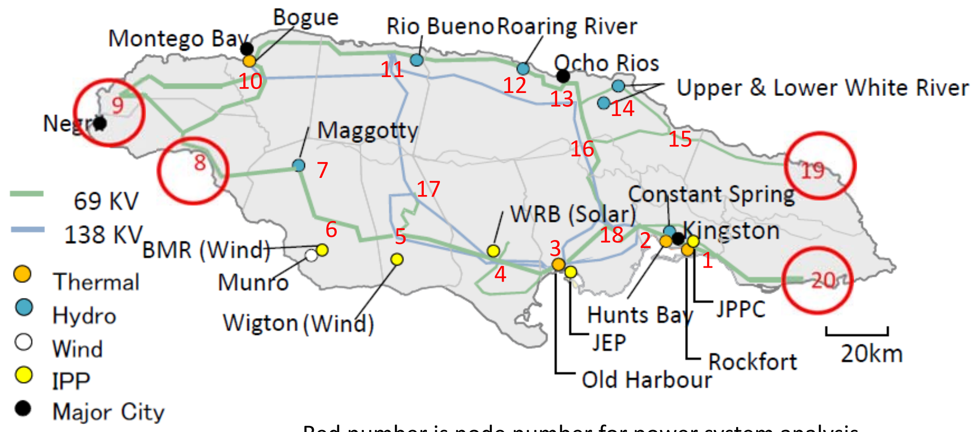


$$\delta_1 = 2.3, \quad \delta_2 = 1.5, \quad \delta_3 = 0.5$$

$$P_{12} = 1.0, \quad P_{23} = 1.0, \quad P_{34} = 1.0$$

Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

4. Load Flow Analysis and Evaluation - Grid of Jamaica -



Red number is node number for power system analysis. Voltages of nodes in red circle became low in the load flow analysis.

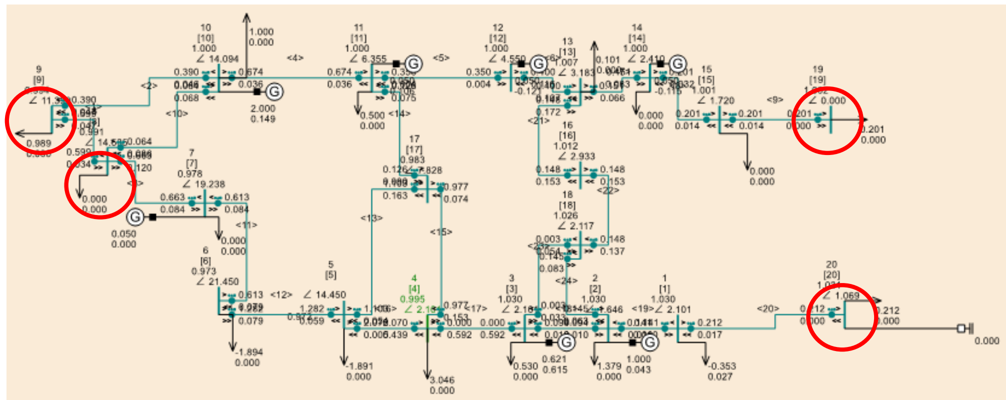
* Map is from the presentation document of JPS(Jamaica Power Sector) on May 27, 2019.

Per Unit Base in Jamaica

Vbase: Base Voltage
(VA)base: Base Apparent Power
Ibase: Base Current, Zbase: Base Impedance
Rbase: Base Resistance, Xbase: Base Reactance
Rp: Per Unit Resistance, Xp: Per Unit Reactance

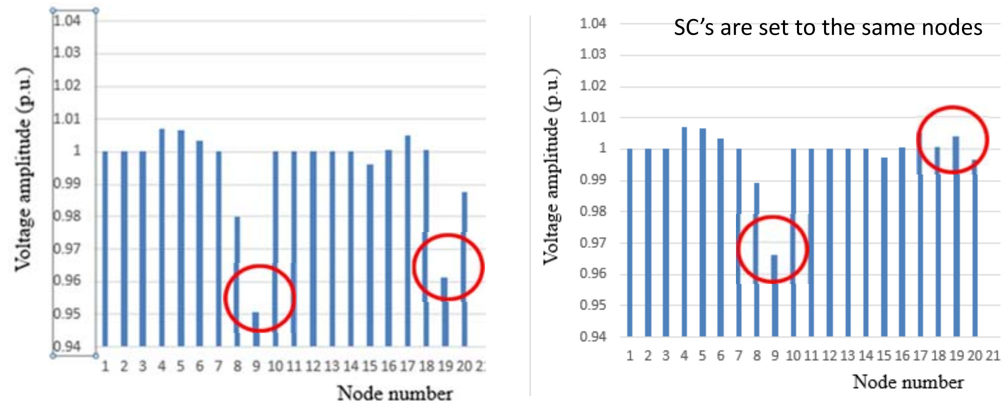
- Vbase=69.0kV
- (VA)base=100MVA
- Ibase=(VA)base/Vbase=1.45kA
- Zbase=Vbase^2/(VA)base=47.6Ω
  - R=0.10Ω/km, X=0.15Ω/km
  - Length =5km
  - Rpu=0.10x5/47,6=0.01 → 2line circuit:0.05
  - Xpu=0.15x5/47.6=0.015 → 2line circuit:0.0075
- Resistance value (Rpu)
  - In high voltage transmission line Rpu can be ignored into 0.0.
  - In low voltage transmission line value of Rpu is similar to Xpu.
  - Rpu of 69.0kV line is set to 70% of Xpu.

Load Flow Analysis of Jamaica Grid



Calculated by CPATFree(CRIEP's Power System Analysis Tools)

Load Flow Analysis Jamaica by Microgrid Designer with/without SC(Shunt capacitor)



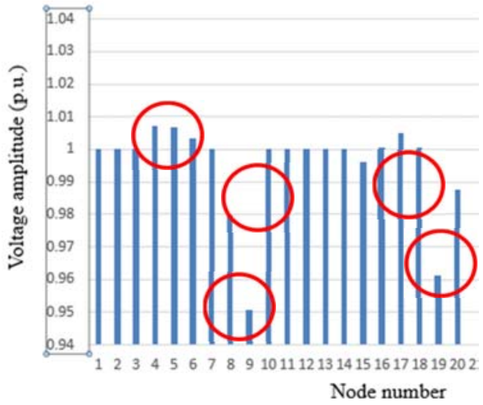
Effect of Shunt Capacitor

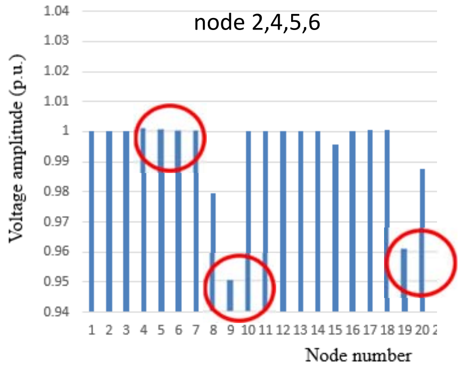
without SC in end nodes — with SC in end nodes

Calculated by Microgrid Designer

Load Flow Analysis Jamaica by Microgrid Designer with/without Battery

Batteries are set to node 2,4,5,6





Effect of Battery

without Battery in end nodes

with Battery in end nodes

Calculated by Microgrid Designer

Between Session 4 and Session 5 --- For Jamaica Future Grid ----

- Please let us know your idea about future Jamaica Grid with RE and grid stability with following form:

[redacted]

Session No. 5
Transient Stability Analysis and Evaluation of Stability

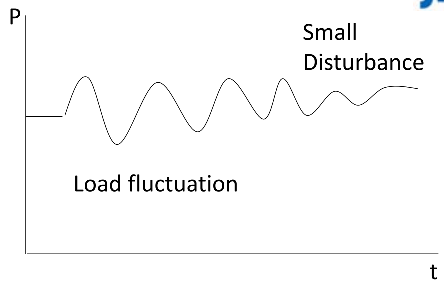
1. Overview of Stability
2. Equal Area Criterion
   Simple method to solve stability manually
3. Exercise of Equal Area Criterion

1. Overview of Stability

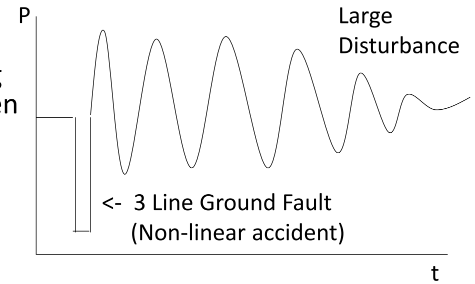
- STABILITY (Definition)
  - If the oscillatory response of a power system during the transient period following a disturbance is damped and the system settles in a finite time to a new steady operating condition, we say the system is stable.
  - If the system is not stable, it is considered unstable.

Type of Frequency/Voltage Stability

- Small Disturbance Stability (time domain graph)
  - Disturbance with minor fluctuation of load, generator, and other power system components
  - Linear modelled phenomena
  - ->Eigenvalue Analysis, Equal Area Criterion



- Large Disturbance Stability (time domain graph)
  - Disturbance with non-linear accidents such as Switching, setting value change, generator trip, sudden load trip, fault in power system components
  - ->Transient Stability Analysis, Equal Area Criterion



Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Stability Analysis

- Equal Area Criterion (Manual calculation)
  - Active Power Flow Dynamics between one Generator and one Load
    - Simplified Stability Calculation
- Transient Stability Program (Simulation Software)
  - Electro-Mechanical Transient Stability
    - Root Mean Square Value Calculation
    - Dynamics of Power Flow including both Active and Reactive Power
    - PSS/E, ETAP, CYME, DigSILENT,,,
  - Electro-Magnetic Transient Stability
    - Instantaneous Value Calculation
    - Dynamics of Electrical Signal
    - EMTP, EMTDC, PSCAD,,,

Swing Equation

- $M\ d^2\delta/dt^2=P_m-P_e=\Delta P$
  - This equation describes relationship between power and frequency.

    $f=2\pi\omega \qquad \omega= d\delta/dt$
  - Power will swing by disturbances caused by unbalance between generation power and consuming load.
- P_m: Mechanical Generation Power
  - Amount of Synchronous Generators, Renewable Energy and other Power Resources
- P_e: Active Power of Load
  - Customers, Facilities, Industries, etc.

M: Inertia capacity
δ: Rotor Angle
Pm: Mechanical Power
Pe: Electrical Power
AVR: Automatic Voltage Regulator
PSS: Power System Stabilizer

Swing Equation

- Swing equation is a mechanical model of generator rotor movement.

$$J\frac{d^2\delta}{dt^2}=T_m-T_e$$

$$\omega=\frac{d\delta}{dt}$$

$$\omega J\frac{d^2\delta}{dt^2}=P_m-P_e$$

$$M=\omega J$$

$$M\frac{d^2\delta}{dt^2}=P_m-P_e=P_a$$

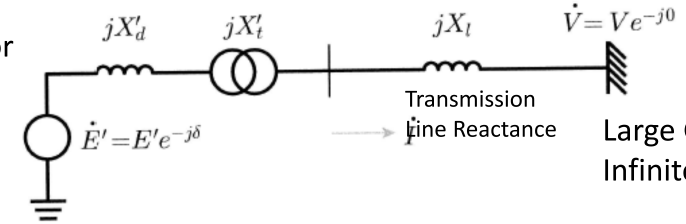
J: Inertia Moment
M: Inertia Capacity
ω: Angle Speed
δ: Rotor Angle
Tm: Mechanical Torque
Te: Electrical Torque
Pm: Mechanical Power
Pe: Electrical Power

2. Equal Area Criterion

- The equal area criterion is a simple graphical method for concluding the transient stability of two-machine systems or a single machine against an infinite bus*.
- This principle does not require the swing equation for the determination of stability conditions.
- The stability conditions are recognized by equating the areas of segments on the power angle diagram between the P-curve and the new power transfer line of the given curve.

* Infinite bus is a constant voltage bus that supplies and consumes any active and reactive power to grid.

Simplified Grid Model



$$P + jQ = \dot{V}\dot{I}^*$$
$$= \dot{V}\left\{\frac{E'e^{-j\delta} - \dot{V}}{j(X'_d + X_t + X_l)}\right\}^*$$
$$= \frac{\dot{V}E'}{X'_d + X_t + X_l}\sin\delta + j\frac{\dot{V}E'\cos\delta - \dot{V}^2}{X'_d + X_t + X_l}$$

$$X = X'_d + X_t + X_l$$

P-δ Equation $$P = \frac{\dot{V}E'}{X}\sin\delta$$

Synchronizing Force $$S = \frac{dP}{d\delta} = \frac{VE'}{X}\cos\delta$$

E': Transient Induced Electromotive Force
V: Grid Voltage
Xd': Transient Reactance
Xt': Transformer Reactance
Xl: Transmission Line Reactance
P: Active Power Output
Q: Reactive Power Output

Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Equal Area Criterion for Stability Analysis

A: Acceleration Energy
B: Deceleration Energy
Pm: Power in operation
Pmax: Maximum of Power
δ_0: Phase in operation
δ_a: Minimum Phase in disturbance
δ_b: Maximum Phase under disturbance

*P*max=>ATC

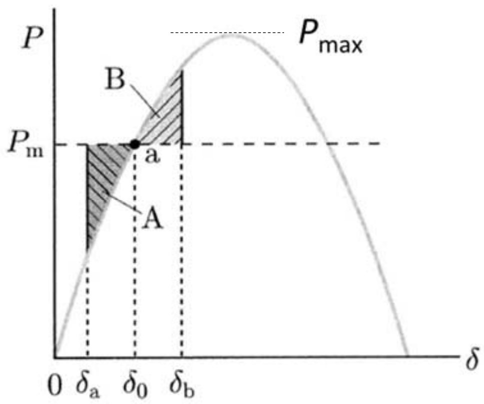


Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

Equal Area Criterion for Stability Analysis

- $P = \frac{V_i V_j}{X} sin\delta$
- $\frac{dP}{d\delta} = \frac{V_i V_j}{X} cos\delta$

A: Acceleration Energy
B: Deceleration Energy

- Synchronizing Force is differential value of power which is the force ' return previous operating point.
- Gradient of Power Curve
- If Pm reaches to Pmax, synchroniz force will be 0.

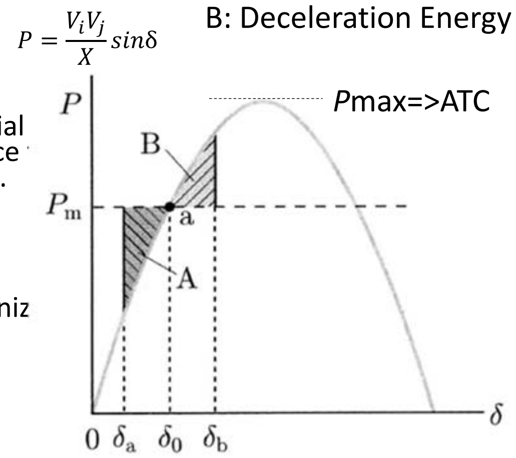


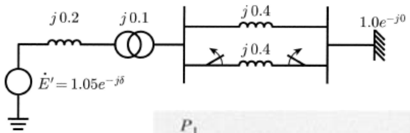
Figure is cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

3. Exercise of Equal Area Criterion

- Operation: 3LG(3 Line Ground Fault)-> 1 line Open from 2 line circuit
- Area A is acceleration energy, area B is deceleration energy.
- By opening 1 line circuit, deceleration energy can be provided.

$$V = 1.0, \quad E' = 1.05$$

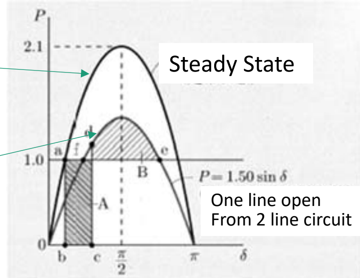
$$X = 0.2 + 0.1 + \frac{0.4}{2} = 0.5$$



$$P = \frac{1.05}{0.5}\sin\delta = 2.10\sin\delta$$

$$X = 0.2 + 0.1 + 0.4 = 0.7$$

$$P = \frac{1.05}{0.7}\sin\delta = 1.50\sin\delta$$

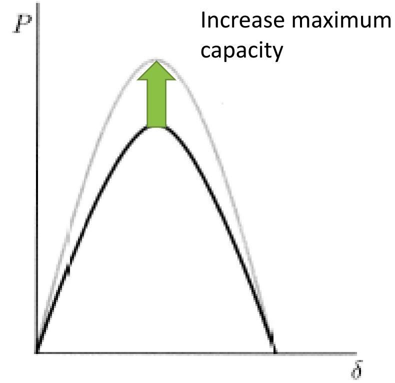


Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

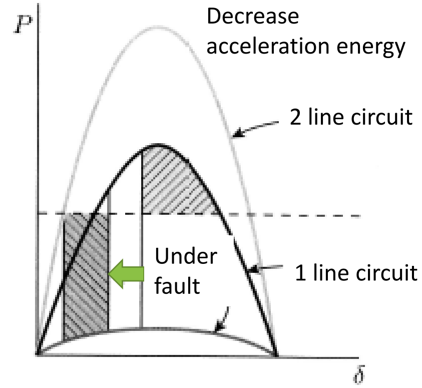
Solution for stability(1) through Equal Area Criterion

$$P = \frac{V_i V_j}{X} sin\delta$$

(a) To increase Voltage



(b) High Speed Circuit Breaker

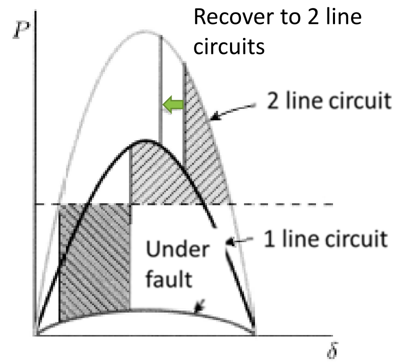


Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

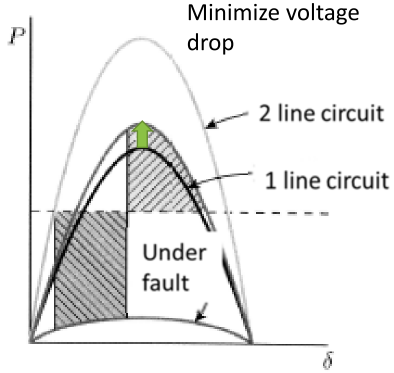
Solution for stability(2) through Equal Area Criterion

$$P = \frac{V_i V_j}{X} sin\delta$$

(c) High Speed Recloser



(d) High Speed AVR

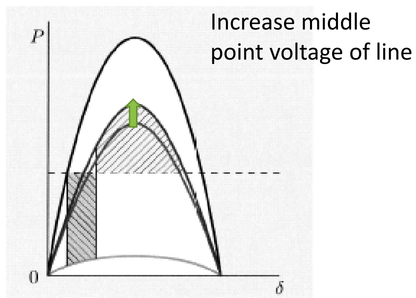


Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

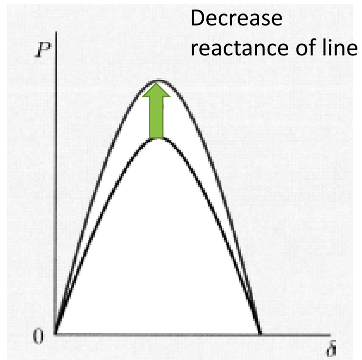
Solution for stability(3) through Equal Area Criterion

$$P = \frac{V_i V_j}{X} sin\delta$$

(e) Middle Point Switch Gear Station



(f) Series Capacitor



Figures are cited from
M.Kato & H.Taoka, "Fundamental Power System Engineering," Suurikogaku-sha, 2011.

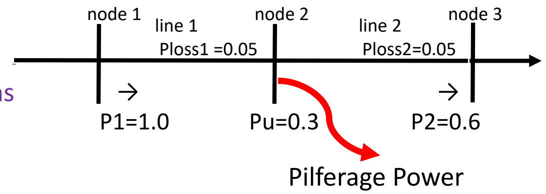
Session No. 6
State Estimation for Multi-point Pilferage

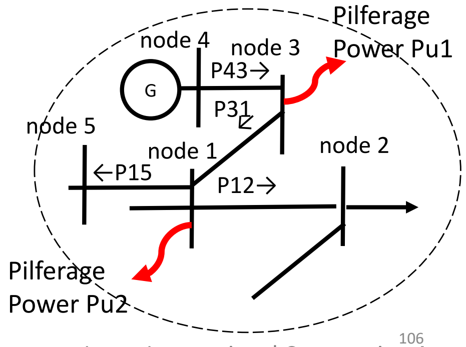
- Warning based on State Estimation Evidence of calculated data from state estimation
  - Pilferage Power (ex. next page's Pu1) can be used as evidence for pilferage warning.
  - -> Detection by State Estimation
- Metering System and its Analysis -> Detection
  - Server of Metering Data is located in Control Center, Substation
  - -> Detection and Control by Metering System

State Estimation is a computer method that computes the state (voltage magnitudes and angles) of the Grid using the network model and real-time measurements.
Line flows, transformer flows, and injections at nodes are calculated from the known state variables and the transmission line parameters.
State Estimation has the capability to detect and identify bad measurements or unreliable data. It will be applied to detect pilferage point and amount from the known data.

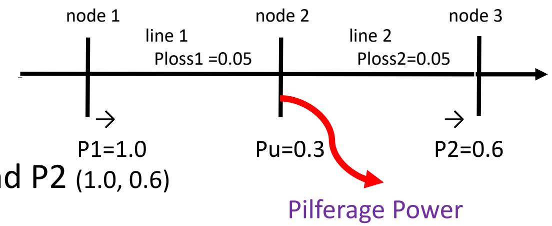
Example of Application of Grid Analysis to find Multi Point Pilferage Amount

If there are multi point pilferage, we have to consider multiple conditions at the same time. Load flow analysis can provide answer for all pilferage at the same time using simultaneous equations of load flow. This load flow analysis is called state estimation.
For example, in a lower figure, pilferage power Pu1 and Pu2 cannot be obtained independently.
It requires simultaneous equations which include conditions of node 1, 2, 3 ,4 ,5, respectively.
Estimate Power flow of pilferage can be formulated as P43=P31+Pu1, P31=P15+P12-Pu2. Line flow is described by quadratic equations of voltage.
Then they are set up as simultaneous quadratic equations.





State Estimation for One Point Pilferage

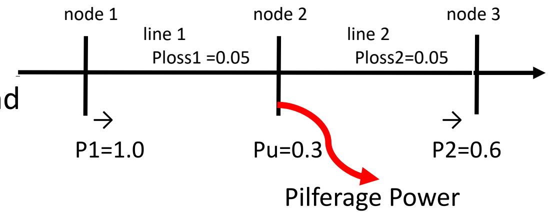


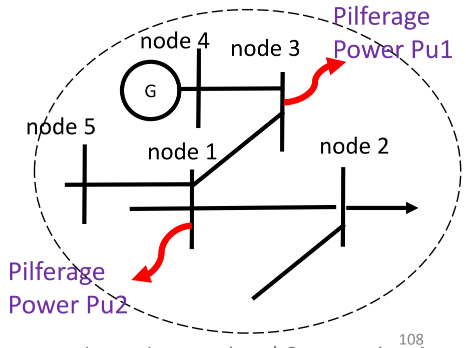
1. Input **Known** Power P1 and P2 (1.0, 0.6)
   - Get data by meter
2. Calculate **Loss** Ploss1 and Ploss2 (0.05, 0.05)
   - Calculate from line impedance and voltage of node1 and node 2
3. Calculate **Pilferage** Power Pu
   - Pu=P1-P2 –(Ploss1+Ploss2)
     =1.0-0.6-(0.05+0.05)=0.3

P1: Active power from node 1 to node 2
P2: Active power from node 2 to node 3
Ploss1: Loss power of line 1
Ploss2: Loss power of line 2
Pu: Pilferage power

State Estimation for Multi Point Pilferage

1. Input **Known** Power (active and reactive power of transmission line, injection from generator and load) and **Known** Voltage and Current at Nodes (magnitude and phase angle)
2. Estimate **Unknown** Voltage by **State Estimation** (magnitude and phase angle)
3. Calculate Power **Loss and Flow** of Transmission Line and Nodes
4. Output **Pilferage** Power





Purpose of State Estimation

- Bad data detection and repairing by Energy Management System
  - USA, EU, Japan, etc.
  - Find trouble of metering
  - Proposed by Dr. Schweppe(1970)
- Finding and possible countermeasures for pilferage by Distribution Management System
  - Middle-East Area Case in 1980's
  - Long transmission line in desert
- To check consumption of customers who do not allow meter reader person (ex. gang) to read proper meter
  - Japanese Utility's Case from 1970's
  - Automatic Meter Reading -> Smart Meter
- Control of Renewable Energy
  - Prediction and control the output of RE

Session No. 7
Discussion for future grid and VRE in Jamaica

- Current Grid of Jamaica
  - Currently it goes well according to the several measures by JPS.
  - Simulation results shows the well controlled grid.
- Assumption of Future Grid (Large amount of RE) in Grid Model and Simulation
  - PVs at east side and west side nodes with/without BESS and Compensators
- Measures
  - BESS , Compensators(SC, SCO, STATCOM)
  - SPS(Special Protection System)

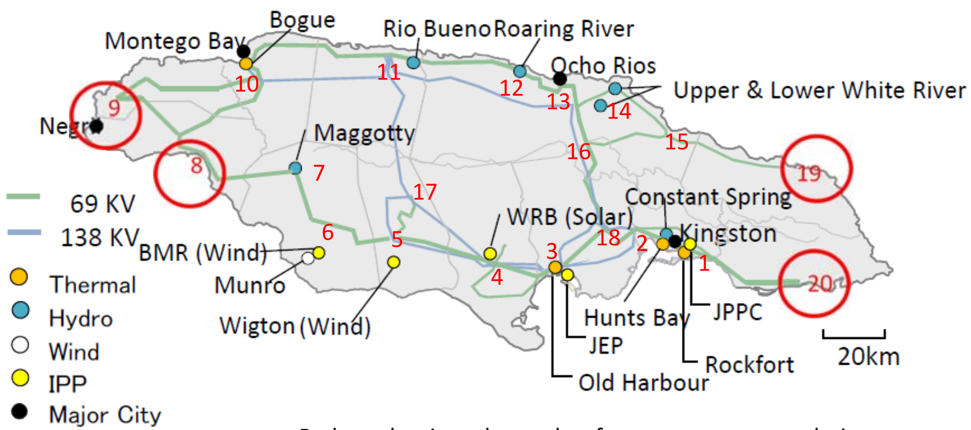
Special Protection System

<Definition>

-> Optional functions installed by utility to improve grid protection according to each grid code.

- An automatic protection system designed to detect abnormal or predetermined system conditions, and take corrective actions other than and/or in addition to the isolation of faulted components to maintain system reliability.
- Such action may include changes in demand, generation (MW and Mvar), or system configuration to maintain system stability, acceptable voltage, or power flows.

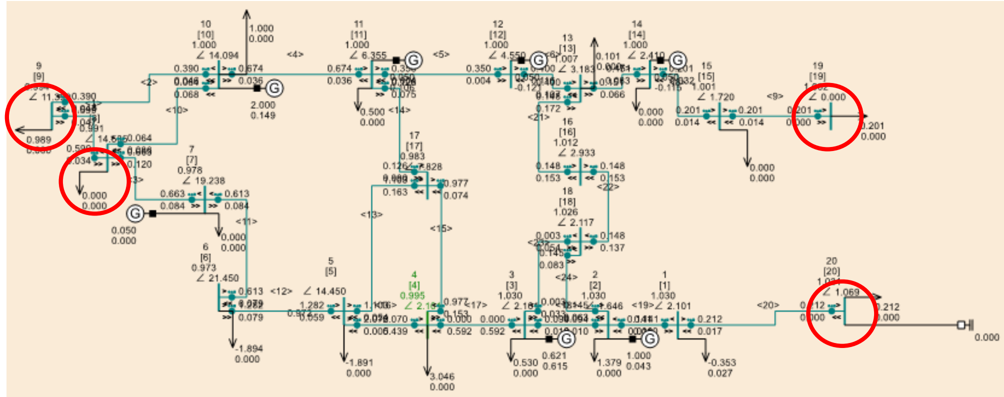
Grid of Jamaica



Red number is node number for power system analysis. Voltages of nodes in red circle became low in the load flow analysis.

* Map is from the presentation document of JPS(Jamaica Power Sector) on May 27, 2019.

Load Flow Analysis of Jamaica Grid



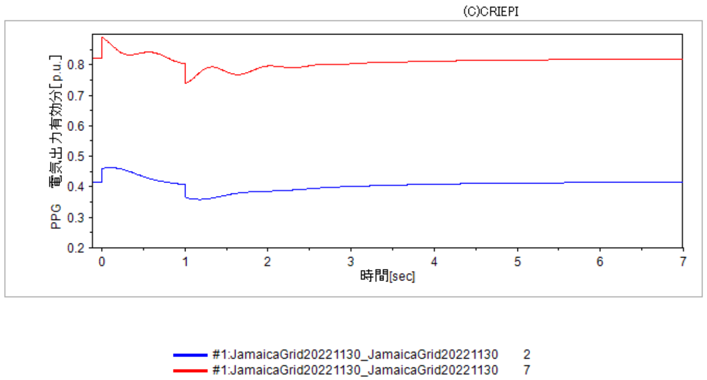
Calculated by CPATFree(CRIEP's Power System Analysis Tools

Evaluation of Jamaica Grid

- Well designed
- Large PV installation causes the increase of voltages and overload of transmission lines
- All PV output is 0 during 1 second.
- In case output of PV drops from Max (36.3MW) to Zero for 1 second

Transient Stability Analysis in Jamaica (Case Study)

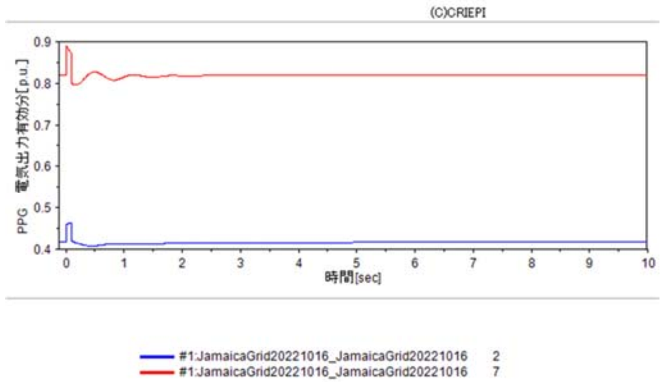
- In case output of PV drops from Max (36.3MW) to Zero for 1 second -> Stable



Calculated by CPATFree(CRIEP's Power System Analysis Tools)

Transient Stability Analysis in Jamaica (Case Study)

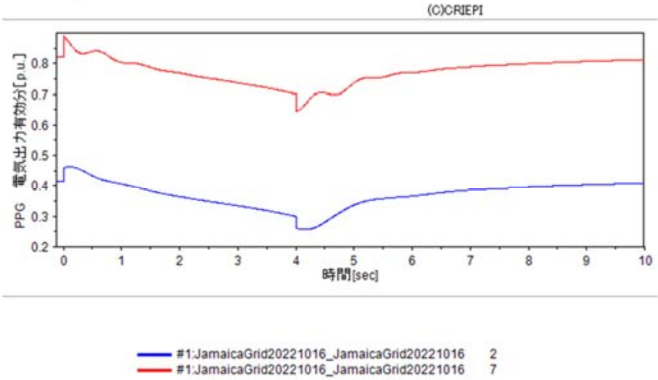
- In case output of PV at node 4 drops from Max (36.3MW) to Zero for 1 second -> Stable



Calculated by CPATFree(CRIEP's Power System Analysis Tools)

Transient Stability Analysis in Jamaica (Case Study)

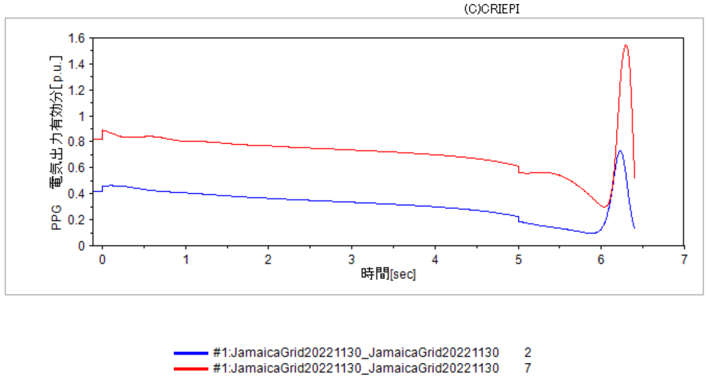
- In case output of PV at node 4 drops from Max (36.3MW) to Zero for 4 second -> Stable



Calculated by CPATFree(CRIEP’s Power System Analysis Tools)

Transient Stability Analysis in Jamaica (Case Study)

- In case output of PV at node 4 drops from Max (36.3MW) to Zero for 5 second -> Unstable



Calculated by CPATFree(CRIEP’s Power System Analysis Tools)

Steps of Stability Analysis and Evaluation

Steps to evaluate stability will be as follows:

1. Load Flow Analysis
2. Equal Area Criterion
3. Short Circuit Ratio
4. Available Transmission Capacity
5. Spinning Reserve

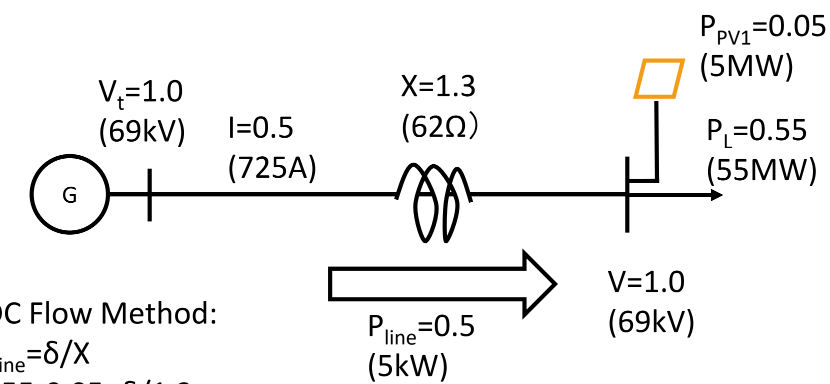
Simple Power System Model

- Generator model can be emulated as follows:
  - Utility
  - Generator Plant
  - Substation
- Lines of any voltage can be modelled.
  - Transmission Line (69kV)
  - Distribution Line (11kV, in case of Jamaica, 12, 13.8 & 24 kV)
  - Feeder from distribution line (400V)

Grid Model for Transmission Network and Distribution Network

- Transmission Network
  - Base VA 100MVA
  - Base Voltage 69kV
  - Base Current 1.45kA (=100/69)
  - Base Impedance 47.6Ω (=69*69/100)
  - Base Admittance $0.021\Omega^{-1}$ (=1/47.6)
- Distribution Network
  - Base VA 100kVA
  - Base Voltage 400V
  - Base Current 250A (=100000/400)
  - Base Impedance 1.6Ω (=400*400/100000)
  - Base Admittance $0.625\Omega^{-1}$ (=1/1.6)

Transmission Network Model



(1) DC Flow Method:

$P_{line}=\delta/X$

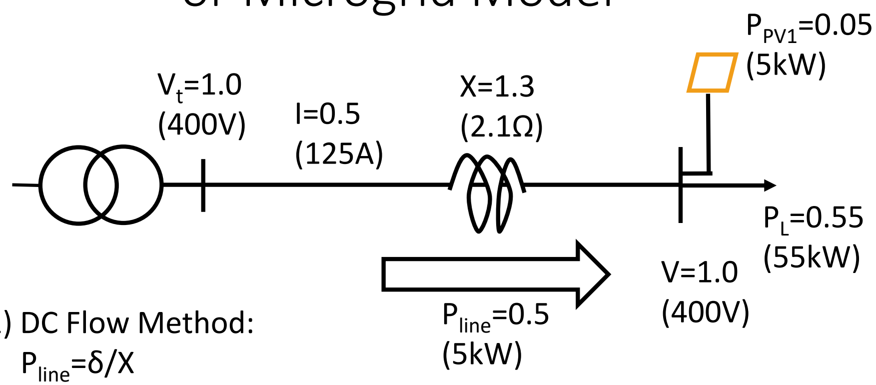
$0.55-0.05=\delta/1.3$

$\delta=0.65\text{rad}=37\text{deg}$

If δ<90deg, these area is stable.

$I=(P_L-P_{PV1})/V=0.5/1.0=0.5=725A$

Distribution Network Model or Microgrid Model



(1) DC Flow Method:

$P_{line}=\delta/X$

$0.55-0.05=\delta/1.3$

$\delta=0.65\text{rad}=37\text{deg}$

If δ<90deg, these area is stable.

I=(PL-PPV1)/V=0.5/1.0=0.5=125A

P-δ Curve and Stability Evaluation

(2) Pmax=1*1/1.3=0.77

(3) Pop=0.5

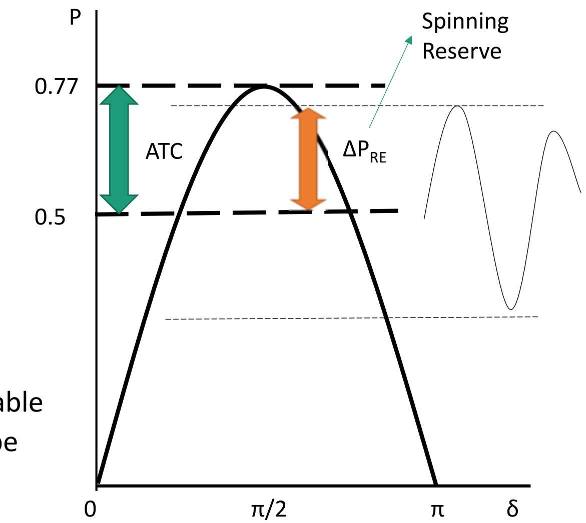
(a) Currently ΔP_{RE}= 0.15
-> Stable

(b) If ΔP_{RE}> 0.27
-> Unstable

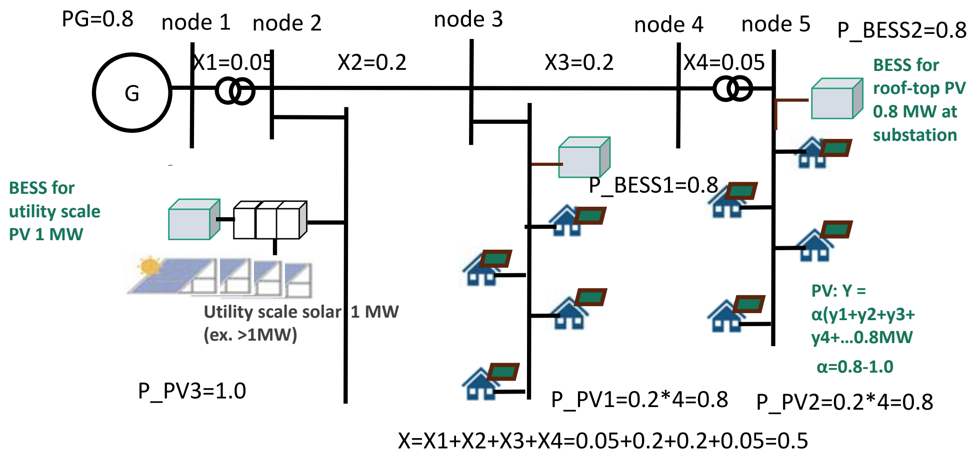
$SCR=Pop/\Delta P_{RE}$
should be over 3
=(a) 3.33 -> Stable
=(b) 1.85 -> Unstable

(4) ATC=0.27 -> If ΔP_{RE}> 0.27
-> Unstable

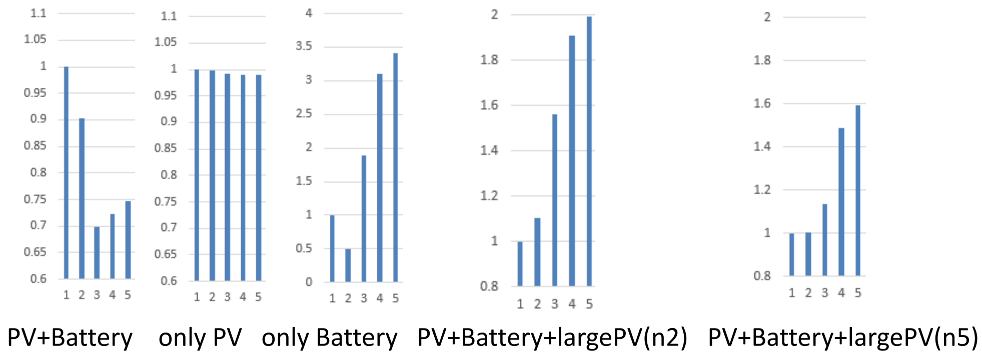
(5) Spinning Reserve should be more than ΔP_{RE}
=0.15



Simple Grid Model for RE



Simple Grid Model for RE -Typical PV location-



- If batteries are connected with no advanced control and output of PV goes zero, node voltage will be high.
- Large PV will cause the increase of node voltages.

Suggestion from You

- Do you have any subject to be solved?
- JICA team may conduct grid simulation based on your idea about generation source and other items that will be necessary for future Jamaica grid.
- Please suggest if any other needs to consider in grid model and simulation.
- Please let us know your request through the following google form, if any additional. (same as the one before session 5)

[redacted]

- We will include your idea or request as a subject in the next Grid Stability Seminar in January, 2023.

Request of Feedback

- Please provide your kind feedback with the form below:

[redacted]

Thank You!!

Appendix 3-4-2 Attendant list, and Q&A, of the 2nd RE & Grid Stability Seminar (Jamaica)

Technical Cooperation to Promote Energy Efficiency in Caribbean Countries

Participants List of 2nd Workshop on Grid Stability with Large RE Penetration in Jamaica **45**

NAME	ORGANIZATION	TITLE	DEPARTMENT	Online Paticipation
Alaina Rose	JPS	Protection Engineer	System Protection	OK
Andre Lindsay	OUR	Regulatory Engineer	-	OK
Antonio Johnson	JPS	Engineering Intern	-	OK
Barrington Jackson	MSET	Technical Officer	GPE	OK
Bret Bennett	JPS	Claims Negotiator	Easement	
Brian Richardson	MSET	Chief Technical Director	Energy	
Bryan Johnson	JPS	Manager, SCADA/EMS/DMS	System Operations	
Christopher Lewis	JPS	Reliability Engineer	System Reliability	OK
Clive Samuels	JPS	Claims Investigator	Claims	
Craig Rattray	OUR	Regulatory Engineer	-	OK
Darron Reid	JPS	Technician Engineer	System Protection	OK
David Clarke	JPS	DMS Engineer	Grid Management Systems	OK
David Cook	JPS	Project Manager, New Generation	Generation	OK
David Fleming	JPS	Legal Counsel	Legal & Compliance	
Denton Williams	JPS	Claims Investigator	Claims	OK
Dhario Reid	JPS	Grid Performance Engineer	Grid Performance	OK
Dianne Plummer	JPS	Head of Department, Procurement	Logistics & Inventory Management	OK
Dionne Nugent	JPS	Director, Business Development	Generation	OK
Duane Smith	JPS	Power System Controller	System Control	OK
Dwight Reid	JPS	Resource Planner - T&D	Grid Performance	OK
Dwight Richards	JPS	Manager, Grid Operations	System Operations	
Errington Case	JPS	Manager, Grid Interconnection	Engineering Services	OK
Horace Buckley	MSET	Project Engineer	-	OK
Ian Reid	JPS	Power System Controller	System Control	OK
Iyishla Campbell	JPS	Software Engineer - Real Time Systems	Grid Management Systems	
Jerrord Thomas	JPS	Technician Engineer	System Protection	OK
Jodie Bowes-Morrison	JPS	DMS Engineer	Grid Management Systems	OK
Joseph Lee	JPS	Easement Negotiator	Easement	
Karl Cowan	JPS	Manager, System Control	System Operations	OK
Kayonne Webley	JPS	Power System Engineer - IPP Operations	Grid Performance	OK
Keisuke Harada	JPS	Alternate Director	Executive Management	OK
Kendis Nangle	JPS	Manager, Claims & Insurance	Legal & Compliance	
Kim Robinson	JPS	Legal Counsel	Legal & Compliance	OK
Kirk Gilpin	JPS	EMS Application Engineer - Production Applications	Grid Management Systems	OK
Kolonje McKenzie	JPS	Buyer	Purchasing & Customs	
Latania Morrison	JPS	Power System Engineer – Generation	Grid Performance	
Leigh Dwyer	JPS	Production Planning Engineer	Planning Operations	OK
Lenbern Hopkins	JPS	Director, Transmission	Energy Delivery	OK
Leneka Rhoden	MSET	-	-	OK
Lincoy Small	JPS	Director, System Control	Innovation & Technology	OK
Nackio Fuller	JPS	SCADA/EMS Application Engineer	Grid Management Systems	OK
Oneif Young	JPS	Assistant Control Engineer	System Control	OK
Osawaki Wickham	JPS	Manager, Engineering & Construction	Engineering Services	
Otony Wlliams	JPS	Claims Investigator	Claims	
Ricardo Case	JPS	Director, Engineering Services	Energy Delivery	OK
Roald Garel	JPS	Assistant Control Engineer	System Control	OK
Romar Taylor	JPS	Assistant Control Engineer	System Control	OK
Sameer Simms	JPS	Director – Generation Operations, Planning & Performance	Generation	
Samuel Davis	JPS	Director, Government & Regulatory Relations	Finance	OK
Shane Brown	JPS	Specialist Engineer	System Protection	OK
Shawn Watson	JPS	Power System Engineer - T&D	Grid Performance	OK
Shawna Farquharson	JPS	Protection Engineer	Standards & Meter Testing Services	OK
Sheridane Francis	JPS	Claims Negotiator	Easement	
Sherika Gilpin	JPS	Assistant Control Engineer	System Control	OK
Shogo Otani	JPS	Director	Executive Management	
Steve Dixon	MSET	T&D Expert	IRP	
Steve Roberts	JPS	Claims Investigator	Claims	OK
Takuya Kokawa	JPS	Marubeni Representative	Executive Management	
Tanya Hylton	JPS	Engineer, Transmission & Distribution	Transmission & Distribution	
Todd Johnson	MSET	-	-	OK
Valentine Scott	JPS	Claims Investigator	Claims	OK
Vashawn Burnett	JPS	Plant Engineer	Generation Planning & Performance	OK
Wilbert Cain	JPS	Easement Negotiator	Easement	
Xaundrae McDonald	JPS	Intern	Recruitment & Employee Services	OK
Yenoh Wheatle	JPS	Senior Power System Engineer – Generation	Grid Performance	OK

Technical Cooperation to Promote Energy Efficiency in Caribbean Countries
Q&A on 2nd Workshop on Grid Stability with Large RE Penetration in Jamaica

From	Question from Participant	Answer from JET
JPS	I think grid forming inverters are commercially available now so the plan should be in the next IRP to ensure that inverters on future BESS units and some VRE sites utilize grid forming inverters that will come in handy too for black starting needs	Thank you for the comment. The timing of grid forming inverter commercially available in the market is not yet but will be soon in a few years. Synvertec was a first company to sell a grid forming inverter, but stopped to sell, because a producer with synvertec went bankrupt. Japanese companies are on the way to develop grid forming inverter now.
JPS	Is using grid forming inverters (GFM) sufficient to maintain system inertia for stability or do you require a mixture of IBRs with grid forming inverters and synchronous generators?	Some mixture of IBR by grid following inverter(GFL) may need to be considered. GFL operates with MPPT and power producer who wants to maximize power output of PV would need GFL. Power factor adjustment with MPPT may be necessary. So, some portion of GFL need to be mixed with GFM in future. Synchronous generator type resource is required for the case of the lack of enough electricity from RE, but it is not mandatory if you have enough inertia from GFM.
JPS	How did you determine the SCR for the Jamaica model?	Based on IEEE1204-1997(R2003)", IEEE Guide for Planning DC Links Terminating at AC Locations Having Low Short-Circuit Capacities, SCR >3 is recommended. We will share the material.
CTE, GPE	Why did you site shunt capacitors at nodes where PVs are installed? Why not centrally?	It is because the simulation was conducted feeder base. Generally, shunt capacitor is placed at the biggest demand area. In this simulation case of this presentation, analysis was conducted for each feeder. To keep voltage for the feeder, shunt capacitor is placed at the feeder. The purpose of shunt capacitor in our simulation was checking the ability to keep voltage by injecting reactive power to the PV node. The result was not good.
JPS	Thanks for the informative session, but the accent was definitely a part of the barrier.	Sorry for the inconvenience. We will try to improve.

Technical Cooperation to Promote
Energy Efficiency in Caribbean Countries

3rd Seminar on Grid Stability and Large RE In Jamaica

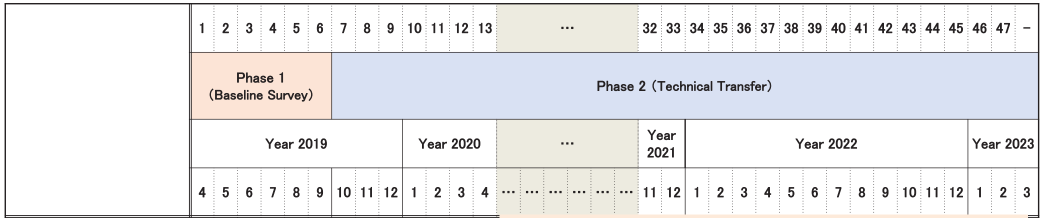
8 Feb 2023

JICA Expert Team consists of
Nippon Koei Co., Ltd.
PADECO Co., Ltd.

Agenda

1. Opening Remark
2. Project outline, Review and Feedback of 2nd Seminar
3. Grid Scenario proposed and stability analysis
4. Development Status of Grid Forming Inverter and its Safety
   - Current Status, Blackout with GFM & Black Start using BESS
5. Transmission lines and Remedial Action Schemes
   - Special Protection System, PV/Wind Turbine Trip
6. Microgrid planning
7. Technology options
8. Policy recommendation
9. Discussion, sharing good practice of Jamaica, and way forward

Project Outline and Schedule



Output 1
The basic information is confirmed for the capacity building for the introduction of RE

Output 3
The human and institution capacity are enhanced for the mass introduction of RE

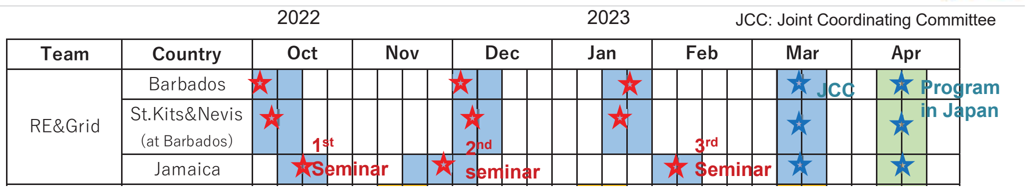
Output 2
The basic information is confirmed for the capacity building for the promotion of EE

Output 4
The human and institution capacity are enhanced for the promotion of EE

RE and Grid Stability activity is to:
- introduce micro-grid concept in one of the agreed areas and develop modelling based on existing grid data.
- introduce computer modelling for grid analysis and examine issues associated with a large penetration of VRE
- propose the way to enhance resiliency
- consider and propose the necessary technologies for achieving the RE goals, including grid stabilization,
- consider and propose additional policy legal system for achieving RE goals
- prepare necessary training plan
- provide recommendations on design of the policy/ legal system

Introduction

Schedule and Key Events for RE&Grid Activity



Title	Date	Objective	Contents
1st Seminar	12 Oct 2022	To share basic technical knowledge for grid analysis with large RE	Overview of Power system, per unit method, modeling, asset management, load flow analysis, introduction of method, software and tools
2nd Seminar	30 Nov 2022	To conduct and exercise grid modeling and analysis	Grid modeling, Microgrid, example, Load flow analysis and stability analysis, evaluation
3rd Seminar	8 Feb 2023	Review and exercise of grid analysis with scenario cases	Detailed system and countermeasures, protection, Exercise of tools for grid analysis with various RE scenarios
Final JCC	Mar 2023	To confirm outcome of project and way forward	Review of TC activity output, policy recommendation, Program in Japan

Feedback at the 2nd Seminar

SCO: Synchronous Condenser
BESS: Battery Energy Storage System
GFM: Grid Forming Inverter
T&D: Transmission and Distribution

Items	Feedback	3rd Seminar
How much MW or % you propose to add in future Jamaica grid?	PV70%, Wind 30% Nuclear 30%, WTE 7%, Solar 33%, Wind 20%, Hydrogen 10% PV30%; Wind 10%; Gas 9% 30% each, providing battery storage PV-15%, Wind-15%, WtE-5%, Pumped storage hydro- 14% 30% PV 30% Wind, 15% WTE, 25% Gas Up to 200MW LNG/Hydrogen, 150MW PV,100MW Wind, 20MW each for Biofuel/WtE (IRP) 150MW&Wind 100MW , or PV 100MW& Wind200MW,etc…	In no.3 today, some of cases will be assessed.
Other requests to consider in grid model and simulation.	1) Double circuit transmission lines in north coast areas 2) RE plants fitted with capability to be slack units +- 10MW to respond to frequency changes 3) RE plants to offer MVAR support 4) current profile of the Wind output and battery	To be answered in no.3 and no.5 today. 4) Will be in no.1, 6
Other than generation source, what is necessary for future Jamaica grid with 50%RE?	Hydrogen for Storage Additional BESS, HESS Grid Forming Inverters, Capacitor Banks STATCOMS, Synchronous Condensers, Bulk Capacitor bank, switchable capacitors at large loads SMR Nuclear.	-Hydrogen storage is included in EE seminar - nuclear is not target of this seminar

Feedback at the 3rd Seminar (2)

Items	Feedback	3rd Seminar
Questions that you would like to know more details in the seminar	1) Possible impact of bio-fuels/waste-to-energy on Jamaica's Electricity Grid 2) Hydrogen Storage and Generation for Renewable Integration. Transmission Expansion for Large RE integration. 3) Microgrid Planning	1) Biofuel/WtE is same as thermal. Limitation is fuel cost &feedstock. 2) In EE seminar 9-10 Feb 3) No. 6 today
What component did you find convenient	• Grid Modelling Basics, Load Flow Analysis, and Stability Analysis • Grid forming inverter applications • Protection • Power System Analysis, Microgrid Systems	
what is the best finding in 2nd seminar	- How to calculate the SCR to determine grid stability - Grid forming inverter seem to provide some viable options that are worth considering to address grid stability issues associated with VRE	

Summary: Jamaica

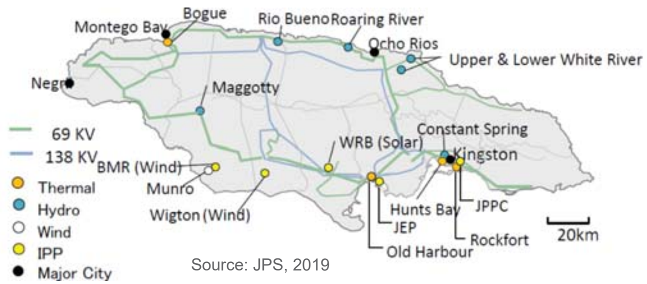
*1 JPS Annual Report 2021 *2 IRP Feb 2020
*3 Interview to JPS *4 Transmission Code

Item	Description	Project Activities
Energy Efficiency	• **Energy Source: Oil (53%) , Electricity (37%)** • **Peak Demand: 654.5MW (2018)→622MW (2021)*1** • **Generated 4356 GWh (2018)→4,303 GWh (2021)*1** • **1833 kWh/customer/yr, 0.34 USc/kWh (2021)*1** • **Peak Period: 6:30pm – 8:30pm**	**Priority 1: BEMS** **Priority 2: Mini split AC with inverter** **Priority 3: LED**
Renewable Energy	• **RE target 33% by 2030, 49% by 2037** *2 • **Hydro 28.6 MW, VRE 175 MW (PV utility 53+ distributed 20-40MW , wind 102MW)** *2**, RE 15% of grid**	**Recommendation for 50% RE target** **Micro-grid concept study** **Introduction of asset management**
Grid Stabilization	• **>50.5Hz:0.5sec, <49.5 Hz: 20 sec, <48Hz:0.5 sec** *4 • **RE Fluctuation affects gird stability***3 • **JPS 21.5MW/16.6MWh Li BESS +3MW 16.5MWs flywheels**	
O&M of Thermal Power Generation	• **Thermal power plant: total 20 units including IPP** • **Installed Capacity: Total 1036.5MW including GTCC in Old Harbour P/S (190MW)** • **Heat rate 11,330(2017)→9,392 (2022) kj/kWh** *1 • **Predictive Maintenance: Considering to apply**	-

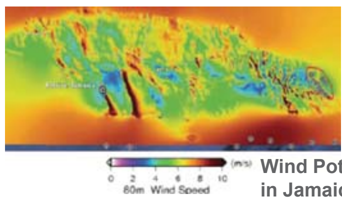
RE Status in Jamaica

Challenges for RE & Grid:

- ✓ Increasing RE capacity >20%, RE generated energy >14%.
- ✓ Future increase of RE with stability
- ✓ System losses 26.3%(2018) →28.3%(2021)
- ✓ Large number of distributed PV → need database management
- ✓ Wind & PV potential unevenly distributed →less smoothing



Source: JPS, 2019



Wind Potential in Jamaica

Source: Sustainable Energy Roadmap 2013

VRE Projects in Jamica

Location/Project		Capacity MW	Generation GWh estimated	Year	Tariff USc/kWh	Investment mil USD
Wigton I	Wind	20.7	52	2004	10.21	26
Wigton II	Wind	18	47	2010	10.723	45
Wigton III	Wind	24	63	2016	13.4	46.5
Munro	Wind	3	10.5	2010	(JPS)	
BMR Wind	Wind	36.3	120	2016	12.9	90
Content Solar (WRB)	PV	20	34	2016	18.8	65
Independent roof-top	PV	20?			--	
Eight River (EREC)	PV	33.1		2019	8.5	
Wigton IV	Wind	34		?		
VRE under operation		**142**	**326.5**			

Source: Prepared by JET with several data sources

Scenario Cases for 50%RE in 2030

Capacity and Energy in 2030/2040 to be used in scenario cases

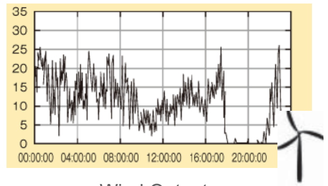
Category	MW%	2021 MW*	GWh%	2021 GWh*	2021 GWh assumed uwith loss	2030 GWh (CAGR 1.43%**)	2040 GWh (CAGR 1.43%**)
Fossil Fuel	75%	1050	86.5%	4092	2,934.0	4,649.8	5,359.2
Total RE	25%	350	13.5%	640	458.9	727.2	838.2
Hydro	3.0%	42	2.9%	136	97.5	154.5	178.1
Solar	9.0%	126	2.6%	124	88.9	140.9	162.4
Wind	9.8%	136.5	5.9%	280	200.8	318.2	366.7
Bioenergy	3.3%	45.5	2.1%	100	71.7	113.6	131.0
Total	100%	1,400	100.0%	4732	3,392.8	5,377.0	6,197.4

* IRENA Energy Profile, Jamaica   ** IRP(2020), most likely case

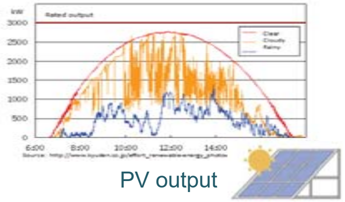
Category	Capacity factor 2020 Jamaica	Capacity factor IRP2020	Capacity factor IRENA	2021 GWh	GWh target %	2030 GWh	2030 MW	2030 MW	2040GWh	2040 MW	2040 MW %
Fossil Fuel	44%	54%	41%	4,092	50%	2,689	748.6	39%	3,099	862.8	39%
Total RE				640	50%	2,689	1,190	61%	3,099	1,372	61%
Hydro	37%	61%	52%	136	10%	538	118.0	6%	620	136.1	6%
Solar	11%	21%	15%	124	15%	807	613.8	32%	930	707.5	32%
Wind	23%	38%	32%	280	15%	807	287.7	15%	930	331.6	15%
Bioenergy	25%	95%	36%	100	10%	538	170.5	9%	620	196.5	9%
Total				4,732	100%	5,377	1,939	100%	6,197	2,234	100%

- IRP is preparing the official % of each source
- Target is energy (MWh) base, not output (MW) base
- Demand growth needs to be considered
- MW of each generation source depends much on capacity factor
- With IRENA capacity factor, 39% thermal and 61% RE will achieve 50% RE

Characteristics of VRE



Wind Output


PV output

Wind
- Unpredictable generation output change
- produce ramps according to weather condition
- Depending on geographic areas, fluctuation comes at once if it installed in the same valley

PV
- No output in night-time and rainy day
- Large fluctuation in tropical climate (likely to change 80% in a minute)

Both (VRE):
- It does not always generate when needed. **Load-supply matching** is an issue
- Time coincidence of VRE, there can be times when there is too much supply. Curtailment of VRE is necessary →**energy storage/control cost need to be considered.**

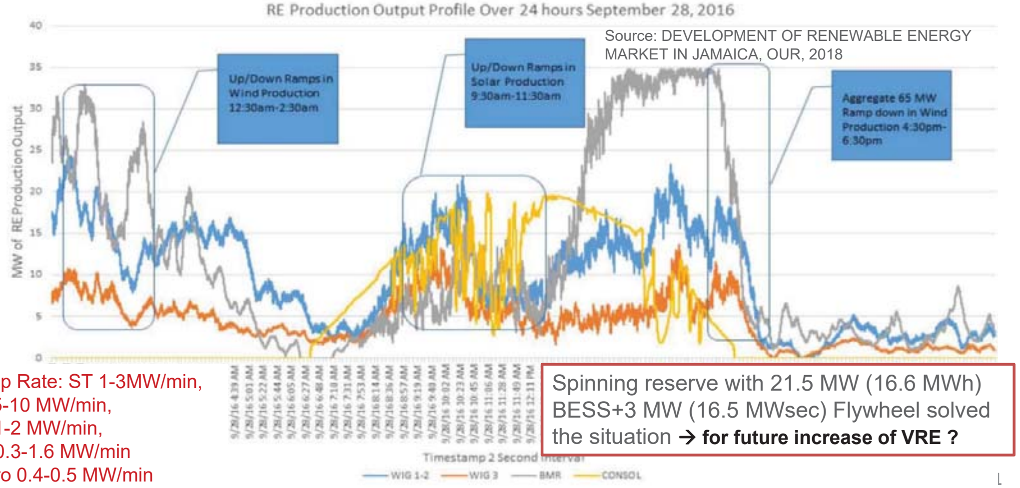
Caribbean Islands:
- Lower cost than tariff →rapid private investment
- Limited area for transmission
- Frequent change of weather condition
- Limited stable RE (hydropower/geothermal)

Challenges for
- **Cost for stability** : who covers?
- Technical and regulatory matters

RE: Grid Stability Issue with VRE in Jamaica

Grid Stability issues due to significant VRE fluctuation

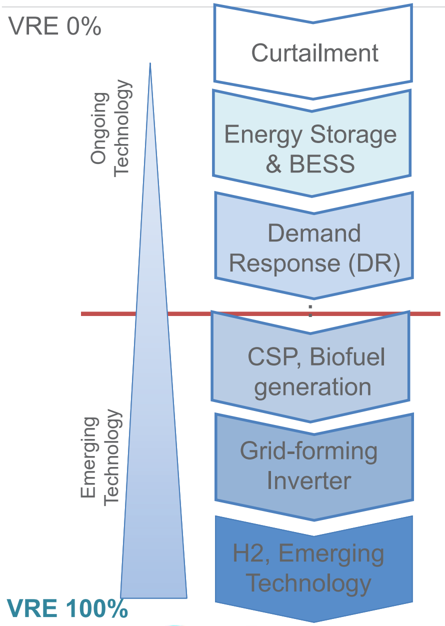
- Limitation of generating units, unable to ramp fast to counter rapid variations in VRE
- Adverse effect on Heat Rate (Efficiency) and increase of production cost
- Part-load operation of generating units, increasing emissions and reducing operating life of equipment
- Impacts System reliability, security, stability and power quality



Ramp Rate: ST 1-3MW/min, GT 5-10 MW/min, CC 1-2 MW/min, DG 0.3-1.6 MW/min Hydro 0.4-0.5 MW/min

Spinning reserve with 21.5 MW (16.6 MWh) BESS+3 MW (16.5 MWsec) Flywheel solved the situation → **for future increase of VRE ?**

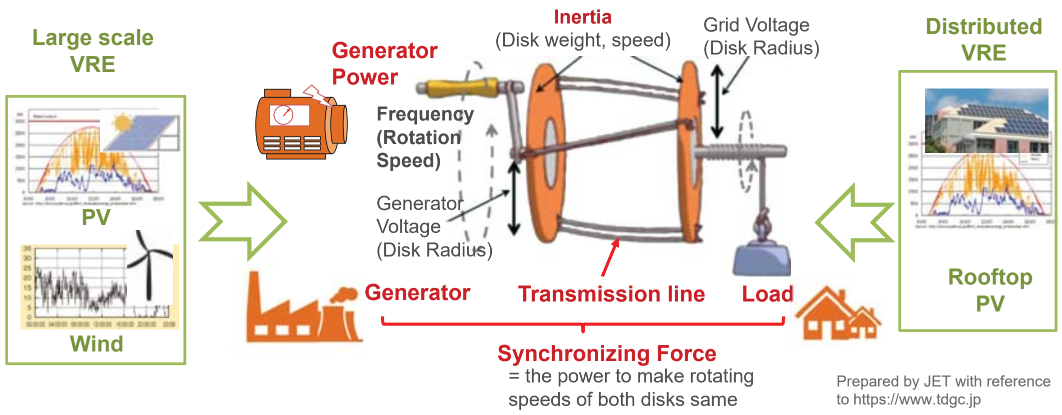
Arrangement toward 100% RE



Voltage and frequency Stabilization
- Curtailment of VRE energy in PCS to make grid stables, smart inverter
- **Governor Free (GF), Economic Load Dispatch (ELD), Load Frequency Control (LFC)**
- **Energy storage: Battery, flywheel**
- **Synchronous condenser, Statcom**
- EV charging time shift
- Demand side management
- Regulatory framework change, **review of grid code**

Insufficient Inertia, Synchronizing Force
- **Battery-Motor generator set**
- **Biofuel (diesel, jet) for DG**
- CSP (Concentrated Solar Thermal Power)
- Gravitational Power
- **Grid forming Inverter**
- H2 generation from RE by electrolysis
- Seasonal large scale storage

Inertia and Synchronizing Force with RE



Prepared by JET with reference to https://www.tdgc.jp

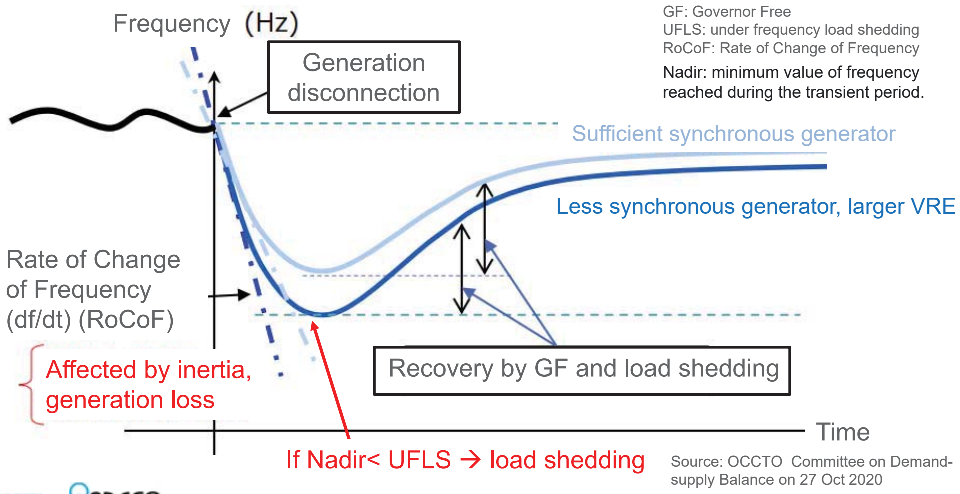
Inertia: The force to keep the rotation of disk when load is changed
Synchronizing Force: The force to keep rotation speed of disks. It keeps back to the same rotation when generation power and load is varied, without entangling.

Fluctuation of large scale VRE affects to generator at generation side and load side
→ Inertia and Synchronizing Force need to be enhanced for grid with large VRE

Inertia and Synchronizing Force with RE

Synchronous generator: The power source establishes voltage and frequency with reactive power, and combines with generators by synchronizing force
VRE/BESS with inverter: DC converted to AC. There is no rotation, no synchronizing force. It monitors grid AC voltage and wave and adjust accordingly → no contribution for stability

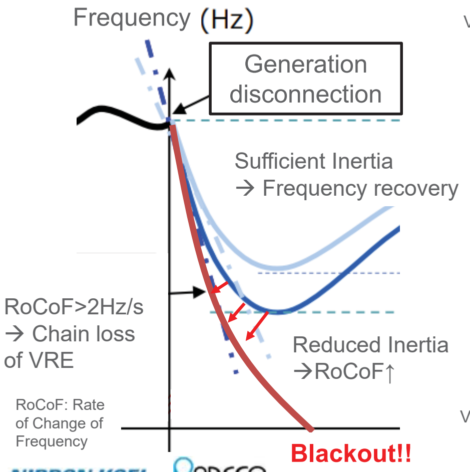
GF: Governor Free
UFLS: under frequency load shedding
RoCoF: Rate of Change of Frequency
Nadir: minimum value of frequency reached during the transient period.

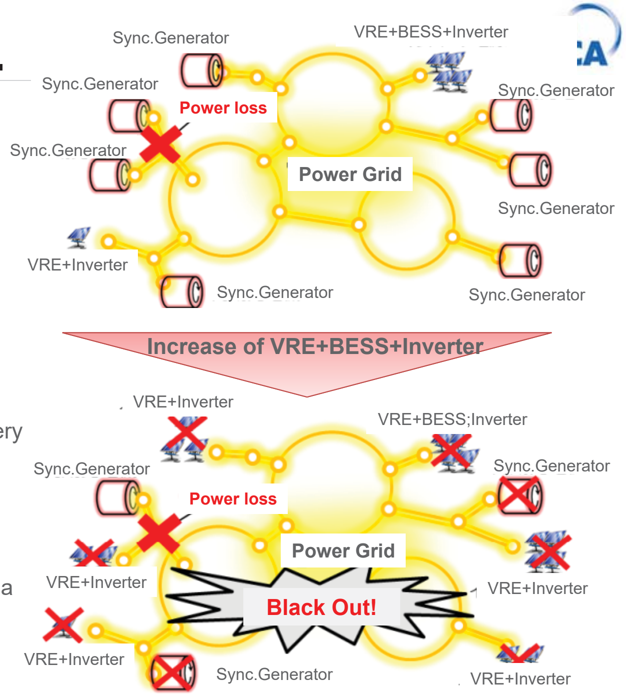


Source: OCCTO Committee on Demand-supply Balance on 27 Oct 2020

Black-out when insufficient Sync. Gen.

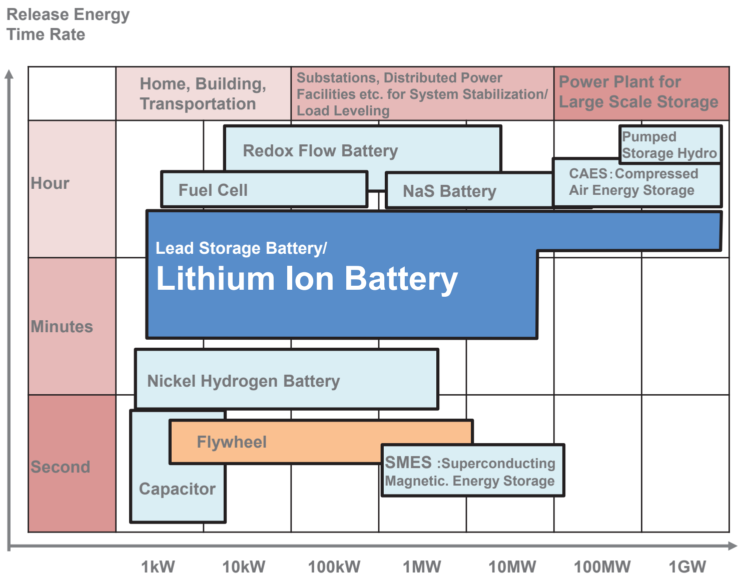
If synchronous generator is reduced and inertial is not sufficient, power loss
→ Frequency drop, with no recovery
→ Chain reaction of loss of VRE
→ **Black out**

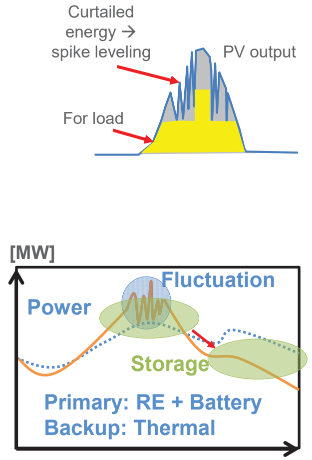




Source: Transmission and Grid Council, Japan

Battery and Energy Storage
Positioning for Energy Storage Technology





Source: NEDO Renewable Energy Technology White Paper Chapter 9

Feedback: What is Cost of grid stability based on various RE?

Cost of comparison of Grid Stability for various RE

Cost of stability is depending on plant factor and fluctuation of VRE
- lower plant factor requires large battery storage size (inverse proportion)
- larger and more rapid fluctuation requires larger ramp rate of spinning reserve and battery discharge speed
- Smaller cost of kW output requires larger cost of grid stability
- Total cost of RE and grid stability needs to be considered in planning

→ RE cost is site specific. F/S for respective project is necessary.

	Total installed costs (2021 USD/kW)			Capacity factor (%)			Levelised cost of electricity (2021 USD/kWh)		
	2010	2021	Percent change	2010	2021	Percent change	2010	2021	Percent change
Bioenergy	2 714	2 353	-13%	72	68	-6%	0.078	0.067	-14%
Geothermal	2 714	3 991	47%	87	77	-11%	0.050	0.068	34%
Hydropower	1 315	2 135	62%	44	45	2%	0.039	0.048	24%
Solar PV	4 808	857	-82%	14	17	25%	0.417	0.048	-88%
CSP	9 422	9 091	-4%	30	80	167%	0.358	0.114	-68%
Onshore wind	2 042	1 325	-35%	27	39	44%	0.102	0.033	-68%
Offshore wind	4 876	2 858	-41%	38	39	3%	0.188	0.075	-60%

Source: RENEWABLE POWER GENERATION COSTS IN 2021 (IRENA)

Cost of comparison of Grid Stability for various RE

RE Source	Capacity factor	Fluctuation	USc/kWh	Availability	Cost for stability	Remark
PV	13-18%	High	4-10	Everywhere	Highest. Need spinning reserve and battery for rain day/night time	Lowest generation cost, Highest stability cost
CSP	30-80%	No	15-40	Limited	Zero	Emerging technology
Wind	25-50%	High	5-15	Limited potential area	Need spinning reserve/battery	Cost can be reduced by smoothing in wide area installation
Geothermal	- 95%	No	15-20	Quite limited	Zero or negative, as base load. Ramp rate : 20%/min of output	Ideal
Hydro	10-90%	No	4-20	Very limited	Negative, as spinning reserve . Ramp rate: 10-30%/min	Seasonal fluctuation of water availability
Biomass	20-80%	No	8-20	Limited by Feedstock	Zero. Ramp rate: 1-4%/min	Depends on feedstock availability
Biofuel	0-80%	No	20-40	Need import .	Negative. It can be used as spinning reserve. Ramp rate: 20%min	Fuel cost is high
Biogas	20-90%	No	10-20	Limited	Negative. Best as spinning reserve. Ramp rate: 50%/min of output	Depends on tank size and feedstock

3rd Seminar on Grid Stability and Large RE
on line session

3. Grid Scenario proposed in 2nd seminar and stability analysis
   - Proposed Scenario Cases Analysis and Recommendation for the Penetration of RE
4. Development Status of Grid Forming Inverter and its Safety
   - Current Status
   - Blackout with GFM & Black Start using BESS
5. Transmission lines and Remedial Action Schemes
   - Special Protection System including Load Shedding, PV/WT Trip

6. Microgrid planning
   - Grid Stability Analysis

8. Policy recommendation
   - Recommendation for Jamaica Grid Code

Keep grid stable with good quality of electricity under penetration of Renewable Energy
-> Grid Forming Inverter(GFM)

Normal State

Special Protection System

Security Assessment
Preventive Control
-> Restructuring
-> Operation Planning

Fault

Security Control
Collective Control
-> Generator Trip
-> Load Shedding

Emergency State

Blackout

Black Start using BESS

3. Grid Scenario proposed in 2nd seminar and stability analysis

In the answer of Q3 of the 2nd Seminar on Grid Stability and Large RE, the following future 50% renewable energy grid scenarios of Jamaica were proposed.

Rate is described as --
PV: Wind: WtE: Hydrogen: Nuclear: Battery: Hydro(including Pumped Storage

A) 33: 20: 7: 10: 30: 0: 0[%] (total 100%)
B) 70: 30: 0: 0: 0: 0: 0[MW] (total 300MW)
C) 6: 7: 3: 0: 25: 3:15[%] (total 59%)
D) 150:100:20:200: 0: 0: 0[MW] (total 470MW)
E) 30: 10: 0: 0: 0: 0: 0[%] (total 40%)
F) 15: 15: 5: 0: 0: 0: 14[%] (total 49%)
G) 150:100: 0: 0: 0: 0: 0[MW] (total 250MW)
H) 100:200: 0: 0: 0: 0: 0[MW} (total 300MW)

Proposed Grid Scenario Cases for stability analysis

Selected future grid scenarios
%value means the capacity in MWh of a year.

No.1 -- PV:30%, Wind:10%, Hydro:10%	Average of A-H proposed
No.2 -- PV:50%	All PV
No.3 -- PV:15%, Wind:15%, Hydro:10%, Biofuel:10%	PV and Wind are equal
No.4 -- PV:25%, Wind: 5%, Hydro:10%, Biofuel:10%	PV is larger Wind
No.5 -- PV: 5%, Wind:25%, Hydro:10%, Biofuel:10%	Wind is larger PV

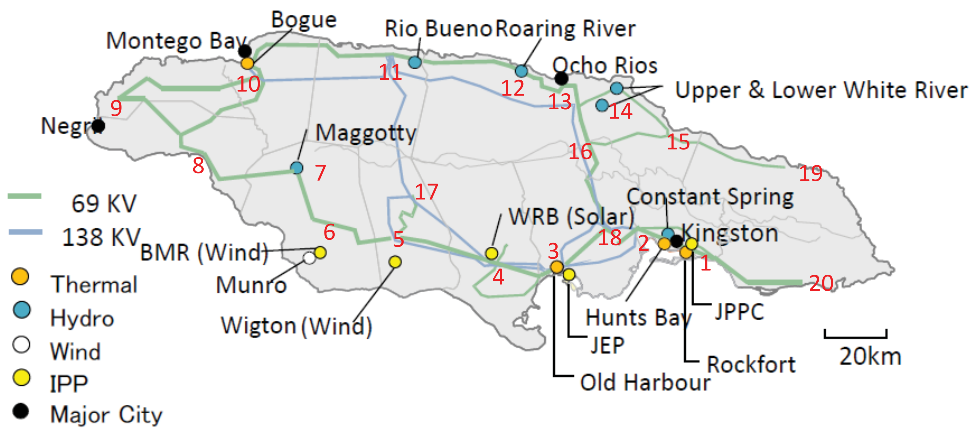
No.3-5 include Hydro and Biofuel
Listed value means the installed rate of MWh in a year.

From the annual total capacity of MWh in Jamaica, each RE' s capacity in MWh per year is calculated.
Next, capacity of each RE in MW can be obtained by dividing with capacity factor and total hours in a year,
Table shows the capacity of RE in MW in the case of proposed grid scenario.

In transient stability analysis, the event of three phase grounding fault at Hunts Bay 69kV bus is set at 1 seconds after simulation starts, and the fault is successfully cleared after 0.1 seconds for 5 cycles after the fault.

Grid of Jamaica

Grid structure and each impedance of transmission lines are obtained from the map used in the presentation document of JPS(Jamaica Power Sector) on May 27, 2019.

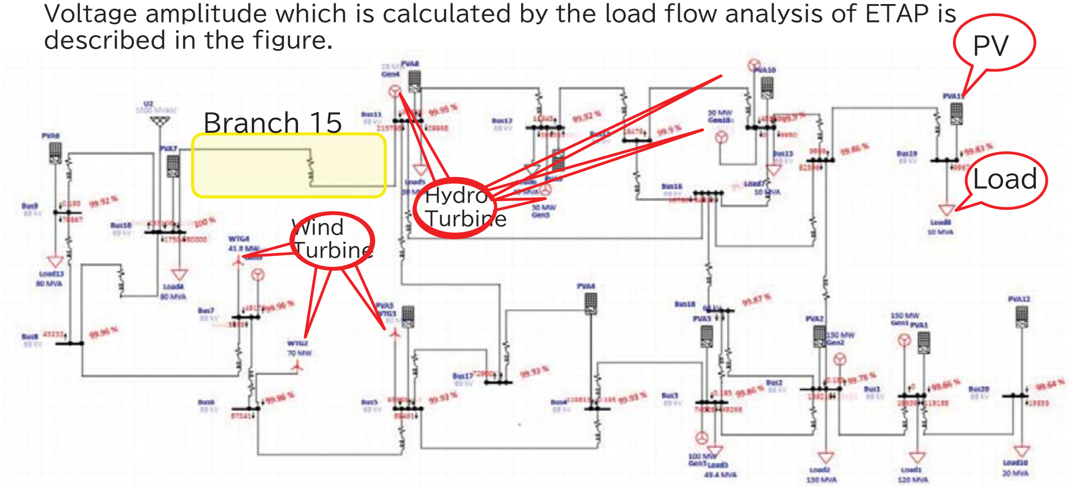


Red number is node number for power system analysis.

Load Flow Analysis of Jamaica Grid

The steady state load flow is analyzed by using Microgrid Designer and ETAP, according to the grid structure and each impedance of transmission lines obtained from the map used in the presentation document of JPS(Jamaica Power Sector) on May 27, 2019.

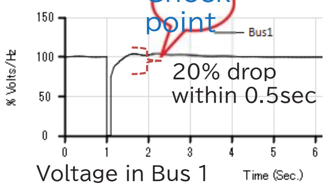
The following figure is the single line diagram of Jamaica grid.
Voltage amplitude which is calculated by the load flow analysis of ETAP is described in the figure.



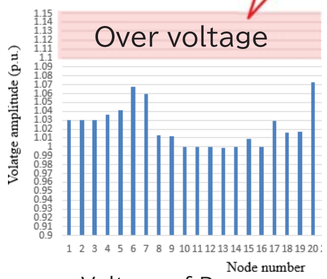
Case Study of Proposed Energy Mix
No.1 -- PV:30%, Wind:10%, Hydro:10% in MWh/year

Category	Capacity factor 2020 Jamaica	Capacity factor IRP2020	Capacity factor IRENA	2021 GWh	GWh target %	2030 GWh	2030 MW	2030 MW %
Fossil Fuel	44%	54%	41%	4,092	50%	2,689	748.6	33%
Total RE				640	50%	2,689	1,537	67%
Hydro	37%	61%	52%	136	10%	538	118.0	5%
Solar	11%	21%	15%	124	30%	1,613	1,227.6	54%
Wind	23%	38%	32%	280	10%	538	191.8	8%
Bioenergy	25%	95%	36%	100	0%	0	0.0	0%
Total				4,732	100%	5,377	2,286	100%

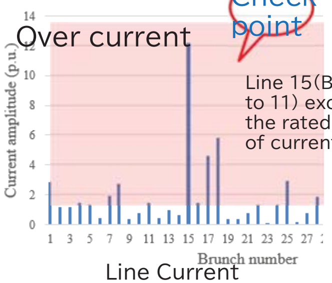
This is the typical case proposed in the 2nd seminar's feedback data.



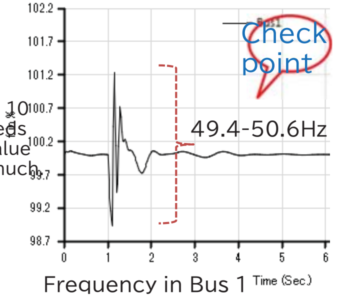
Voltage in Bus 1



Voltage of Buses



Line Current



Frequency in Bus 1

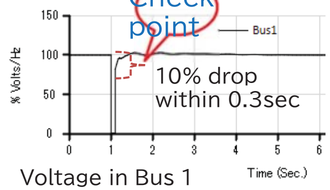
Load Flow Analysis by Microgrid Designer

Transient Stability Analysis by ETAP

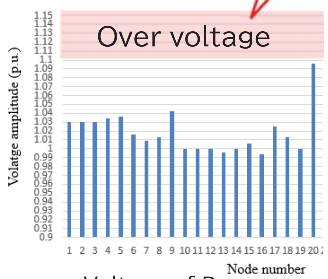
Case Study of Proposed Energy Mix
No.2 -- PV:50% in MWh/year

Category	Capacity factor 2020 Jamaica	Capacity factor IRP2020	Capacity factor IRENA	2021 GWh	GWh target %	2030 GWh	2030 MW	2030 MW %
Fossil Fuel	44%	54%	41%	4,092	50%	2,689	748.6	27%
Total RE				640	50%	2,689	2,046	73%
Hydro	37%	61%	52%	136	0%	0	0.0	0%
Solar	11%	21%	15%	124	50%	2,689	2,046.1	73%
Wind	23%	38%	32%	280	0%	0	0.0	0%
Bioenergy	25%	95%	36%	100	0%	0	0.0	0%
Total				4,732	100%	5,377	2,795	100%

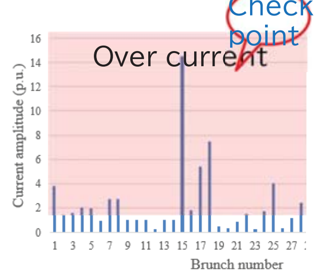
50% of total capacity is provided by PV. Much PV causes the large fluctuation of frequency but not voltage.



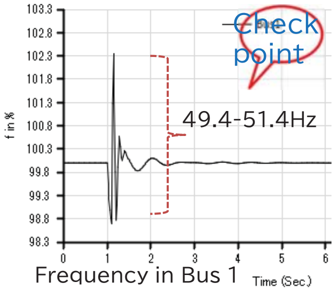
Voltage in Bus 1



Voltage of Buses



Line Current



Frequency in Bus 1

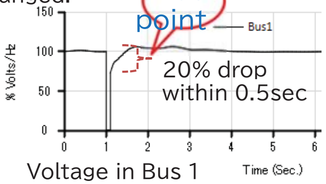
Load Flow Analysis by Microgrid Designer

Transient Stability Analysis by ETAP

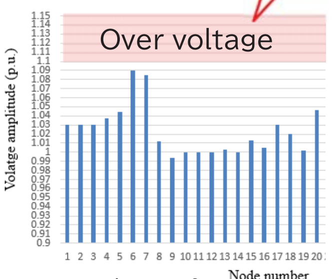
Case Study of Proposed Energy Mix
No.3 -- PV:15%, Wind:15%, Hydro:10%, Biofuel:10% in MWh/year

Category	Capacity factor 2020 Jamaica	Capacity factor IRP2020	Capacity factor IRENA	2021 GWh	GWh target %	2030 GWh	2030 MW	2030 MW %
Fossil Fuel	44%	54%	41%	4,092	50%	2,689	748.6	39%
Total RE				640	50%	2,689	1,190	61%
Hydro	37%	61%	52%	136	10%	538	118.0	6%
Solar	11%	21%	15%	124	15%	807	613.8	32%
Wind	23%	38%	32%	280	15%	807	287.7	15%
Bioenergy	25%	95%	36%	100	10%	538	170.5	9%
Total				4,732	100%	5,377	1,939	100%

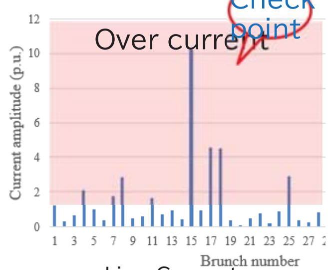
No. 3-5 shows the cases which hydro and biofuel are installed, and ratio of PV and wind is changed.



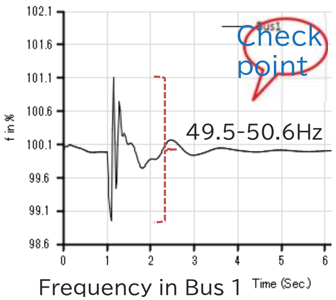
Voltage in Bus 1



Voltage of Buses



Line Current



Frequency in Bus 1

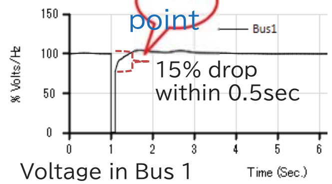
Load Flow Analysis by Microgrid Designer

Transient Stability Analysis by ETAP

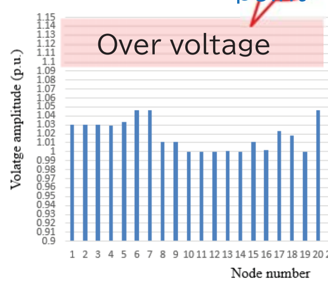
Case Study of Proposed Energy Mix
No.4 -- PV:25%, Wind:5%, Hydro:10%, Biofuel:10% in MWh/year

Category	Capacity factor 2020 Jamaica	Capacity factor IRP2020	Capacity factor IRENA	2021 GWh	GWh target %	2030 GWh	2030 MW	2030 MW %
Fossil Fuel	44%	54%	41%	4,092	50%	2,689	748.6	35%
Total RE				640	50%	2,689	1,407	65%
Hydro	37%	61%	52%	136	10%	538	118.0	5%
Solar	11%	21%	15%	124	25%	1,344	1,023.0	47%
Wind	23%	38%	32%	280	5%	269	95.9	4%
Bioenergy	25%	95%	36%	100	10%	538	170.5	8%
Total				4,732	100%	5,377	2,156	100%

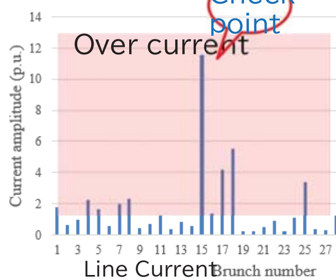
PV keeps voltage within the rated value.



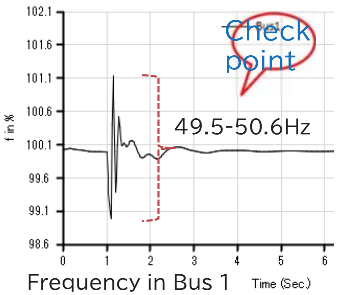
Voltage in Bus 1



Voltage of Buses



Line Current



Frequency in Bus 1

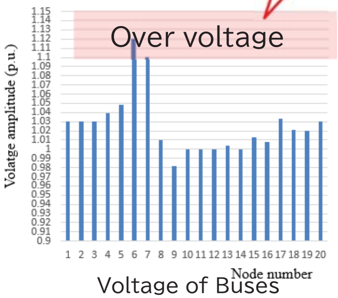
Load Flow Analysis by Microgrid Designer

Transient Stability Analysis by ETAP

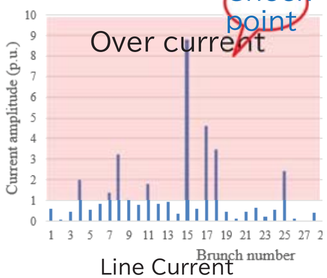
Case Study of Proposed Energy Mix
No.5 -- PV:5%, Wind:25%, Hydro:10%, Biofuel:10% in MWh/year

Category	Capacity factor 2020 Jamaica	Capacity factor IRP2020	Capacity factor IRENA	2021 GWh	GWh target %	2030 GWh	2030 MW	2030 MW %
Fossil Fuel	44%	54%	41%	4,092	50%	2,689	748.6	43%
Total RE				640	50%	2,689	973	57%
Hydro	37%	61%	52%	136	10%	538	118.0	7%
Solar	11%	21%	15%	124	5%	269	204.6	12%
Wind	23%	38%	32%	280	25%	1,344	479.5	28%
Bioenergy	25%	95%	[illegible]	[illegible]	10%	538	170.5	10%
Total				[illegible]	100%	5,377	1,721	100%

Wind power causes the increase of voltage because of high capacity. But fluctuation of frequency is low.

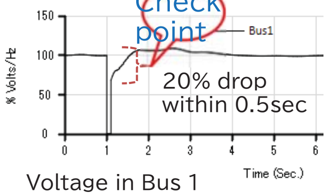


Voltage of Buses

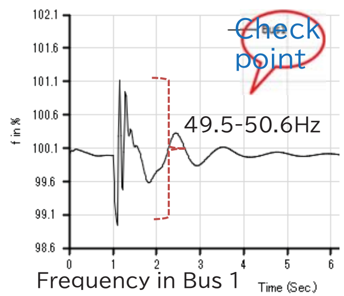


Line Current

Load Flow Analysis by Microgrid Designer



Voltage in Bus 1



Frequency in Bus 1

Transient Stability Analysis by ETAP

Evaluation and Measurement of Case Studies

<Load Flow Analysis>

- Node voltage except for node 6 in Case 5 is within +-10% of rated value.
- Node 6 in Case 5 is over 10% of rated value, because the capacity of wind turbine is large.
  -> DVS or STATCOM should be installed to node 6 to control node voltage.
- Line 15, transmission line between Bogue and Rio Bueno, exceeds the rated value of line current, because output of hydro turbine generator in Rio Bueno flows a lot to Bogue. -> The capacity of transmission line should be increased by upgrading voltage or installing double circuit to transmission line.

<Transient Stability Analysis>

- All cases are stable in the case of 3 phase grounding fault for 100 msec.
- Fluctuation of voltage and frequency are acceptable except for Case 2 and 5. -> BESS should be installed at nodes which has PV. As for in Case 5, the capacity of transmission line needs to be increased by upgrading voltage or installing double circuit transmission line connected to wind power.
- For Case 1 to 5, Voltage at node 1 drops 10-20% from the rated voltage within 0.5 sec. This voltage drop is considered to be acceptable if FRT(Fault Ride Through) function is equipped to an inverter of the wind turbine. The above voltage fluctuation is within the limit of FRT.

Evaluation and measurement of Case 1 to 5

Case No.	RE Resource Ratio (% of MWh/year)	Evaluation of Load Flow Analysis	Evaluation of Transient Stability Analysis
1	PV:30%, Wind:10%, Hydro:10%	Voltage is within +-10% of rated value.	Node 1 has 20% drop of voltage after fault. Fluctuation of voltage and frequency are acceptable.
2	PV:50%	Voltage of east end node is high, but acceptable within +-10% of rated value.	Fluctuation of frequency after fault exceeds by +-0.5Hz from the base frequency.
3	PV:15%, Wind:15%, Hydro:10%, iofuel:10%	Voltage of west end node is high , but acceptable within +-10% of rated value.	Node 1 has 20% drop of voltage after fault. Fluctuation of voltage and frequency are acceptable.
4	PV:25%, Wind:5%, Hydro:10%, iofuel:10%	Voltage is within +-10% of rated value.	Fluctuation of frequency after fault is about +-0.5Hz from the base frequency.
5	PV:5%, Wind:25%, Hydro:10%, iofuel:10%	Voltage of west end node is more than 10% from rated voltage.	Node 1 has 20% drop of voltage after fault. Fluctuation of frequency after fault exceeds +-0.5Hz from the base frequency.

Feedback from 2nd Seminar on Grid Stability and Large RE

This section is a feedback and request of current states of the development of Grid Forming Inverter (GFM) and safety condition of GFM

4. Development Status of Grid Forming Inverter and its Safety

Lot of companies are developing grid forming inverter, but products are not provided into market.

<Current project for the development of GFM>

- GFM Projects in Japan
  - STREAM: New Energy and Industrial Technology Development Organization(NEDO) project with **Tokyo Electric Power Co. (TEPCO), National Institute of Advanced Industrial Science** and Technology(AIST)
- GFM projects in the world
  - Europe Union(EU): OSMOSE, MIGRATE, Smart Net
    Grid Code: National Grid GC0137, VDE2020
  - USA: SuNLaMP, SETO
    Grid Code: IEEE2800-2022, NERC IRPS, UNIFI

OSMOSE : https://www.osmose-h2020.eu/
MIGRATE : https://www.h2020-migrate.eu/
SmartNet : https://smartnet-project.eu/

National R&D project in 2019-2021 in Japan

Next-Generation Power Network Stabilization Technology Development for Large-Scale Integration of Renewable Energies

Project of NEDO (New Energy and Industrial Technology Development Organization) 2019-2021 (Partially last to 2023)

The development of Grid Forming Inverter is one of the subject of Item 3 in the following 4 items of this project.

Item1: Development of control units for Japanese connect and manage grid (last to 2023)

Item2: Development of control method to cope with decrease in inertia using phasor measurement unit

Item3: Development of optimal method to control voltage and power flow in distribution system with IBR

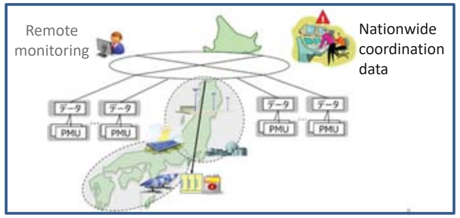
Item4: Development of optimal islanding detection method in high voltage distribution system

https://www.nedo.go.jp/english/activities/activities_ZZJP_100150.html

National R&D project in 2019-2021 in Japan

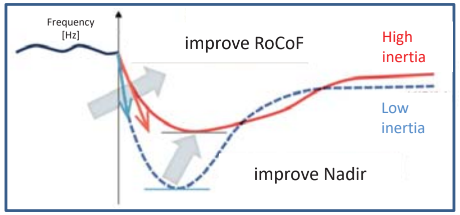
Item 3: Development of basic technology to cope with decreases in inertia (Scope)

① R&D for real-time inertial estimation



Develop the inertia monitoring system

② R&D for inverter-based synthetic inertia



Develop countermeasure for low inertia

Cf. TEPCO report

■ **Scope:**

- R&D for the inverter-based synthetic inertia.
  - ✓ Option 1: Add a new function to the legacy **Grid-following Inverter (GFL)**
  - ✓ Option 2: Develop the novel **Grid-Forming Inverter (GFM)**
- Development of simulation model and evaluation of inverter-based synthetic inertia capability.

https://www.nedo.go.jp/english/activities/activities_ZZJP_100150.html

National R&D project in 2022-2026 in Japan

STREAM Project

Future-generation power network Stabilization Technology development for utilization of Renewable Energy As the Major power source

Project of NEDO (New Energy and Industrial Technology Development Organization)

- Development of Inverter Based Resources(IBR) as Measure against Low Inertia Grid (Group1-3)
  - Test Grid Forming Inverters Produced by 4 models and 5 functions
  - Show the revised proposal of grid code for Grid Forming Inverter(GFM) to Organization for Cross-regional Coordination of Transmission Operators(OCCTO)
- Development of Grid Forming Inverter(GFM) for Microgrid with Renewable Energy for major power source

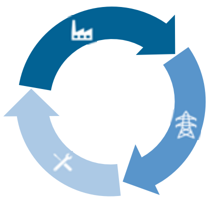
STREAM Project overview of Group1 and Group2

Group1 Development of Inverter-based Countermeasures for low system inertia (TEPCO Holding(HD), TEPCO Power Grid(PG), AIST)

- Requirement and specification study.
- Design & development of Prototype.
- 3 venders for battery storage inverter and 1 institute with vender for PV inverter.

Group2 Validation and testing (TEPCO HD, TEPCO PG, CRIEPI, AIST, JET)

- Study for Key Performance Indicator(KPI), Lab/Field testing, and certification of grid forming inverter.



Laboratory testing
- Development of test procedure achieving certification.
- Impact assessment of new function with Virtual(HIL) testing technologies

Demo field testing
- Testing on full-scale distribution systems
- Remaining test that lab testing do not cover

Prototype improvement
- Grid interconnection testing and conformance to requirements
- Revision of inverter requirements

Lab testing: Smart System Research Facility, AIST

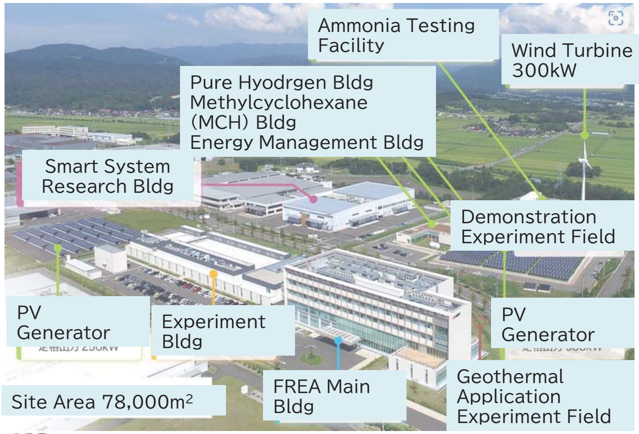
Demo field testing: Akagi testing Center, CRIEPI

Output
- The standard for equipment specifications
- Data/report for revision of Grid Code

TEPCO:Tokyo Electric Power Co.
CRIEPI:Central Research Institute of Electric Power Industry
AIST: Advanced Industrial Science and Technology
JET:Japan Electric Safety & Environment Technology Laboratory

The Fukushima Renewable Energy Institute, AIST (FREA)

National Institute of Advanced Industrial Science and Technology(AIST) established the Fukushima Renewable Energy Institute in Koriyama, Fukushima Prefecture in April 2014, to promote R&D into renewable energy.
The Fukushima Renewable Energy Institute, AIST (FREA) has two basic missions:
(1) Promotion of R&D into renewable energy, which is open to the world as a novel research base to develop innovative technologies in collaboration with domestic and international partners.
(2) To make a contribution to industrial clusters and reconstruction



Smart System R&D Test Platform (FREA-G)

One of the world largest testing facility for Smart Grid
Grid Forming Inverter is tested for development worldwide here.

A. Grid Connection Test Bed

- Compatible with worldwide interconnection test for DER (Fault-Ride-Through, anti-islanding, etc.) with grid simulator.
- Grid simulator is a programmable AC source that emulates grid characteristics to evaluate performance and reliability of grid-connected equipment.
  - Maximum capacity of Grid simulator: 5 MVA
  - PV and Battery emulator: 3.3 MW up to 2000V
  - Inverter testing capability: up to 3 MW

B. Safety Test Bed

- Emulate realistic temperature and humidity environment to evaluate safety and long-term reliability of grid-connected equipment. e.g., thermal cycle and humidity freeze test, surge voltage test, etc.
- Other safety testing e.g., surge voltage test

C. EMC Test Bed

- Testing for electromagnetic radiation from/to grid-connected equipment.

D. System Performance Test Bed

- Evaluate multiple system level DER capabilities e.g., microgrid lab-based demonstration, energy management system (EMS) testing such as DERMS, VPP, etc.

Black Start using BESS for Grid

This is a feedback about question of the way to supply power to the grid when the grid power goes off.

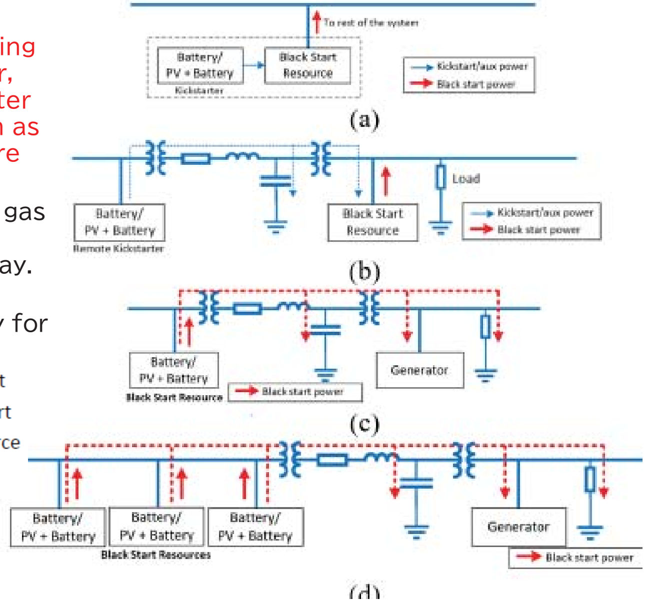
In order to continue to supply electricity for large grid, Grid Forming Inverter(GFM) can be a kick starter, when black start will be applied after blackout, if energy resources, such as charged battery, battery with PV are available with GFM.

If not, hydro turbine generators or gas turbine generators excited by permanent magnet is alternative way.

NREL(National Renewable Energy Laboratory), USA proposes the way for black start using GFM in 4 ways.

(a). Config. 1: On-site Kick-Starter for a Blackstart
(b). Config. 2: Remote Kick-Starter for a Blackstart
(c). Config. 3: Fully Functional Black-Start Resource
(d). Config. 4: Collective Blackstart

BlackstartH. Jain, G. Seo, E. Lockhart, V. Gevogian and B. Kroposki, "Blackstart of Power Grids with Inverter-Based Resources, IEEE 20PESGM1199



Black Start using BESS for Microgrid

This is a feedback about question of the way to supply power to the grid when the grid power goes off.

Grid Forming Inverter(GFM) can be a main electricity resource for black start.

Prime generators are:

GFM + battery (if it is enough to be charged)
GFM + battery + PV

This section is a feedback and request of example of special protection system (SPS) with RE and impact of load shedding of feeders with PV penetration

5. Transmission lines and Remedial Action Schemes

- Special Protection System(SPS) including Load Shedding, PV/WT Trip -

<Before Fault>

Security Assessment, Remedial Action Scheme

About 1000 N-1 case simulation is required to predict future accident and measurement by load flow analysis and transient stability analysis

If severe accident is predicted, its measurement to avoid is planned and operated.

<Required Technologies>

State Estimation for covering unknown data
Screening for choosing severe cases from thousands of N-1 cases
Security Assessment for evaluating possible unstable cases

Remedial Action Schemes
- Special Protection System(SPS) including Load Shedding, PV/WT Trip -

<After Fault> installed in JPS

Security Control, Contingency Control

Transient stability analysis is using current data collected from grid after fault accidents

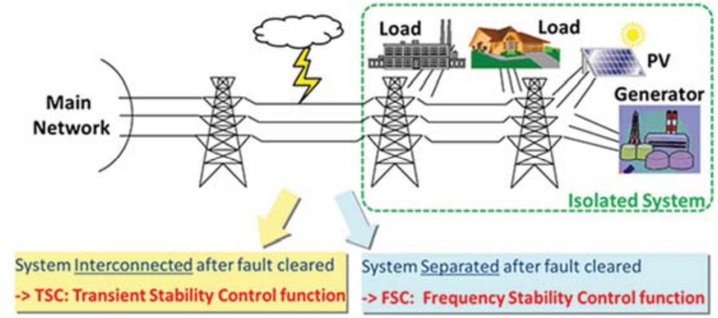
High speed simulation which is faster than real time action is required in order to predict and avoid more severe accidents caused after faults.

<Actions for SPS>

- Trip of Synchronous Generator
- Control of Connection and Output of PV and Wind Turbine
- Shedding of Load
- Operation of Circuit Switch or Closer

Trunk Transmission Integrated Stability Control System (ISC) -Overview-

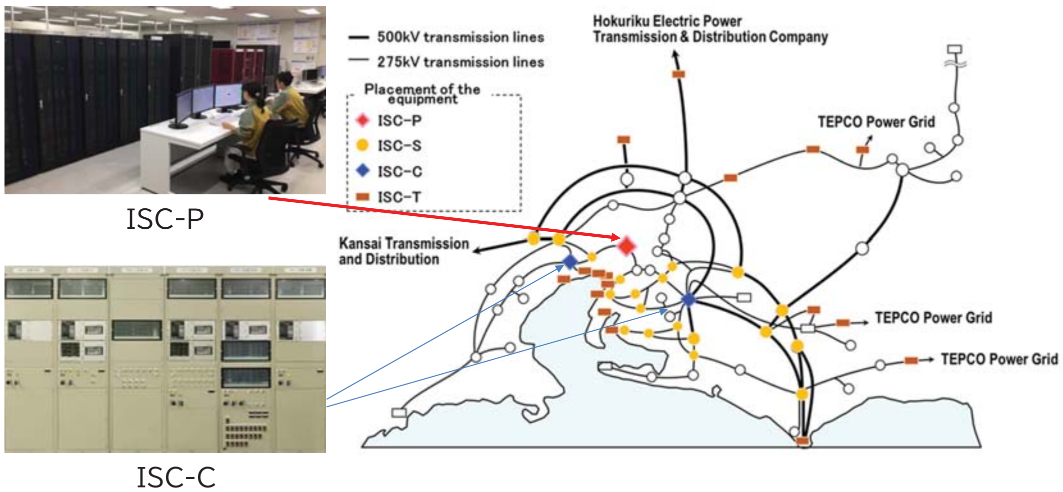
- When a fault occurs in the power system, the ISC system trips the unstable generators and control switch gear instantly according to the results of calculated transient stability analysis of the system.
- When a grid separation is detected in the power system, the ISC system trips the surplus generators or sheds the demand according to the solution of frequency stability analysis.
- The ISC system recognizes the power system configuration in real time and automatically change several operation settings.



https://powergrid.chuden.co.jp/english/technical/operation/isc/

Trunk Transmission Integrated Stability Control System (ISC) -Allocation of control stations-

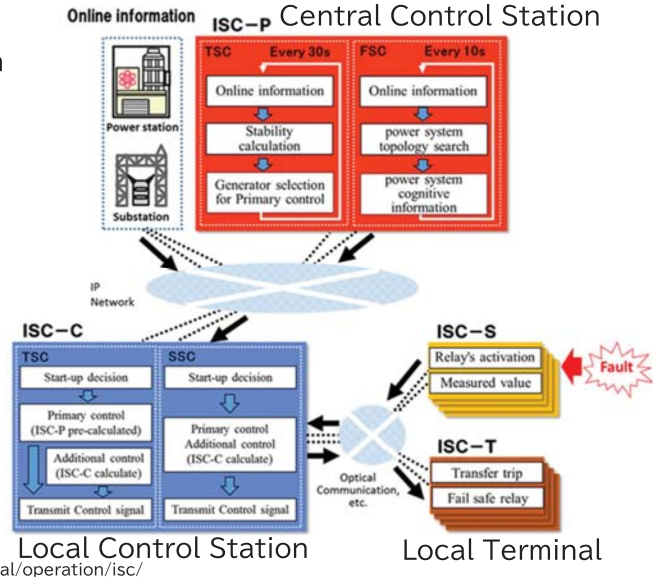
Control stations and terminals are located in wide area of the grid.



https://powergrid.chuden.co.jp/english/technical/operation/isc/

Trunk Transmission Integrated Stability Control System (ISC) -Function of control stations-

- **Master control station (ISC-P) : for Precalculation**
  - The system will conduct grid transient stability calculation every 30 seconds for more than 1000 N-1 fault cases, and inform operators within a certain minutes in case significant accident is likely to occur.
- **Local control station (ISC-C) : for Postcalculation**
  - The system calculates the transient stability of present grid condition. In case unstable case is occurred, countermeasure is directed that can minimize affect of fault.

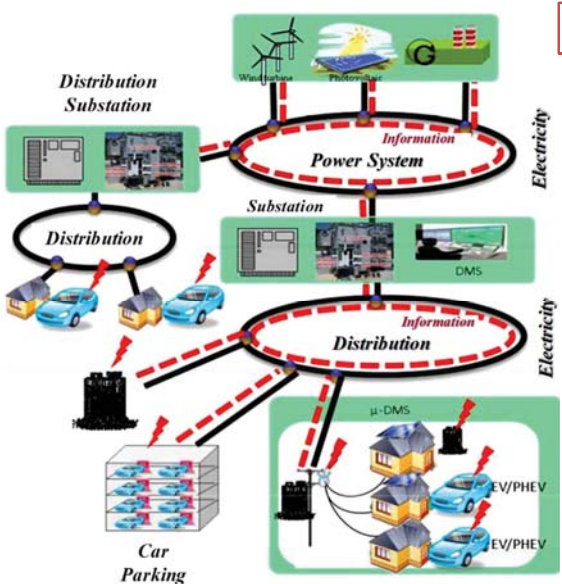


https://powergrid.chuden.co.jp/english/technical/operation/isc/

Agenda

1. Opening Remark
2. Project outline, Review and Feedback of 2nd Seminar
3. Grid Scenario proposed and stability analysis
4. Development Status of Grid Forming Inverter and its Safety
   - Current Status, Blackout with GFM & Black Start using BESS
5. Transmission lines and Remedial Action Schemes
   - Special Protection System, PV/Wind Turbine Trip
6. Microgrid planning
7. Technology options
8. Policy recommendation
9. Discussion, sharing good practice of Jamaica, and way forward

Microgrid Concept



Source: Smart City Development and Recent trend in Electric Power Network, Waseda Univ.

Concept of Micro-grid

- ✓ Respective Micro-grid is connected each other, and each Micro-grid can work independently
- ✓ Local energy production for local consumption
  - ✓ Generation: PV, wind, biomass, DG, GT, battery, etc.
  - ✓ Demand: industry, commercial, home, EV, etc.
- ✓ No transmission → loss saving
- ✓ With IoT, control system, EMS, demand response, smart meters
- ✓ Enhance resiliency

Microgrid Planning

1	**Study for legal requirement of regulators considering affect on transmission line outside of Microgrid**	- Legal requirement for microgrid by the regulatory authority - Method for emergency recovery, switching from microgrid to master grid, Affect on adjacent areas.
2	**Estimation of load and demand at peak condition in Microgrid**	- Estimate demand of daily curve, total demand of the day/week / year, at peak condition, abnormal condition
3	**Plan for system structure of Microgrid in distribution lines based on demand**	- Determination of capacity of generation system, design, selection of equipment. - Preparation for emergency (load shedding, control, etc.) - Protection and control method considering supply and demand
4	**New system installation/enhancement for stabilization facility requirement for RE and supply-load balancing**	- Plan RE facility with energy storage based on demand - Consider necessary stabilization equipment considering fluctuation and output instability. - Grid plan: Load flow analysis and transient analysis
5	**System requirement and legal confirmation for inside and outside Microgrid**	- Review regulation and rules including grid code for connection to transmission line - Operation method at the time of emergency recovery and minimize outage
6	**Finalization of system configuration and specification for whole Microgrid**	- Based on supply-load balance, finalize system configuration &Spec - Operation and EMS development, communication system

Microgrid Planning : Analysis for Stability

Grid Investment plan:
(Capacity of grid with planned RE)
→ Power Flow Analysis

Additional RE power to grid :
Is current grid capacity enough to accommodate planned RE?
→ **Power Flow Analysis** is necessary to confirm :
- if grid capacity can accommodate RE
- to check if active / reactive power, voltage is acceptable

The steady state with most severe case (maximum power) is applied → grid modification plan to be prepared

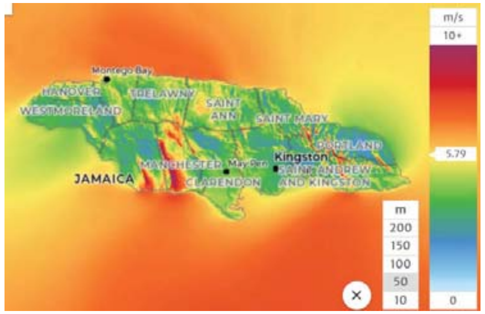
Grid Operation plan:
(stable operation avoiding disturbance, accident, power cut, black out)
→ Transient Analysis

Voltage and frequency will fluctuate according to VRE
→ **Transient Analysis** is necessary :
- Power system stability with VRE fluctuation need to be calculated by using acceleration and deceleration of energy
- Necessity of Available Transmission Capacity and Spinning Reserve can be analyzed
- Requirement for Stabilizing equipment to be assessed

Optimum operation
→Economic Load Dispatch / LFC

Operation of generators based on merit order to minimize fuel cost for generators (especially with thermal spinning reserve)
→ **Economic Load Dispatch** provides operation mode for optimized operation
- ex. Cost of Battery vs Cost of biodiesel

Microgrid Conceptual Plan : PV and Wind Potential Assessment

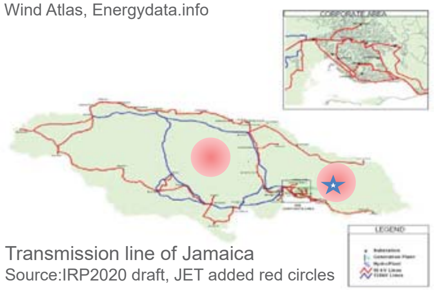


Source: Global Solar Atlas and Global Wind Atlas, Energydata.info

Consideration for microgrid site selection:

- South area has higher solar potential
- Wind potential is south St. Elizabeth, Valley of Manchester, and hilly area of Blue Mountain
- North Clarendon-South St. Ann, border of St. Andrew and St. Thomas has low voltage at the time of incident

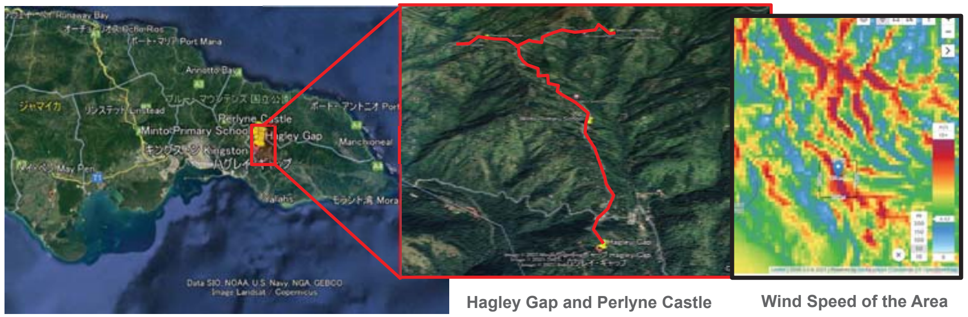
→ **Hagley Gap in St. Andrew** was selected



Transmission line of Jamaica
Source:IRP2020 draft, JET added red circles

Target Area for Microgrid Conceptual Plan: Hagley Gap

This is NOT Feasibility Study. The data used in this plan is based on assumption, and it needs site confirmation and review .



Hagley Gap and Perlyne Castle   Wind Speed of the Area

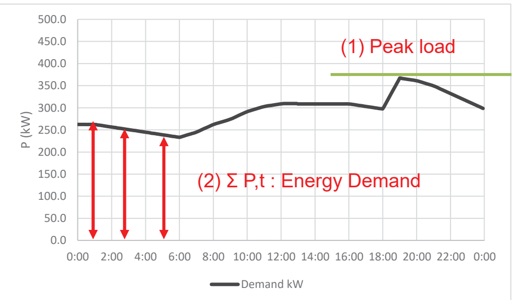
- Target area: around Hagley Gap in St. Andrew
- Good wind potential (7-10m/s)
- Road transportation available (need confirmation with turbine blade length)

*1 nos of household is from visual check of Google Earth. It may have error and needs to be reviewed by administration data.
*2 Assumed from 1.5 kW /hh, 30kW/facility. It needs to be reviewed by accrual data of the area.
*3 Wind speed at available road. Better wind speed may be obtained at hilltop, but road construction will be necessary.

Total residential consumer	166	hh*1
Max daily energy consumption	7,029	kWh/day*2
Peak load	367.2	kW*2
Hagley Gap mean wind speed	7.6	m/s @10mH*3
Wind rated output	500	kW
Wind average output	301	kW
Hagley Gap solar irradiation	4314	kWh/kWp/day
Total Solar PV output	105	kWp
Diesel Generator	400	kW

Determination of kW (power) and kWh (energy)

Estimation of load and demand at peak condition in Microgrid



P,t: Load kW at time t
Dy: Demand kWh after Y year from X
Dx: Demand kWh of the year X
α:compound annual growth rate (CAGR)

Output (kW) is determined from Peak Load. It is minimum output requirement.

- Peak load: Peak load data of highest peak load day among 3-10 years

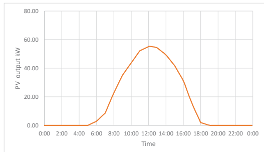
Energy Demand (kWh) is determined from the day of largest energy demand (kWh)

- Largest energy demand of the year among 3-10 years(kWh)
- Demand increase need to consider growth in project period, including EV
  $D_y = D_x (1+\alpha)^{(y-x)}$
- Output need to be adjusted so that it can produce necessary amount of energy demand considering reserve rate. It will be much larger than peak load.

Both need to consider future increase of peak and demand.

Microgrid Planning : Determination of kW and kWh

Plan for system structure of Microgrid in distribution lines based on demand



PV	(7) 95	kW
Wind output	305	kW Ave.
Nos Wind units	(6) 1	units
Wind capacity	0.5	MW
Total PV + Wind	594.7	kW
Battery capacity	1.05	MWh
Battery output	0.26	MW

Time	PV kW	Demand kW	Wind kW at Hagley Gap	PV+Wind	Battery Charge-Discharge	Battery Charge kWh	Battery milage
0:00	(1) 0.00	262.3	(2) 194.4	194.4	67.9		67.9
0:05	0.00	262.3	216.8	216.8	45.5		45.5
0:10	0.00	262.3	240.9	240.9	21.4		21.4
0:15	0.00	262.3	280.8	280.8	-18.5	18.5	18.5
:							
11:55	54.69	308.4	370.5	425.2	-116.7	116.7	116.7
12:00	54.93	308.9	350.5	405.5	-96.5	96.5	96.5
12:05	55.16	309.4	398.7	453.9	-144.5	144.5	144.5
12:10	55.08	309.4	371.3	426.4	-117.0	117.0	117.0
:							
23:50	0.00	300.2	407.0	407.0	-106.8	106.8	106.8
23:55	0.00	298.7	343.9	343.9	-45.2	45.2	45.2
0:00	94.70	297.3					
24h total kWh	413.1 (4)	7,010.8	7,320.0 (3)	7,733.2	(5) -722.4	1,048.7	1,375.0
Gen-Demand kWh					(5) 722	250.4	0.81
kWh/kW/d	4.362			Loss	(5) 10.3%		

$P_{PV,t}$: PV output at the time of t, P_{PVp} : Peak output of PV
η: total efficiency (design coefficient) of PV
E_{total}: total energy of PV and Wind
$P_{wind,\ t}$: output of Wind at the time of t
$B_{total\ C\text{-}D}$: total of charged and discharged amount of Battery
B_{loss}: charge-discharge loss of Battery,
B_{charge}: energy Charged in Battery (negative value)
D_t: Demand at the time of t

(1) PV kW at every 5 min: calculated from irradiation data and specific output/d
$P_{PV,t} = P_{PVp} \times \eta \quad \eta \fallingdotseq 0.75$

(2) Determine Wind kW (next slide)
$P_{wind} = P_{wind/unit} \times unit$

(3) PV and Wind total E_{total} (kWh)
$E_{total} = \Sigma\ (P_{PV,t} + P_{wind,t}) \times 5/60$
(in case of 5 min data)

(4) Demand kWh/d : $\Sigma D_t \times 5/60$

(5) Battery Charge-Discharge (kWh)
$\Sigma B_{totalC\text{-}D} < 0$, ($B_{charge}$: Negative)
Battery capacity $B_c > \Sigma B_{charge} + B_{loss}$
$B_{loss} > 10\% \times (-1) \times \Sigma B_{total\ C\text{-}D}$

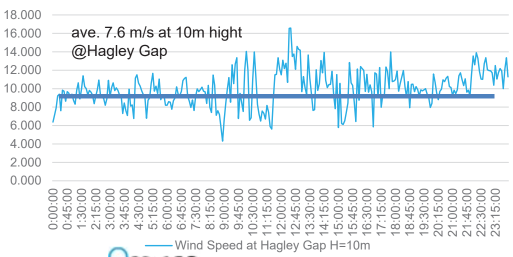
(6) Set unit nos of turbine for wind

(7) Set P_{PVp} so that (5) is satisfied.

Microgrid Planning : Determination of Wind powers

This is NOT Feasibility Study. The data used in this plan is based on assumption, and it needs site confirmation and review .

	Average Wind Speed		(1) 7.6	m/s
	Average Output from Power Curve		305	kW
Timestamp	**Reference Wind Speed m/s**	Wind Speed at Hagley Gap H=10m	Difference from Average Wind Speed	Wind generation output kW
0:00:00	2.34	(2) 6.379	-3.63	(2) 194.37
0:05:00	2.61	7.115	-2.89	216.80
0:10:00	2.90	7.906	-2.10	240.89
:				
23:50:00	4.90	13.358	3.35	407.01
23:55:00	4.14	11.286	1.28	343.88
Average	**3.67**	10.01		305.00
Total kWh				(3) 7320



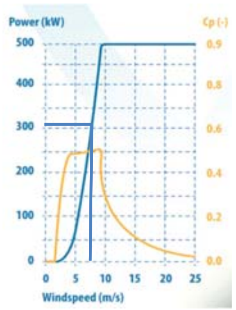
(1) Determine average output from Power curve of turbine

(2) Calculate $P_{wind,t}$ from wind speed data and power curve with wind speed

(3) Total $E_{wind} = \Sigma P_{wind,t} \times 5/60$

$P_{wind,t}$: Wind output at the time of t

E_{wind}: Total generated energy of the day by wind



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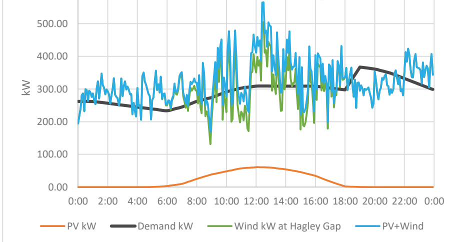
Source: EWT DirectWind

Provisional Cost Estimation for Microgrid in Hagley Gap

This is NOT Feasibility Study. The data used in this plan is based on assumption, and it needs site confirmation and review .

Case: Wind 500 kW + Rooftop PV 95 kW



- The estimation is just trial, based on much assumptions, which need to be reviewed.
- Feasibility is much depending on wind speed
- Both PV and wind has fluctuation. BESS or DG is necessary to absorb fluctuation and levelized output.
- Initial cost : DG < BESS
- Cost of DG needs fuel cost. BESS needs consideration of replacement and cycle life.

With Battery, 260 kW-1.05 MWh

Item	Amount	unit	Remark
Unit cost of PV	1000	USD/kW	
Rated Output of PV	95	kW	
Cost of PV installation	94,700	USD	
Unit cost of Wind	2,500	USD/kW	
Rated output of Wind	500	kW	
Cost of Wind	1,250,000	USD	
Unit cost of 24 kV system	400,000	USD/km	
Length of 24 kV	0.3	km	
Cost of 24 kV system	120,000	USD	
Requirement of SCO	149	kVA	25% of PV+Wind output
Unit cost of SCO	200	USD/kVA	
Cost of SCO	29,735	USD	
Unit cost of Diesl Generator	300	USD/kW	
Capacity of Diesel Generator	400	kW	
Cost of Diesel Generator	120,000	USD	
Total Cost	**1,913,918**	**USD**	

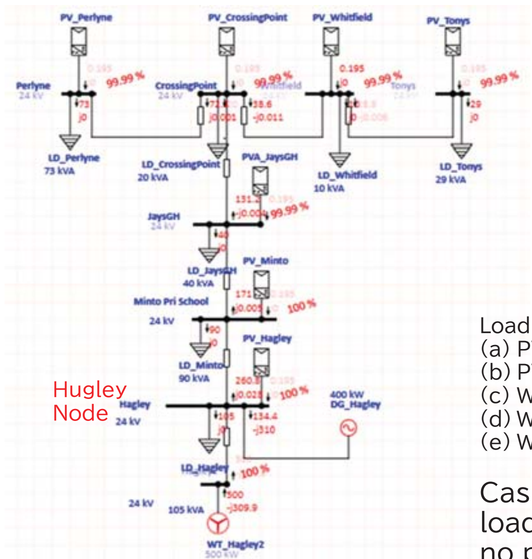
With Diesel Generator

Item	Amount	unit	Remark
Unit cost of PV	1000	USD/kW	
Rated Output of PV	95	kW	
Cost of PV installation	94,700	USD	
Unit cost of Wind	2,500	USD/kW	
Rated output of Wind	500	kW	
Cost of Wind	1,250,000	USD	
Unit cost of 24 kV system	400,000	USD/km	
Length of 24 kV	0.3	km	
Cost of 24 kV system	120,000	USD	
Requirement of SCO	149	kVA	25% of PV+Wind output
Unit cost of SCO	200	USD/kVA	
Cost of SCO	29,735	USD	
Unit cost of Diesl Generator	300	USD/kW	
Capacity of Diesel Generator	400	kW	
Cost of Diesel Generator	120,000	USD	
Total Cost	**1,614,435**	**USD**	+ Fuel Cost

Notes about Microgrid of Hagley Gap

- Target household and demand is assumed. It needs to revise with actual data.
- Cost of 24 kV system upgrade is not included.
- 100% RE will be possible in case good wind potential site is found. 100% RE with PV will require quite large battery cost.
- The wind potential much depends on wind velocity at site.
  - Wind output is proportional to the cube of wind speed : $P_{wind} \propto V_{wind}^3$
  - Cost with installation of wind at high wind potential site with road construction need to be compared. (305kW@7.6 m/s, 500kW@10m/s)
- BESS cost/kWh much affect on total cost.
  - Best effort cost is now leached at 140 USD/kWh.
- BESS cycle life and charge-discharge milage is much affected for replacement cost. Local Wind/PV fluctuation data should be assessed.
- Cost of BESS vs DG: maintenance cost is depending on charge-discharge amount..
- More frequent small charge-discharge by wind fluctuation may cause battery deterioration. The affect of frequent small charge-discharge need to be assessed by totaling fluctuation amount with actual wind speed measurement.
  - Installation of wind at different place to achieve smoothing effect is recommended to mitigate small fluctuation

6. Microgrid planning - Grid Stability Analysis – Hagley Gap Microgrid Condition and Load Flow Analysis Result



Load Flow Analysis Result of Case (a)

The following parameter is assumed for modeling Hagley Gap Microgrid for load flow analysis and transient stability analysis. All of inverters for PV and wind turbine generators are GFL(Grid Following Inverter).

- Place: Mountain area between Hagley Gap and Perlyne Castle
- Voltage: 24kV
- Load(Private and Public) 367kW
- PV Generator 95kW
- Wind Turbine Generator 500kW
- Diesel Generator 400kW

Load Flow Analysis Cases:
(a) PV95kW, Wind500kW, Diesel400kW
(b) PV95kW, Wind500kW
(c) Wind500kW
(d) Wind500kW, Diesel400kW
(e) Wind500kW, Diesel100kW

Case (a)-(e) reached to normal state in load flow analysis. Load flow analysis has no problem about voltage and load.

Transient Stability Analysis Condition

Table of Transient stability analysis Condition for each case

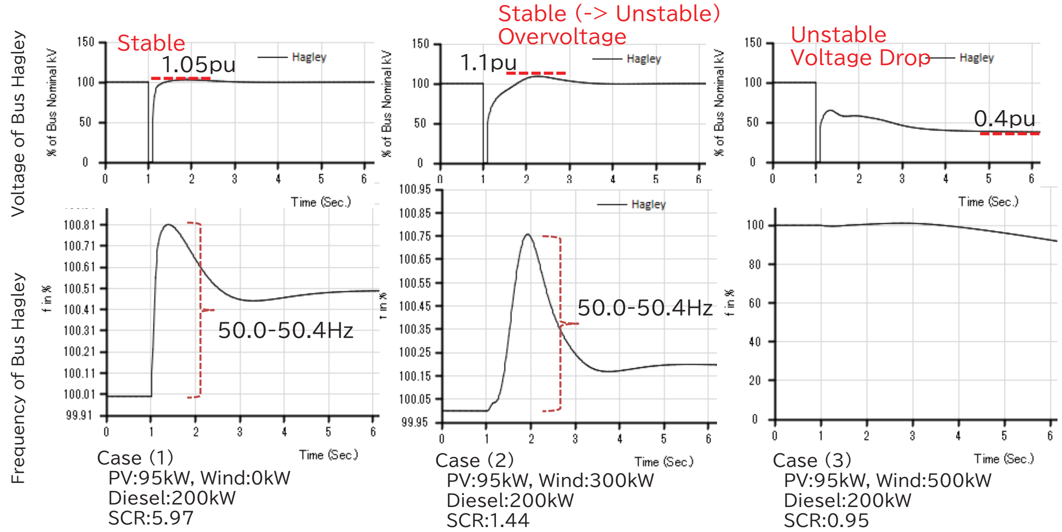
	Load (kW)	PV (kW)	Wind (kW)	Diesel (kW)	BESS (kW)	SCR
Case (1)	367	95	0	200	0	5.97
Case (2)	367	95	300	200	0	1.44
Case (3)	367	95	500	200	0	0.95
Case (4)	367	95	0	400	0	8.07
Case (5)	367	95	500	400	0	1.29
Case (6)	367	0	500	400	0	1.53
Case (7)	367	95	500	200	260	1.39

In order to evaluate grid stability of Hagley Gap Microgrid,
7 conditions listed in the left table are assumed for transient stability analysis.

Figures in the following slides show the results of frequency and voltage in the transient stability analysis with condition of 100 millisecond 3 phase grounding fault at Hagley Node.

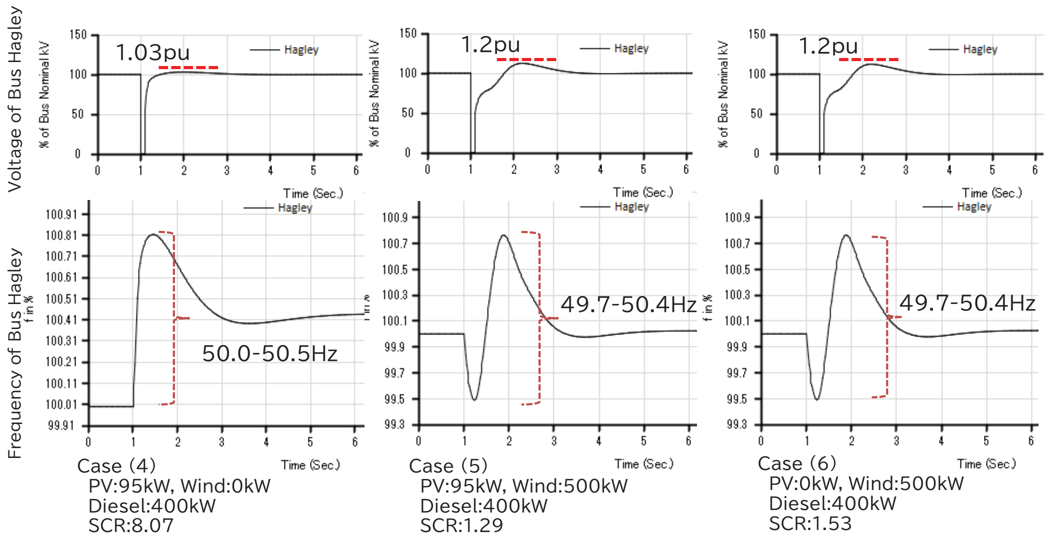
Transient Stability Analysis Result for Evaluation by SCR

The fluctuation of frequency is within +-0.5Hz error of rated frequency in Case (1) & (2).
Case (2) is close to unstable state. Its SCR is between 1 and 3.
Case (3) is unstable. Its SCR is under 1.



Transient Stability Analysis Result in conditions of installed RE

The fluctuation of frequency is within +-0.5Hz error of rated frequency in Case (4), (5) & (6).
Case (5) & (6) are stable but the voltage of Hagley node is about 10% over.
Case (5) & (6) are close to unstable state. SCR of these cases is under 3.



Evaluation and Measurement of Case (1) – (6)

In Hagley Gap Microgrid, power of wind turbine generator flows from Hagley Gap to Perlyne Castle.
Output of wind turbine generator influences grid stability. Because the output of wind turbine generator is large, overvoltage is caused at Hagley Gap Node.

In Case (1) to (3), output of diesel generator is 200MW.
In Case (3), out put of wind turbine is 500MW and grid is unstable. This is because wind turbine generator is too large for this microgrid.

In Case (4) to (6), output of diesel generator is 400MW.
In Case (5) and (5), output of wind turbine is 500MW, but diesel generator controlled frequency and voltage into stable state.
-> GFM should be installed into the inverter of wind turbine generator to be able to control frequency and voltage.

Evaluation and Measurement of Transient stability analysis

	Evaluation	Measurement
Case (1)	Stable, Voltage and Frequency are normal.	
Case (2)	Stable, Overvoltage	STATCOM, DVS
Case (3)	Unstable, Voltage drop	GFM for wnd
Case (4)	Stable, Voltage and Frequency are within acceptable value	
Case (5)	Stable, Overvoltage	GFM for wind
Case (6)	Stable, Overvoltage	GFM for wind

Transient Stability and SCR(Short Circuit Ratio)

SCR(Short Circuit Ratio) for inverter is defined and proposed in the following reports.
IEEE std 1204-1997(R2003) : 3 definitions of SCR
NERC Reliability Guideline, Dec. 2017 : 4 definitions of SCR
Here we use the following definition in page 5 of IEEE std 1204-1997(R2003)
SCR=AC Grid Capacity (Including Spinning Reserve)/Rated GFL Inverter Capacity

If SCR is larger than 3, grid is stable.
If SCR is smaller than 1, rated GFL inverter capacity exceeds grid capacity and the grid is unstable.
In the case which SCR is between 1 and 3, it can be stable by voltage and frequency control circuit of generators or inverters.

In Hagley Gap Microgrid, diesel generator with AVR(Automatic Voltage Regulator) will control to keep grid stable even if SCR is between 1 and 3. However, in Case (3), SCR is under 1. PV and wind turbine generator covers all demand of microgrid and grid is going to be unstable.

If control circuit, such as DVS(Dynamic Voltage Support), AVR(Automatic Voltage Regulator), PSS(Power System Stabilizer) and/or speed governor, are installed into inverter or generator, grid may be stable in frequency and voltage, even if SRC is between 1 and 3.

SCR under 1 means that majority of the power of microgrid is supplied by only GFL. Grid is going to be unstable and reach to blackout.

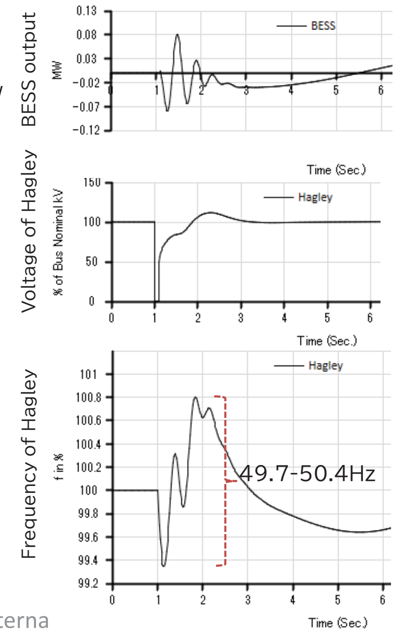
Transient Stability Analysis Result of Hagley Gap Microgrid with BESS

In case (7), BESS(260kW,1.05MWh) with GFM is assumed to be installed at Hagley Node in Hagley Gap Microgrid.
Figures in the right side are the results of transient stability analysis of Case (7). Here BESS is assumed to be able to charge and discharge with continuous output value.

Case (7)
PV:95kW
Wind:500kW
Diesel:200kW
BESS:260kW
SCR:1.39

BESS with GFM can make grid stable by controlling charge and discharge of battery.

SCR(Short Circuit Ratio) should be considered at the installation of RE and BESS.
Grid with SCR over 3 is stable.
SCR under 1 makes grid unstable.

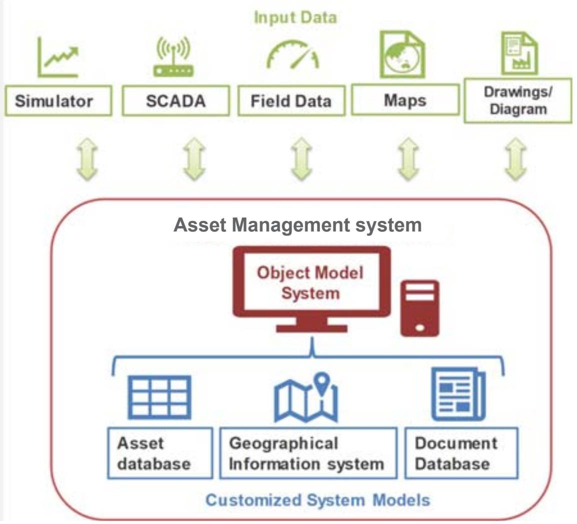


Agenda

Asset Management for Resilience: as system platform

- To Optimize planning
- To Minimize time for recovery from failure with system integration

- ✓ **GIS: Spec. for each facility & equipment on the map**
- ✓ **CAD: analyze each spec. with comprehensive & panoramic view**
- ✓ **SCADA: Real time monitoring on the map**
- ✓ **ERP: liked immediately with updated facility data into ERP**
- ✓ **Others (Simulator, etc.)**

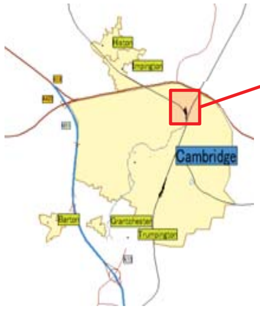


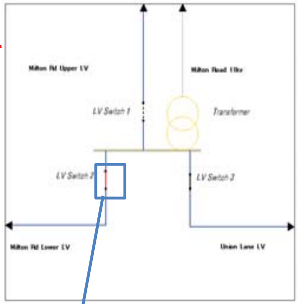
Asset Management for Power System Resilience

Asset data of equipment status in PS and SS, network trace, fault finding

Electricity LV lines

Substation single line diagram





Service wire status and photo/drawing

Field name	Value
Id	938606
Known As	
Voltage	LV
Status	In service
Length	16.77 m
Centreline	✓

LV Switch connection status

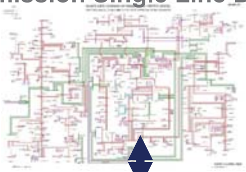
[Electricity] Switch

Field name	Value
Known As	LV Switch 2
Voltage	LV
Switch State	closed
Annotation	✓
Substation Internals	268910066
Primary Connection	✓
Secondary Connec...	✓

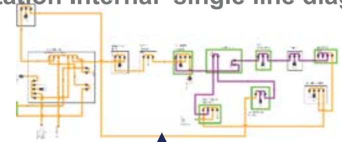
Asset Management for Resiliency

Linking all asset data on to one data platform

Transmission Single Line Diagram



Substation Internal single line diagram



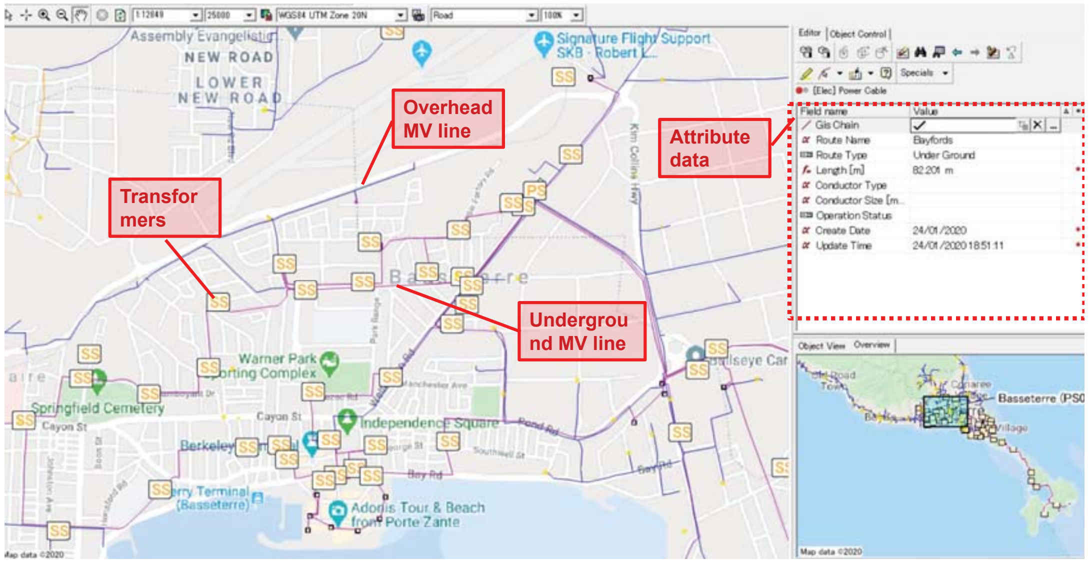
Power distribution network to meter

Power Network Mapping Data

- Visualization of precise location
- Base for fast fault recovery
- Asset management of small VREs
- Database for EE verification

Asset Management System example: St.Kitts

Network infrastructure mapping with database → easy to obtain precise location

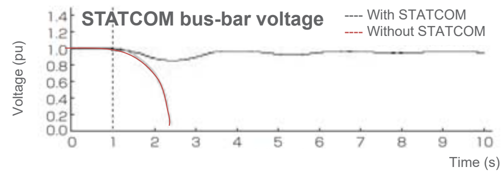


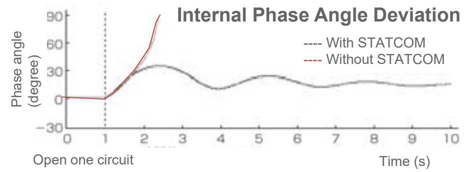
SCO and STATCOM for Reactive Power

SCO (Synchronous Condenser):
SCO is DC-excited synchronous machine (large rotating generators) whose shaft is not attached to any driving equipment. Though changing field excitation, SCO adjusts reactive power and provides reactive power at the time of voltage drop.

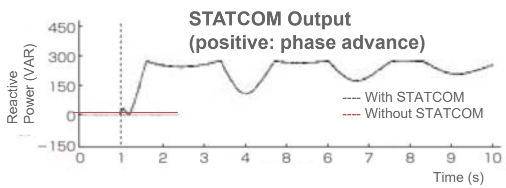
https://energy-shift.com/news/af737655-0462-4655-81ae-b17d86b5784d

STATCOM (STATic synchronous COMpensator):
For compensation of reactive power, it generates/absorbs reactive power, and stabilize voltage continuously at high speed by self-commutated inverter.



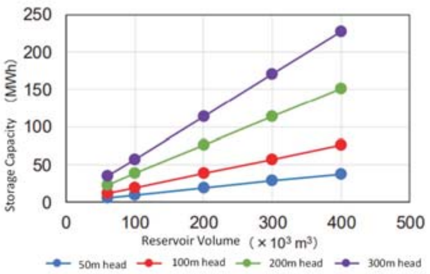


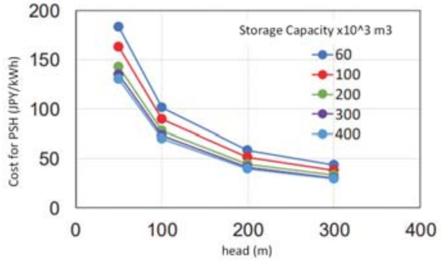
Source: Enhancement of Steady—State Stability and Suppression of Over—Voltage using 450MVA GCT—STATCOM, Mitsubishi Denki Giho, pp.52-55, Vol.87, No.11, 2013.



https://www.hitachi.co.jp/products/energy/STATCOM/about/index.html

Pumped Storage vs Battery



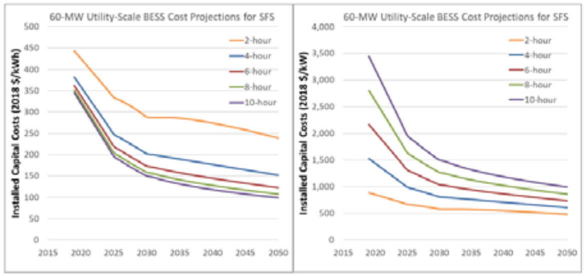


Note: headrace 1500m is assumed for head 200m
Source: Potential Capacity and Cost of Pumped-Storage Power in Japan Strategy for Technology Development Proposal Paper for Policy Making and Governmental Action toward Low Carbon Societies, LCS-FY2018-PP-08, 2019

Is pumped storage considered an economically viable technology option for Japan and what are the challenges?

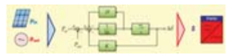
- Challenges: Topology and water. Higher head, lower cost: 700USD/kWh@100m, 350USD/kWh@200m (100,000m3) .
- Long lead time, Environmental Impact Assessment
- Advanta40-50 years life, black start possible
- LiB : 350-450USD/MWh @2022 (for 60MW scale), Cycle: 5000-20,000 @DoD 80-90%

DoD: Depth of Discharge



Source Utility-Scale Battery Storage | Electricity | 2021 | ATB | NREL

Emerging technology for large RE with Grid stabilization : Generation with Inertia and Synchronous Power

Type of Technology		Advantage	Develop stage
 Source: taiyo-electric	Motor generator (MG)	- Energy in battery provides synchronization and inertia - Small scale supply, for micro grid	- Used as frequency conversion - Commercial operation
 energyvault.com/gravity	Gravity Storage Battery	- Gravity of recycled Concrete block 35ton/nos - Provides inertia - Half cost of Li-ion battery	Pre-commercial, 35 MWh, 4MW per tower η=85% 52.5GW planned in USA
 /www.nedo.go.jp/news/press/AA5_100756.html	CAES (Compressed air energy storage)	- Compressed high pressure air - (Liquid air may be developed) - Provides inertia	-demonstration by NEDO - 900 MW in California - η=70-80%
 electrek.co/	CSP (concentrating solar power) Solar thermal	- With turbine, provides inertia and synchronization - Cost decrease expected, higher efficiency than PV, η=50%	- Commercial operation at Ivanpah392MW 22 bil USD - Heat storage (molten solt, etc) under development
 Source: CIGRE	Grid-forming inverter	- Dynamic active/reactive power, FRT, frequency control, inertia - Applicable to existing PV - (Smart Inv: FRT, VRT, voltage support)	- Under development - (Smart inverter by IEEE1547, Mandatory in Hawai)

Agenda

1. Opening Remark
2. Project outline, Review and Feedback of 2nd Seminar
3. Grid Scenario proposed and stability analysis
4. Development Status of Grid Forming Inverter and its Safety
   - Current Status, Blackout with GFM & Black Start using BESS
5. Transmission lines and Remedial Action Schemes
   - Special Protection System, PV/Wind Turbine Trip
6. Microgrid planning
7. Technology options
8. **Policy recommendation**
9. Discussion, sharing good practice of Jamaica, and way forward

NIPPON KOEI PADECO

Feedback at the 2nd Seminar

SCO: Synchronous Condenser
BESS: Battery Energy Storage System
GFM: Grid Forming Inverter
T&D: Transmission and Distribution

Items	Feedback	Comment
System interruption (momentary outage) may be increased according to RE %. How do you assume acceptable when RE target is achieved.	• No customer accepts power interruption • 2 days/year/customer 18 hrs/customer 2 Min/day • Approx. 50 min/yr 60min per year • Persons working remotely we have to think of less or no interruptions. Therefore RE plants has to be futuristic and designed to meet this new aged demand Momentary outages are not acceptable, • That is difficult to say. At the moment MAIFI of < 5 mins is not penalized	The smaller interruption, the more cost for stability. Practical level need to be considered.
For achieving RE target with sufficient grid stability, how to cover the cost of grid stability?	- Increase tariff < 5% - Some tariff increase of medium to large customers - The price of electricity is already considered high, so we need to be very careful of tariff impact. - New T&D system to manage ancillary services from BESS,STATCOM,SCO. Some tariff support for new T&D capital support Government should invite private investors, BOOT - VRE IPP should be responsible for the Storage or associated device incl. GFM - International grants could be a big help and could be done through climate change funds as the increased RE penetration reduces GHG emissions.	- Consumer, utility, and IPP all need to work but finally consumer will have to pay - International cooperation with climate finance can be fully utilized. Please advise what is needs for JICA.

Recommendation for Future RE and Grid Plan for 50%RE by 2030

Item	Description
Storage for smoothing output and peak shift	- Mandatory installation of BESS, for example, more than 80% of Peak MW and 4hrs storage for utility scale VRE
Investment to secure inertia and spinning reserve for grid	- Maintaining sufficient synchronous generator for spinning reserve - Introduction of Grid Forming Inverter (GFM) for VRE once available, application of Weather projection system
Investment for voltage and reactive power	- Mandatory application of Inverter with reactive power compensation for Wind/Solar IPP
Sharing responsibility of grid stability among utility, IPP, consumers	- Utility: maintaining transmission and distribution line frequency and voltage stability, ancillary service - VRE IPP: installation of inverter with VAR compensation &energy storage - Consumer: demand response, ToU setting& EV charging, peak shifting
Option for storage (especially with inertia)	- In addition to BESS, consideration of V2G, hydrogen, (pumped storage), Compressed Air Energy Storage (CAES) and Gravity Storage in future
Microgrid	- To promote microgrid to strengthen resiliency
Data management	- GIS for distributed PV, Database management, Asset management
Recycle/disposal	- Consideration for disposal and recycling of battery and PV panel
Finance	- Use of climate finance, international finance cooperation for RE&stability
"Best-Mix" Energy	- Gas for fluctuation mitigation as intermittent measurement. - Multiple alternative for RE and storage, not a single source (Solar/CSP/Wind/Biomass, BESS/Thermal/new storage, etc.)

8. Policy recommendation
- Recommendation for Jamaica Grid Code -

Current Grid Code

＊: Electric Utility Sector Code Book
Dispatch Code
Distribution Code
Supply Code
Generation Code

- Frequency
  - Normal condition : 49.5 - 50.5Hz
  - Contingency condition: 48.0 - 52.5Hz
- Voltage:
  - normal condition -> ±5%
  - contingency condition -> ±10%
  - Voltage between +5% and +10% shall not be last longer than 15 minutes unless abnormal conditions prevail.
- Power Factor:
  - 0.9 lagging to 0.95 leading

Recommendation for Grid Code

- Power Factor:
  - Power factor should be 0.85 lagging to 0.85 leading
  - If DVS(Dynamic Voltage Support) function is installed into the inverter, the acceptable range of power factor should be wider than current code value: ex..
  - MPPT is secondary requirement for grid stability.

Recommendation of Considering Short Circuit Ratio(SCR)

- SCR=AC System Capacity/Rated IBR Capacity
  - SCR>3 -------- High SCR, Stable
  - 3>SCR>2 ----- Low SCR
    Small fluctuation continues.
  - 2>SCR -------- Very Low SCR
    Sensitivity of IBR to Grid goes high.
    Grid is unstable that may bring blackout.

ref) "IEEE Std 1204-1997(R2003)", IEEE, 2003
- IEEE Guide for Planning DC Links Terminating at AC Locations Having Low Short-Circuit Capacities
- Recognized by ANSI(American National Standards Institute
https://ieeexplore.ieee.org/document/653230

Recommendation for Grid Code

- SCR(Short Circuit Ratio) should be added to grid code, in order to keep grid stable in large RE penetration for grid stability.

Resources which supply inertia to grid Considering Short Circuit Ratio(SCR)

- Following resources can supply inertia to grid.
  - V2G(Vehicle to Grid) of EV(Electric Vehicle) with Grid Forming Inverter
  - BESS(Battery Energy Source System) with Grid Forming Inverter and SOC Control.
    - SOC Control is required to realize Grid Forming Inverter.
  - Biofuel Generator
  - Solar Thermal Generator
  - **Renewable Energy Resources (PV, WT) with Grid Forming Inverter**

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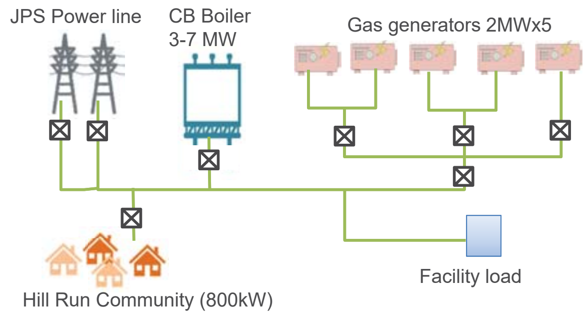
7. Technology options
8. Policy recommendation
9. Discussion, sharing good practice of Jamaica, and way forward

The experience of Jamaica which should be shared with other Caribbean countries-1

Microgrid: Jamaica Caribbean Boiler-JPS

- Microgrid with Combined heat and power (CHP) generation plant and supply to community
- The exhaust heat converted into energy and improve efficiency
- improve its operational efficiency and reliability.
- 5 generators + CB boilers
- Provides power to Hill Run community
- 30% CO2 reduction by fuel switch from heavy oil to LNG

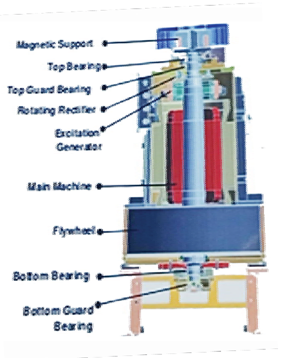
https://www.cvmtv.com/news/major-stories/jps-and-cb-group-collaborates-on-new-power-plant/



The experience of Jamaica which should be shared with other Caribbean countries -2

JPS Hybrid Energy Storage System (HESS) of JPS in Jamaica

- **24.5 MW HESS (Hybrid Energy Storage System)** installed at Hunts Bay power station
- HESS stabilizes VRE output fluctuation (approx. 175 MW for 650 MW peak load, VRE is 15.2% energy base but capacity is 27.3% average peak, 39.6% at off-peak time)
- Flywheel absorbs small instantaneous fluctuation and prevents battery deuteriation

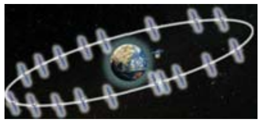


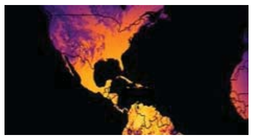
Item	Flywheel
System integrator	ABB RE+
Manufacturer	Pillar Germany
Capacity	3MW, 16.5 MWs
Speed	1800-3600 rpm
Bearing life	8yrs
Response speed	100 ms
Efficiency	>96%
BESS	LG Chem, 21 MWh

Item	BESS
Manufacturer	LG Chem (Korea)
Type	Li-ion
Module	128Ah, 92.3kWh
Capacity	21.5 MW, 16.6 MWh

The experience of Jamaica which should be shared with other Caribbean countries -3

Weather prediction system for VRE





Weather prediction system provides forecast PV output
- Satellite is used for more than 1hour ahead prediction
- The system enables preparation of optimized spinning reserve and contribute stability
- Jamaica JPS already applies AWE system

In case of Solcast API
- Analysis on live and forecast data
- The live and forecast data products deliver PV power, irradiance, and weather data globally, with spatial resolution of 2km and data updates every 5 to 15 min

% errors of Intraday & Day-Ahead PV Power Forecast

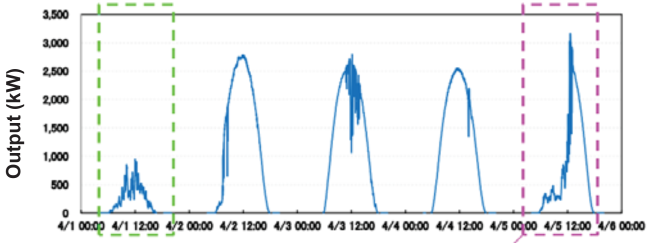
Type	Data source	+1 hours ahead error(%)	+3 hours ahead error(%)	+24 hours ahead error(%)
Tropical/Subtropical, Humid (7 sites)	Solcast	(2.4% to 3.8%)	(3.2% to 5.6%)	(4.5% to 7.0%)
	Smart Persistence	(3.0% to 5.3%)	(3.7% to 6.9%)	(3.8% to 8.6%)
	GFS		(4.6% to 8.5%)	

https://solcast.com/forecast-accuracy

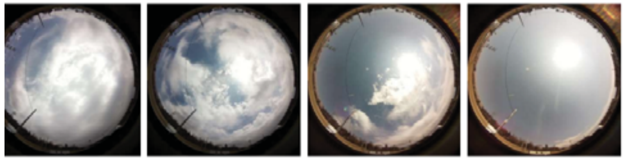
Weather prediction system by Sky Camera for VRE

For short time advance prediction, whole-sky camera system will do.

- Weather prediction for 5-30 minutes advance by detection of cloud movement with Whole-Sky Camera
- AI reads image and predict short-term irradiation (ex. SolarMi by Skyperfect JSAT)



PV output time series variation (1 Apr to 4 Apr9)



https://www.data.jma.go.jp/sat_info/himawari/kondan/kai3/shiryou3_2-2.pdf

Thank you for Participation!!

Please kindly provide your feedback via:

https://forms.gle/ES8LrKbuvzpzmKUa6

Appendix 3-5-2 Attendant list, Q&A, and Feedback, of the 3rd RE & Grid Stability Seminar (Jamaica)

Technical Cooperation to Promote Energy Efficiency in Caribbean Countries

3rd RE and Grid Stability Seminar for Jamaica

List of Participants for Online Attendance (8 Feb 2023)

No	Name	Agency	Title	Department
1	Brian Richardson	MSET	Chief Technical Director, Energy	Energy Division
2	Todd Johnson	MSET	Principal Director, Energy	Energy Division
3	Leneka Rhoden	MSET	Dir., Energy Systems & Conservation	Energy Division
4	Barington Jackson	MSET	Technical Officer	Generation. Procurement Entity
5	Andre Lindsay	Office of Utilities Regulation		
6	Craig Rattary	Office of Utilities Regulation		
7	Cheryl Lewis	Office of Utilities Regulation		
8	Phillip Whittingham	JPS	Director: Generation Planning	Generation
9	Shogo Otani	JPS	Director	Executive Management
10	Keisuke Harada	JPS	Director	Executive Management
11	Takuya Kokawa	JPS	Marubeni Representative	Executive Management
12	Charitha Fernando	JPS	Internal Audit Director	Internal Audit
13	Dervin Hanlan	JPS	Internal Audit Manager	Internal Audit
14	Karl Cowan	JPS	Manager	System Control
15	Duane Smith	JPS	Power System Controller	System Control
16	Donovan Wint	JPS	Power System	System Control
17	Oneif Young	JPS	Assistant Control Engineer	System Control
18	Aston Shaw	JPS	Assistant Control Engineer	System Control
19	Dhario Reid	JPS	Grid Performance	Grid Performance
20	Kayonne Webley	JPS	Pwr Systems Engineer-IPP Oprts	Grid Performance
21	Leigh Dwyer	JPS	Production Planning Engineer	Operations Planning
22	Polly Vernon	JPS	Network Planning Engineer	Operations Planning
23	Kenneth Batchelor	JPS	Resource Planner T&D Ops.	Operations Planning
24	Charley Parchment	JPS	Manager: Operations Planning	System Operations
25	Winston Blackwood	JPS	Head, Digital Trans.&Business	Innovation & Technology
26	David Fleming	JPS	Legal Counsel	Legal & Compliance
27	Tevin Clarke	JPS	Student	University of Technology
28	Lincoy Small	JPS	Director Operation	Innovation & Technology
29	Krystal Owens	JPS	Operations Technician	GAMG JPS 10MW Hill Run
30	Stephany Thompson-Taylor	JPS		
31	Jodie Bowes-Morrison	JPS		
32	Kirk Gilpin	JPS		
33	Vashawn Burnett	JPS		
34	Yannick Johnson	JPS		
35	Alejo Lee	JPS		
36	Carl Goodwin	JPS		
37	Sameer Simms	JPS		
38	Rick Case	JPS		
39	Steve Windross	JPS		

Technical Cooperation to Promote Energy Efficiency in Caribbean Countries

Q&A List: 3rd RE and Grid Stability Seminar on 8 Feb

No	Day	Item	Content	Name	Answer
3rd RE and Grid Stablitiy Seminar on 8 Feb					
1	8-Feb	Question	Will these presentations be shared with us at the end of today's seminar	Lincoy Small	Yes. We will share it with you later.
2	8-Feb	Question	Was a harmonic study done as well?	Steve Windross	In the microgrid simulation, each inventor has a model of harmonics so we can assume the harmonics rate for each inventor but the result for harmonics can be disappeared through the drop of voltages because the harmonics flows through a feeder. Impedance of feeder is constant so impedance of feeder multiplied by harmonics current will be the drop value of voltages. Therefore, voltage regulation is the appeared data for utilities. Usually 3% or 5% are accepted as grid record for voltage regulations and this will be the harmonic condition for grid.

Feedback on 3rd Seminar on Large RE and Grid Stability in Jamaica, 8 Feb 2023

SN	Q1: What power generation source you think Jamaica need to add to achieve 49% RE penetration target?	Q2: If you check above "other" in Q1, please specify	Q3: Please suggest how much MW or percentage in Q1 that you propose to add in future Jamaica Grid. If you put multiple check in Q1, please provide MW or percentage for each generation source.	Q4: If you have any idea other than generation source that will be necessary for future Jamaica grid, please describe.	Q5: Please explain why you suggest the Q1 and amount Q3 and Q4 is necessary. If there is any concrete plan (such as policy, Feasibility Study, etc.) , please describe.
1	1. PV, 2. Wind, 4, Waste to energy, 7. Other	Hydrogen and Nuclear	Nuclear 30% WTE 7% Solar 33% Wind 20% Hydrogen 10%	Hydrogen for Storage and Energy Production. SMR Nuclear. BESS, Grid Forming Inverters, Capacitor Banks	We perform our own studies and simulations and based on industry trends, these are practical solutions.
2	1. PV, 2. Wind		300MW (70%PV 30%WIND)	Battery Storage	Jamaica's Integrated Resource Plan
3	1. PV, 2. Wind, 3. Biofuel, 4, Waste to energy, 6. Pumped Storage Hydro, 7. Other	Nuclear	PV-6, W-7, B-3, W to E-3, PSH-15, Nuc-25 in %.	Battery and grid forming inverter.	To achieve power stability with surplus, these generating source will be necessary to help the economy to grow.
4	1. PV, 2. Wind, 3. Biofuel, 4, Waste to energy, 5. Gas power, 7. Other	Hydrogen	Up to 200MW thermal LNG/Hydrogen power plant Up to 150MW PV Up to 100MW Wind Up to 20MW each for Bio Fuel & Waste to Energy	Battery, Flywheels, STATCOMS, Synchronous Condensers, Bulk Capacitor banks, Grid forming BESS and VREs.	This was guided by the most recent IRP studies, long term Grid Operating Plans & studies and existing experience in grid management.
5	5. Gas power	Clean & friendly source of power	35%	Batteries	Using gas for generation in a micro-grid setting is stable and more reliable. (Renewable Energy sources are prone to natural disasters)
6	1. PV, 2. Wind, 5. Gas power		PV - 30%; Wind - 10%; Gas - 9%	Battery and Synchronous condenser.	Based on Jamaica's geography, we have a lot of potential for solar and wind energy and currently there are investors who are seeking to install large amounts of PV in the medium term. I think batteries are needed to provide quick response for decline in grid frequency due to a sudden decline in renewable generation and also VAR support. Synchronous condensers are needed for VAR support.
7	1. PV, 2. Wind, 3. Biofuel, 4, Waste to energy, 7. Other	look into increasing capacity of current hydros	approximately 40 % of each	battery	the suggestions in question are cheaper than fossil fuel
8	1. PV, 2. Wind		30% each providing there is battery storage	Battery storage	There is a large amount of wind and sun as Jamaica is in the Tropics. With less expensive battery storage this would be ideal. 30% each would provide us grid security in terms of availability in the presence of volatile fuel market.
9	1. PV, 2. Wind, 4, Waste to energy, 6. Pumped Storage Hydro		PV-15%, WIND-15%, WASTE TO ENERGY-5%, Pumped storage hydro- 14%	Batteries at PV sites, Synchronous condensers, switchable capacitors at large loads	Based on government policy/plans and available RE resources
10	1. PV, 2. Wind, 5. Gas power		Q1 would have been to small a time to attain any additional MW installation. Jamaica has the potentila to have over 100MW of wind Being an island makes having greater PV installation a challenge with the cloud coverage we experience. However, we can see another 150MW installation in the near future. LNG ioffers higher MW values and even more if coupled with HRSG for combustion turbine applications.	Jamaica owns an uninhabited island just off shore, Goat Island. I think we can use this to install a nuclear generating plant. Other than meltdown and disposal of spent rods, nuclear is cleaner than most other thermal generating plants. (Not molten salt)	Any future installation of RE should have energy storage capability to offset the fluctuation of outputs due to cloud coverage and sudden wind speed changes, or be fitted with fast starting generation sets to offset the loss of MW outputs that would cause instability and frequency fluctuations. This is due to the lack of inertia on our grid and slow response due to droop settings. More studies needed to have remote wind monitors and cloud spotters (sensors and detectors that are a few miles out radially and progressively closer to the plant to detect cloud movements and wind changes that can affect the plant) to mitigate against unforeseen possibilities of loss of output.
11	1. PV, 2. Wind	N/A	PV- 100MW. Wind - 200MW	HESS (improved capacity on the existing one or install a new system).	Based on the weather conditions and load demands
12	6. Pumped Storage Hydro		20%	Synchronous Condenser	There is a significant voltage issue on the grid and a Synchronous condenser would provide the much needed VAR support, especially with the introduction of more VRE. The Pumped Storage would provide much needed stable generation plus whenever unwanted VRE is present (Mostly wind at nights) we can use that power to store energy.
13	1. PV, 2. Wind, 4, Waste to energy, 5. Gas power		30% PV 30% Wind, 15% WTE, 25% Gas	BESS	The Government has decided it needs to increase the amount of RE serving the grid. To get to the target, the most feasible technologies will be wind and PV but the government has also had a long-standing interest in WTE as part of an overall solid waste and energy solution. It is my view that it makes sense to continue investing in gas generation solution (in a smaller proportion) to both maximise the returns on the already sunk investment the country has made in gas infrastructure as well as to back the intermittency of the REs with gas and battery storage. This is my view; the IRP will ultimately determine.

Feedback on 3rd Seminar on Large RE and Grid Stability in Jamaica, 8 Feb 2023

SN	Q6: JICA team may conduct grid simulation based on your idea above. Please suggest if any other requests to consider in grid model and simulation.	Q7: System interruption (momentary outage) may be increased when RE penetration % is increased without proper measurement. The more interruption is accepted, the lower cost of grid stability will be become. Then, how much sec/min/hrs of interruption per day or per year do you assume it is acceptable when 49% RE penetration is established?	Q8: For achieving RE target 49% in Jamaica with sufficient grid stability, please provide your opinion how to cover the cost of grid stability, such as tariff increase, subsidy, international loan/grant, etc. If you have any idea like "no tariff should be changed but should be covered by subsidy " or "Tariff may be increased up to 10%", please provide here.	Q9: In Jamaica, do you think who should cover the cost of grid stability to achieve 49% RE, i.e., by Government (subsidy and international grant/loan)? by utility company (tariff)? by VRE IPP (by PPA tariff)? or other?
1	Transmission Capacity Upgrades (Substation and Lines), Remedial Action Schemes (RAS)	2 days/year/customer	Site specific placement of the renewable sites to minimize transmission congestion.	Shared cost between VRE IPP and Utility
2	Location based expansion studies	2 Mins per day	increase tariff not more than 5%	
3	No other now.	3 min.	shared.	Shared
4	No other studies required right now	Momentary outages should not be allowed to increased and solutions should be put in place to prevent that.	1. New VRE should be responsible for including grid forming inverters with some level of BESS support; 2. New T&D market system to manage ancillary services from BESS,STATCOM, Sync Condenser, 3. Some tariff support for new T&D capital improvement and maintenance projects 4. Grant funding	If the inclusion of new generating facilities will have a negative impact on the grid stability then the cost to correct those stability issues should be either the responsibility of that new interconnected generating facility that caused the new grid instability or the utility should be allowed to recover the cost of correcting the grid stability through the tari
5	No	Not Sure	Subsidy	Government (Subsidy & International Grant/Loan)
6	NA	18 hrs/customer	Tariff may be increased.	VRE IPP via PPA tariff.
7		approximately 50 mins per annum	subsidy and international grant	all parties should be involved
8	na	5 minutes for residential customers. Take industrial customers out of u/f.	Grants	International grant and loans.
9	double circuit transmission lines in north coast areas	No customer accepts power interruption, and I would not plan it in operations	The tariff is already high so international loans/grants, increase time to achieve same	Government plus utility company plus tariff for medium to large customers
10	RE plants to be fitted with capability to be slack units +- say 10MW to respond to frequency changes due to loss of a unit or load changes. RE plants to offer MVAR support	If we are thinking "reliability" of supply and with the demand due to access to information, dependability on the grid, telecommunication demands of grid, and persons working remotely we have to think of less or no interruptions. Therefore RE plants will have to be thinking futuristic and designed to meet this new aged demand of grid stability	I think the government should invite private investors and operators to install these plants. With a 99% Jamaican staff offering training and employment, and a view to sell to country after a number of years.	The utility (Grid owner) has the responsibility for grid stability. They should simulate and study the effect of RE on the grid. The RE plant operator/owner should be responsible for loss or power delivered due to load sheds (MW) caused by their facility
11	None	60min per year	Tariff should be covered by subsidies	Government and IPPs
12	Look at the current profile of the Wind output on the grid. This will show why a means of storage is necessary.	Momentary outages are not acceptable, the VRE penetration MUST also include a means to counter generation drops from the VRE	The entity that is coming online with the VRE should also be responsible for the Storage or associated device needed for grid stability	VRE IPP
13	No	That is difficult to say. At the moment MAIFI of < 5 mins is not penalised through the quality-of-service indices. This is a question that both the government and the OUR will need to consider keeping in mind that the objective of adding REs is also about lowering the cost of electricity.	The price of electricity is already considered high, so we need to be very careful of tariff impact. or it could result in more customers leaving the grid and driving prices even higher. International grants to reduce capital cost could be a big help and could be done through climate change funds as the increased RE penetration reduces GHG emissions.	The most realistic option is for a combination of Govt. actions through funding mechanisms - such as international grants/very concessionary loans for climate change funding with very modest tariff change to customers.

ジャマイカ国
バルバドス国
セントクリストファー・ネービス国

北米・中南米地域
カリコム省エネルギー推進プロジェクト

本邦研修受入業務完了報告書

2023 年 5 月

日本工営株式会社・株式会社パデコ

北米・中南米地域 カリコム省エネルギー推進プロジェクト
研修受入業務完了報告書

目 次

第1章 研修概要

1.1 研修コース名称

和文: カリコム省エネルギー推進プロジェクト 本邦研修

英文: Training in Japan for Technical Cooperation to Promote Energy Efficiency in Caribbean Countries

1.2 研修目的

本研修の目的は、カリコム諸国のうち 3 か国(ジャマイカ、バルバドス、セントクリストファー・ネービス)の再生可能エネルギー・省エネルギー分野の人材育成・組織能力強化のため「カリコム省エネルギー推進プロジェクト」(以下、「本プロジェクト」という)の総仕上げとして実施した。

1.3 研修員

3 か国、ジャマイカ、バルバドス、セントクリストファー・ネービスから計 9 名が参加した。本来はセントクリストファー・ネービスからもう 1 名、Mr. Keane Tudor Mark が参加し、計 10 名を予定していたが、経由地で来日を断念した。来日中止に係る詳細は 1.4.2 (2)に記載する。なお、渡航を断念したのは 1 週目の最終日であった。2 週目の研修プログラムのうち、一部の講義の録画を行い、Mr. Mark へ講義資料として提供した。

表 1-1 JICA 研修員リスト

氏名	国名	組織	役職
Leneka Terika Rhoden	Jamaica	MSET	Director of Energy Systems and Conservation
Todd Craig Johnson	Jamaica	MSET	Principal Director, Energy
Denasio Desmond Frank	St. Kitts and Nevis	MPI	Energy Officer
Michelle Wendy Rene Walters	St. Kitts and Nevis	NIA	Energy Commissioner
Keane Tudor Mark *	St. Kitts and Nevis	SKELEC	Electrical Maintenance Engineer
Nelson Horatio Ald Junior Stapleton	St. Kitts and Nevis	NEVLEC	Transmission and Distribution Manager
William Linsay A Hinds	Barbados	MEB	Chief Energy Conservation Officer
Horace Alair Archer	Barbados	MEB	Senior Technical Officer
Heather Patricia Sealy	Barbados	GEED	Deputy Chief Electrical Officer
Robert Anthony Harewood	Barbados	BLPC	System Engineer

注: Mr. Mark は往路のトリニダード・トバゴにて PCR テストを受検したところ、COVID-19 陽性であったため、当地で療養した。
出所:JET 作成

1.4 研修概要

1.4.1 研修実施方法

受注者(以下、JICA Expert Team, JET という)から本邦専門家へ講義、見学を依頼、研修プログラムを作成し、実施した。講師、見学先への依頼事項は以下の通りである。

(1) 講師

- 講義の依頼
- 講義教材の作成、提供
- 研修員からの質疑応答

(2) 見学先

- 見学の受け入れ
- 見学コンテンツおよびルートの設定
- 見学補助資料の作成（必要に応じ、見学先にて準備）
- 研修員からの質疑応答

1.4.2 研修日程

研修スケジュールは添付資料 1 の通りである。4/10（月）～4/21（金）に研修を受講、4/22（土）に離日した。

なおジャマイカ、セントクリストファー・ネービスについて諸事情により本邦への到着が遅れた。理由は以下の通りである。

(1) ジャマイカ

経由地アトランタでの飛行機遅れにより予定していた便へ搭乗できなかったため、飛行機の変更を行い、本邦には 4/10（月）に到着、2 日目の 4/11（火）より参加した。

(2) セントクリストファー・ネービス

VISA 取得のために立ち寄った経由地のトリニダード・トバゴにてワクチン接種 3 回未満者に水際対策で課されている本邦到着 72 時間前の PCR 検査を受検したところ、Mr. Keane Tudor Mark が陽性となった。同行していた他 3 名も陽性者と同じタクシーに同乗しており、マスクを着用していなかったため、日本の基準により濃厚接触者と判断された。濃厚接触者 3 名は判明後、2 日目、3 日目に受検した PCR 検査結果が陰性だったため、予定より 2 日遅れ、4/12（火）に本邦へ到着、4/13（水）から研修に合流した。

なお Mr. Mark については 6 日後の再検査、その後の再々検査も陽性となり、日程的に研修への参加が厳しくなったため、来日を断念した。

第2章 研修結果

2.1 研修プログラム概要および質疑応答

各日の研修概要と質疑応答を以下に示す。研修初日、4/10（月）はオリエンテーションのみであったため、割愛する。なお、発言者の国名は発言者氏名の最後に、J:ジャマイカ、B:バルバドス、S: セントクリストファー・ネービスとして記載する。

表 2-1 研修プログラムの概要および質疑応答

月日	概要・質疑応答
4 月 11 日 （火） 午前	●概要 プログラム名:Recent trends in EEC, Global and in Japan 講師:吉田　公夫、JICA　省エネコンサルタント ●質疑応答 Q1: (Mr. Horace Archer, B) CO2 排出量はどのように推移しているのか？ A1: (吉田氏) 日本では減少傾向にあるが、排出量が増加している国もある。世界全体としては、ほぼ横ばいの状況にある。 Q2: (Mr. Todd Johnson, J) 日本では CO2 排出量は減少傾向にあると述べていたが、どれくらいの速度か？ A2: (吉田氏) 日本の CO2 排出量は少しずつ、ゆっくりと減少している。 Q3: (Mr. William Hinds, B) エネルギーインテンシティが上昇するということは、例えば産業が発達して電力需要が上昇することが考えられる。この場合、GDP とエネルギー使用量の関係からどのように省エネが進んでいるのか、評価したらよいか？ A3: (吉田氏) GDP の上昇割合に比べ、エネルギー使用量の上昇割合が小さければ、省エネを推進できていると評価できる。 Q4: (Ms. Heather Sealy, B) 省エネの実例としてボイラの紹介があったが、その中でバングラデシュのボイラは爆発して、事故を起こしているとあった。この爆発の原因は何か？ A4: (吉田氏) Water tube などのボイラを現地では採用されていることが多く、圧縮された燃料が溜まりやすい構造になっている。そのため、日本で採用されている多缶ボイラに比べ危険性が高い。 Q5: (Mr. Horace Archer, B) 需要側電力使用量から全体の一次エネルギー消費量を推定するとどれくらいになるか？ A5: (吉田氏) 需要側電力使用量の約 3 倍ぐらいが全体の一次エネルギー消費量になる。 Q6: (Mr. William Hinds, B) ロシアのウクライナ侵攻以降、天然ガスの価格が 10 倍になったとあった。どのような国で価格上昇がみられたか？ A6: (吉田氏) EU、日本や韓国などの国で大幅な天然ガスの価格上昇が起きた。 Q7: (Mr. William Hinds, B) スライドの資料をみると、自動車に関する省エネとして EV しか記載がない。選択肢として、バイオ燃料を使った自動車は入らないのか？ A7: (吉田氏) 資料を参照した IRENA や IEA では EV しか記載がないが、選択肢としてバイオ燃料の自動車もある。また、水素自動車や燃料電池車も記載はないが、これらも選択肢として考えられる。従来の化石燃料を使用、かつ非効率的な内燃機関をもつ自動車の継続的使用が好ましくないということである。

月日	概要・質疑応答
4 月 11 日 （火） 午前	Q8: (Mr. William Hinds, B) 日本では 2035 年に、ガソリン車を廃止する目標があるというが、本当に廃止するのか？ A8: (吉田氏) この目標は実現するための目標ではなく、あくまでイメージとして掲げている目標であり、強制力は無い。 Q9: (Mr. Todd Johnson, J) Innovative Technology には原子力は含まれるのか？原子力はどのようなトレンドになっているか？ A9: (吉田氏) 選択肢として含まれている。ただし、技術的な部分だけでなく、政治的な部分についても十分注意を払う必要がある技術である。近年アジアでは原子力発電所の建設が急速に進んでいる。その 1 つにバングラデシュがあるが、バングラデシュの原子力発電所はロシア製である。バングラデシュはロシアとの関係を断ち切れない関係にあり、計画を止められない状況にある。 Q10: (Mr. Horace Archer, B) バルバドスではスライドで示されたように、何十年も同じ家屋を使うことがないが、なぜこのように長いのか？ A10: (吉田氏) ヨーロッパでは 100 年以上同じ家屋を使っている。また、日本でも 100 年近く同じ家屋を使うので、それらが含まれている。 Q11: (Mr. William Hinds, B) 温水などを作るためにボイラを使用しているとあるが、このボイラはどの範囲のものを指している？ A11: (吉田氏) 家、ビル、産業全てが含まれている。 Q12: (Mr. Todd Johnson, J) ジャマイカでは食品工場でボイラが使用されている。ボイラをヒートポンプへ転換するにあたり、どの点を気を付けるべきか？ A12: (吉田氏) 100℃以下の温水を扱うヒートポンプは商業化され、市場に出回っており、この温度帯であれば、ヒートポンプへの転換を推奨できる。一方、100℃以上になると価格が高くなり、コスト面から非推奨である。 Q13: (Mr. Horace Archer, B) 日本では化石燃料に関する税収を再エネ関連補助金へ充てているとあった。具体的にはどのようなものがあるか？ A13: (吉田氏) 再エネに関する設備の開発をサポートする補助金やや導入支援する制度に充てている。 Q14: (Mr. Robert Harewood, B) ZEH に関わる協会に登録するメリットは何か？ A14: (吉田氏) 政府からの認証を得られるだけでなく、所属する企業同士で情報交換できることである。 Q15: (Mr. William Harewood, B) ZEH に関わる協会に登録するメリットは何か？ A15: (吉田氏) 政府からの認証を得られるだけでなく、所属する企業同士で情報交換できることである。 Q16: (Mr. Todd Johnson, J) 日本における家庭での主な電気の使い道は何か？ A16: (吉田氏) 日本人はお風呂に入る習慣があるので、その温水器が一番電力を消費している。 Q17: (Mr. William Harewood, B と Mr. Todd Johnson, J) 九州地方では太陽光発電設備が多く導入されているとあった。大きな変動があったときはどのように対応しているか？ A17: (吉田氏) 系統で吸収できない変動があった場合は、太陽光発電設備を系統から解列するようにしている。

月日	概要・質疑応答
4 月 11 日 （火） 午後	●概要 プログラム名:日本の省エネ家電の取り組み 見学担当者:坂本　康弘、JET、株式会社パデコ ●質疑応答 Q1: (Mr. William Hinds, B) 省エネ表示の他にエアコンの消費電力等、スペックはどこに記載されているのか？ A1: (坂本氏) 省エネ表示が記載された掲示物に含まれている（記載箇所を指さしで説明）。 Q2: (Mr. Todd Johnson, J) 水銀灯は現在日本で使用されているのか？使用は認可されているのか？ A2: (坂本氏) 水銀灯の使用は現在認可されており、使用されている場所もある。 Q3: (Mr. Horace Archer, B) 日本では LED の効率が引き上げられているが、2023 年以降はどのように推移していくのか？ A3: (坂本氏) 2030 年には 100 lm/W となるように開発指標（トップランナー）が示されている。
4 月 12 日 （水）	●概要 プログラム名:FREA 見学、懇談、議論 見学担当者:大谷　謙仁、FREA　研究チーム長 ●質疑応答 Q1: (Mr. William Hinds, B と Mr. Robert Harewood, B) スマートインバータ、グリッドフォーミングインバータに関連した規格はどのような状況にあるか？ A1: (大谷氏) IEC で既に一部発行されている規格がある。IEC62786、IEC63409 になる。 Q2: (Mr. William Hinds, B) インバータのテストモデルに全体発電量のうち、70%を再生可能エネルギーとした場合のモデルはあるか？ A2: (大谷氏) 70%のモデルはない。 Q3: (Mr. Todd Johnson, J) インバータのテスト設備の容量はどれくらいか？ A3: (大谷氏) 5MW まで対応できる。 Q4: (Mr. Robert Harewood, B) インバータに適合規格の記載が無いものを導入しても良いのか？ A4: (大谷氏) 導入可否については、それぞれの国の基準による。 Q5: (Mr. Todd Johnson, J) 系統安定化にあたり、どの指標が重要か。 A5: (田岡氏) バッテリーのコストが重要である。また、グリッドフォーミングインバータは状況により、採算に見合うかどうか判断していく必要がある。解決策は他にも EMS (エネルギーマネジメントシステム)の導入もあり、両方を比較検討して、最良となる方法を検討するのが良い。 Q6: (Mr. Todd Johnson, J) スマートインバータとグリッドフォーミングインバータの違いは何か？ A6: (田岡氏) グリッドフォーミングインバータの一部の機能にスマートインバータが含まれているという認識してもらえればよい。グリッドフォーミングインバータはスマートインバータが持っている機能を有し、かつ新しい特徴を備えているインバータである。 Q7: (Mr. William Hinds, B) グリッドフォーミングインバータはいつ頃市場で調達可能となるか？ A7: (大谷氏) 導入時期は市場形成、動向による。また、FREA は研究機関なので、その点については言及できない。

月日	概要・質疑応答
4月12日 （水）	Q8: (Mr. Todd Johnson, J) グリッドフォーミングインバータには高周波対策機能はあるか？ A8: (大谷氏) インバータを製造するメーカーが対策を施すと考える。
4月13日 （木） 午前	●概要 プログラム名:ダイキンショールーム（フーハ東京） 見学先担当者:井上　究、ダイキン工業株式会社　東京支社渉外室　主事 ●質疑応答 Q1: (Mr. William Hinds, B) 湿度器の日本での平均価格は？ A1: (井上氏) 機種による。 Q2: (Mr. Horace Archer, B) フーハ東京は誰でも見学できる施設なのか？ A2: (井上氏) そうである。 Q3: (Mr. Robert Harewood, B) 熱循環させる機械は商品化されているのか？ A3: (井上氏) 日本では利用可能である。 Q4: (Mr. Heather Sealy, B) サブスクリプションで空調設備の導入、メンテナンスをしてくれるサービスは外国で提供しているか？ A4: (井上氏) 昨年導入されたばかりのサービスでまだ日本しかない。海外でも展開したい考えはある。 Q5: (Mr. Nelson Stapleton, S) なぜダイキンの VRV（天井据え付け型の空調機）は海外で成功しているのか？ A5: (井上氏) 他メーカー比べて、据付工事のしやすさが大きいと分析している。
4月13日 （木） 午後	●概要 プログラム名:Tokyo Denki University, Tokyo Senju Campus, The strategy to the reduction of CO2 emission 講師:百田　真史、東京電機大学未来科学部建築学科　教授 ●質疑応答 Q1: (Mr. Horace Archer, B) 災害が発生した時はなぜ 72 時間も同じ建物にいなければならないのか？ A1: (百田教授) 東京都のルールになる。一斉に帰宅すると、二次災害が起こる可能性が高くなる。 Q2: (Mr. William Hinds, B) 人の数はヒートセンサーで感知しているのか？ A2: (百田教授) 人の姿を認識できるアルゴリズムを搭載したセンサーになる。 Q3:(Mr. William Hinds, B) 地表の温度はどれくらいか？ A3: (百田教授) 季節変動はあるものの、年平均 15℃くらいである。 Q4: (Mr. Robert Harewood, B) 東京電機大学のキャンパスの建物に導入された技術は他の日本の建物に導入されているのか？ A4: (百田教授) Air Flow Windows は 30～40 くらいの建物に入っていると言われている。太陽光の反射フィルムは東京電機大学のみである。 Q5:(Mr. Horace Archer, B) 学生が部屋の中で移動したりすると、それ感知して空調が自動で動くのか？

月日	概要・質疑応答
4 月 13 日 （木） 午後	A5: (百田教授) 空調にそのようなアルゴリズムが搭載されていて、自動で調整してくれる。 Q6: (Mr. William Hinds, B) バルバドスでは出入口にセンサーがあって、それを使って省エネ制御を実現できるか？ A6: (百田教授) 可能だと考える。
4 月 14 日 （金）	●概要 プログラム名:ウィンド・パワーかみす洋上風力発電所 見学先担当者:小松崎　忍、ウィンド・パワー・グループ ●質疑応答 Q1: (Mr. William Hinds, B) 岸に近い理由は？ A1: (小松崎氏) 本事業は日本初であり、13－15 年前の当時は洋上建設できる建設用の船が無かった。建設は全て陸上から行う必要があった。現在は建設用の船がある。 Q2: (Mr. Horace Archer, B) 次期オフショアに 3 年かかる理由は？もっと早くできないのか？ A2: (小松崎氏) 準備で 10 年かかっている。想定していた日立が風力から撤退したため、代わりのメーカーを探す必要があったためである。 Q3:(Mr. Denasio Frank, S) 次期事業の水深、沖合への距離、許認可に苦労した点は？ A3: (小松崎氏) 遠浅で水深は 5-25m。沖合へは 2 km。認可については漁業との調整が難しい。欧米と異なり日本は漁業と場所を取り合う。 Q4: (Ms. Heather Sealy, B) 海水に対する強さやメンテナンスはどう行っているか。メンテで多い問題は？ A4: (小松崎氏) メンテンタンスブリッジがあり故障してもいつでも修理に行ける。沖合の場合は荒天の際に海が落ち着き船を出す日を待たねばならない。定期メンテを 2 回/年、部品交換を 3 年/年実施。次期事業はメーカーから年 1 回のメンテで良いと聞いている。故障は起きうるものと考える必要がある。メンテナンスエンジニアの常駐が必要。ナセルのギア故障が多く、よく交換が必要になる。 Q5:(Mr. William Hinds, B) 風車の高さは？ダウンウインド型を選定した理由、日立を選定した理由は？ A5: (小松崎氏) 風車の高さは 60m。日立は県内の地元企業。日立が採用したのがダウンウインド型だった。この地域で 2MW タービンは 50 機採用されている。安定した出力を出せるのが利点。 Q6: (Mr. Robert Harewood, B) 風力発電の変動による系統への影響は？ A6: (小松崎氏) この地域は鹿島臨海工業地帯で東電管区内の送電線の容量が大きい為、問題になっていない。(中川):東電管区で 20MW 以上あり、100MW の風力が入ってもさほど問題にはならない。系統容量に対し RE の多い九州や東北、北海道では出力抑制が行われている。 Q7: (Mr. Horace Archer, B) 次期事業のシーメンスとの契約は、建設、機器、メンテなどどこまでカバーしているのか。投資回収年は？またローンか、サプライヤークレジットか？ A7: (小松崎氏) 土木建設は別。シーメンスは機器共有とメンテのみ。メンテ要員は常駐する契約。資金はウィンド・パワー社による自社投資。借入れは無い。投資回収年は 10 年を想定。機器は 20 年寿命。 Q8 :(Mr. Robert Harewood, B) 変電所はどこか？ A8: (小松崎氏) 地下ケーブルで 2km 先の 6600V 線に連系している。風車の発電は 1400V。 Q9: (Mr. Horace Archer, B) 保険はどのようにかけているのか？補償内容をどう決めたのか？

月日	概要・質疑応答
4 月 14 日 （金）	A9:(小松崎氏) 建設当時保険の例がなかったため、一つ一つ保険会社と条件を決めた。特に雷の故障が多い。鹿島地域は雷が少ないので保険対象になったが、日本海側など他の地域は多すぎて保険がカバーしない。保険会社は雷の統計を持っている。 Q10: (Mr. Todd Johnson, J) 避雷はどのように行っているのか。防ぐ方法は？ A10: (小松崎氏) ブレードの中に避雷針が埋め込まれている。後のことは、事業者は祈るしかない。 Q11: (Mr. William Hinds, B) 風況のモニタリングは行っているのか？ A11: (小松崎氏) ドップラーライダーで行っている。レーダー式で沖合の風速も観測している。 Q12: (Mr. William Hinds, B) なぜ日立は風力発電から撤退したのか。 A12: (小松崎氏) 日立と共に WindPower 社が 5MW 風力発電機を開発していたが、市場では 7，8，10MW と次々と新しいタービンが出回り、開発が追い付かなくなって諦めた。次期事業では 8MW の風車を導入する。
4 月 17 日 （月） 午後その 1	●概要 プログラム名:来間島マイクログリッド Recent trends in EEC, Global and in Japan 見学先担当者:塩浜 智洋、沖縄電力㈱ カーボンニュートラル推進本部 研究開発部 技術開発グループ 係長 ●質疑応答 Q1: (Mr. Horace Archer, B) なぜ蓄電池の設置エリアの周囲には壁があるのか？ A1: (新垣氏) 蓄電池の稼働率が高くなると、冷却ファンの音が大きくなってくる。周囲には住宅もあるので、騒音対策として設置している。 Q2:(Mr. William Hinds, B) 来間島のマイクログリッドで発電した電力が余った際はどうしているか？ A2: (塩浜氏) 宮古島へ送っている。 Q3: (Ms. Heather Sealy, B) 来間島のホテルがメンテナンスなどに止まっているときは、どのように制御しているのか？ A3: (塩浜氏) 島内の発電量が十分である場合、ホテルへの電力も 0 となるようにするために、宮古島から送られてくる電力が 0 となるように制御を行うようにしている。 Q4: (Mr. William Hinds, B) 災害時は来間島は宮古島と切り離され、独立したマイクログリッドとなることは理解した。しかし来間島にあるホテルはマイクログリッドの系統内にいない構成になっている。災害時のホテルへの配電はどうなるのか？ A4: (塩浜氏) 来間島は住宅を最優先としているため、ホテルは解列されて配電が止まるようになっている。 Q5: (Mr. Robert Harewood, B) 来間島は宮古島と電気的に連携しているとのことだが、どのように接続しているのか？ A5: (塩浜氏) 来間島へ来るために橋を渡ってきたと思うが、橋の中にケーブルを入れるスペースがあり、そこを通じで接続している。 Q6: (Mr. Horace Archer, B) 来間島の住宅などに設置されている太陽光は、住宅居住者ではなく IPP が所有しているとのことだが、住宅居住者にとって、太陽光発電設備を IPP 所有として導入するメリットは何か？ A6: (塩浜氏) 1 つ目は、IPP は補助金を受けた実証事業で設置を行ったため、補助金分だけ導入コストが低減されている。よって、沖縄電力から電気を購入するより、電気料金が若干安い。2 つ目は、災害時には太陽光発電設備と一緒に設置されている蓄電池から電気を賄うことができるため、レジリエンスがある。

月日	概要・質疑応答
4 月 17 日 （月） 午後その 2	●概要 プログラム名:宮古メガソーラー実証跡地 見学先担当者:田岡　久雄、辻　智明、JET、日本工営株式会社 ●質疑応答 Q1: (Ms. Heather Sealy, B) 実証試験中に台風が到来し、被災したとあった。それはいつぐらいのことか？ A1: (田岡氏) 2019 年である。
4 月 18 日 （火） 午前その 1	●概要 プログラム名:狩俣風力発電所 見学先担当者:伊波　幸男、沖縄新エネ開発㈱　事業開発・設備運用グループ　主任 ●質疑応答 Q1: (Mr. Horace Archer, B) 台風により風車が折れたとのことだが、どの辺から折れたのか？ A1: (伊波氏) 根本付近のメンテナンス入口から折れた。構造上、入口付近の強度が弱いためである。また、当時 2 本の風車が折れたが、奇しくも同じ方向にメンテナンス入口が向いていた風車が折れた。残りの 1 本は入口が少し違う方向を向いており、台風から受けていた力の方向が若干逸れて入口に力が加わらず、風車が折れなかったのではないかと分析している。 Q2: (Mr. Nelson Stapleton, S) 沖縄新エネ開発（株）は IPP か？ A2: (伊波氏) そうである。 Q3: (Mr. William Hinds, B) 固有振動の対策はどうなっているか？ A3: (伊波氏) いくつかセンサーが取り付けられており、振動数を感知して共振しないようにしている。 Q4: (Mr. William Hinds, B) 風車により周辺の生物への影響、例えばバードストライクは起きているか？ A4: (伊波氏) 設計前に 1 年間の調査を行い、動物や植物について調べる。この際、狩俣地域では風車のブレードぐらいの高さを飛ぶような鳥はいないと分かった。なお、今までバードストライクは起きていない。 Q5: (Mr. Robert Harewood, B) 風車で発電した電力を変圧する変圧器はどこに設置されているかか？ A5: (伊波氏) 風車の根本にある。 Q6: (Mr. William Hinds, B) 風車の発電機は同期発電機か？ A6: (伊波氏) そうである。
4 月 18 日 （火） 午前その 2	●概要 プログラム名:宮古第二発電所 見学先担当者:砂川　直哉/平良　寛和、沖縄電力㈱ 離島カンパニー　宮古支店 発電グループ　砂川マネージャー、平良係長 ●質疑応答 Q1: (Mr. Nelson Stapleton, S) ディーゼル発電機はどこのメーカーか？ A1: (砂川氏) Diesel United というメーカーである。 Q2: (Mr. William Hinds, B) 今日の発電電力はどれくらいか？また時期によるが、最低発電電力はどの程度か？再エネ変動に対する予備力はどうなっているのか？

月日	概要・質疑応答
4月18日 （火） 午前その2	A2: (砂川氏) 今の時間は 20MW くらいになる。再エネにとって好条件がそろった日はさらに低下し、12MW 程度の出力で運転している。各ディーゼル発電機の定格出力の半分くらいで運転し、残りの半分が予備力となっている。 Q3: (Mr. Nelson Stapleton, S) 風力からの電力はどの程度系統へ入っているか？ A3: (平良氏) 風力だけでなく、全ての再エネをまとめて誰かが監視している訳でないので、実際のところは分からない。再エネをまとめている各 IPP から情報を得て、確認するしかない。一方、分散型 PV がどれくらい入っているかは把握が難しい。 Q4: (Mr. Nelson Stapleton, S) 例えば系統に接続されている風力発電機が停止すると、この発電所のモニターで表示されている発電出力は上昇するのか？ A4: (平良氏) その通りである。 Q5: (Mr. Todd Johnson, J) デマンドレスポンスはどのように判断して行っているのか？ A5: (平良氏) LFC（Load Frequency Control）という装置があり、その装置が系統の周波数変化を検知、自動で発電機へ制御指令を出す。 Q6: (Mr. Horace Archer, B) 系統安定度をどのように保っているのか？ A6: (平良氏) LFC と短時間の天気予測を行い、予想を立てながら運転している。 Q7: (Mr. Todd Johnson, J) 沖縄電力としての脱炭素方針はどのようなものがあるか？小型モジュール炉（原子力）は計画にあるか？ A7: (砂川氏) 沖縄本島では脱炭素に向けて取り組みを段階的に行っている。一方、離島での電力事情を考えると、ディーゼル発電機を全て無くすことについては難しい部分がある。また、原子力については、現時点で将来計画に含まれているとは聞いていない。 Q8: (Mr. Robert Harewood, B) 発電機の運転は変動が大きくても自動で行っているのか？ A8: (平良氏) 変動調整が自動制御で間に合わない場合は、手動で調整を行っている。 Q9: (Mr. Nelson Stapleton, S) なぜガスタービンではなく、ディーゼル発電機を優先して動かしているのか？経済的に優位なのか？ A9: (砂川氏) その通りである。ディーゼル発電機の方が、経済的優位性がある。
4月18日 （火） 午後	●概要 プログラム名:再エネ導入拡大による周波数へ与える影響、再エネと大型蓄電池を用いたピークシフト対応 講師:塩浜　智洋、沖縄電力㈱ カーボンニュートラル推進本部 研究開発部 技術開発グループ 係長 ●質疑応答 Q1: (Mr. Nelson Stapleton, S) 風力発電機のバックアップとして設置されている非常用発電機はどれくらいの容量が適切なのか？ A1: (塩浜氏) 状況によるが、風力発電の定格の 10～20%程度は必要だと思われる。設計段階になって、どの程度必要になるか確認することが肝要である。 Q2: (Mr. William Hinds, B) 沖縄電力では系統周波数制御の上限、下限を 60Hz の±0.3 Hz で制御しているとのことだが、これは日本の法律に則って決めているのか？

月日	概要・質疑応答
4月18日 （火） 午後	A2: (塩浜氏) 電気事業法等では電圧については定められているが、周波数はそうではない。各地域の電力会社が決定し、それに基づき周波数制御を行っている。 Q3: (Mr. William Hinds, B) 周波数変動によって、需要家への影響はどのようなものがあるか？ A3: (塩浜氏) 電圧であれば、変動によって家庭の照明がチラついたりする。周波数変動が住宅などの一般的な需要家へ与える影響は小さい。しかし、工場などの回転機械や精密機械がある特別な需要家では周波数の影響を受けることがある。一方、離島はそのような特別な負荷があるわけではないので、そもそも会社が定めた周波数の上限、下限を守って運用するべきかどうか、議論が為される場合がある。 Q4: (Mr. William Hinds, B) 大量の再エネが入ってきた場合は AFC（Auto Frequency Control）をどのようにすれば良いか？ A4: (塩浜氏) 制御の幅を持たせるために、AFC 対象発電機を広げ、AFC 装置を 2 台に増やして分担させたり、バッテリーを系統に導入して調整能力を持たせたりと、そのようなことが考えられる。 Q5: (Mr. William Hinds, B) 再エネが好条件で発電しているときには、これらが系統の全発電量の何%程度を占めているか？ A5: (塩浜氏) 手元に情報がないため断定はできないが、宮古島の場合は 50%程度の再エネが入っていると推測する。 Q6: (Mr. William Hinds, B) バッテリーの制御は ΔP 制御と Δf 制御のどちらで制御した方がよいか？ A6: (塩浜氏) 電力会社から制御できるのは Δf である。一方、個別に監視できる場合、例えば IPP 所有の再エネ発電設備に細かく監視できる装置があるならば、各々に責任を持たせて ΔP での制御をすることも可能である。 Q7: (Mr. Robert Harewood, B) ΔP 制御の方がよりバッテリー容量を必要とするのか？ A7: (塩浜氏) その通りだと考える。なお、日本では大型の再エネ発電設備を導入する事業者には系統周波数への影響を小さくするため、バッテリーの導入とそのバッテリーを用いて系統へ出力する電力の周波数制御を義務付けている。 Q8: (Mr. Todd Johnson, J) どの程度再エネ導入が進むと、ΔP 制御の方が優位になるか？ A8: (塩浜氏) 分散型 PV 含め、全ての発電設備を監視でき、個々の変動を検出できるのであれば、ΔP 制御の方が優位になると考える。しかし、そのように全てを監視するのは日本では難しいため、系統周波数を見ながら制御することになるため、Δf 制御が選択肢となる。 Q9: (Mr. Todd Johnson, J) 再エネの発電割合に基づいて、ΔP 制御と Δf 制御を比較検討するようなアルゴリズムはあるか？ A9: (塩浜氏) そのような手法はまだ確立されていないと考える。
4月19日 （水） 午前	●概要 プログラム名:Demand Side Management in Electric Power 講師:佐々木　正信、東京電力エナジーパートナー株式会社 販売本部　副部長 ●質疑応答 Q1: (Mr. Nelson Stapleton, S) 電気料金の段階性料金について、詳しく説明してほしい。また、Demand Charge についても詳しく。 A1: (佐々木氏) 使用電力量を 3 つに区切って、それぞれの範囲で価格を設定、各需要家の使用量に応じて電気料金を計算している。また、Demand Charge はピーク電力の値に応じて、計算している。 Q2: (Mr. Horace Archer, B) ショッピングモールの省エネ紹介で下水を予熱などに利用しているとあったが、そのシステムで使用されている下水はどこから来ているのか？

月日	概要・質疑応答
4 月 19 日 （水） 午前	A2: (佐々木氏) 公共、すなわち地元自治体の下水場から持ってきている。 Q3: (Mr. William Hinds, B) NAS バッテリーの運転温度はどれくらいか？ A3: (佐々木氏) 運転温度は 400℃くらいになる。また、内部ではなくバッテリーの外側は 25～30℃程度になる。 Q4: (Mr. Horace Archer, B) 電力の予備力を大きくすれば、電力抑制に係る度合いも減らすことができるのではないか？ A4: (佐々木氏) 確かにその通りであるが、それは供給側の対策で従来のやり方になる。これからは需要側の制御も必要になるため、電力抑制手法やその取り組みに重きを置いている。 Q5: (Mr. Horace Archer, B) アグリゲーション、アグリゲーターについてもう詳しく説明してほしい。 A5: (佐々木氏) アグリゲーションコーディネーターは公的機関ではなく、民間会社である。発電設備をもつ電力会社などから需給調整に係る手数料をもらい、収益を上げるビジネスモデルである。元々欧州や米国でビジネスモデルがあったが、日本の発送電分離により電力市場が開かれ、海外の会社が参入してきている。手数料の金額はアグリゲーションを行う会社が収益を考えて、独自に決めている。 Q6: (Mr. William Hinds, B) 電気料金は毎時変わるのか？ A6: (佐々木氏) 一般的な需要家にはこの仕組みは提供されておらず、電気小売業を行っている会社へ卸価格として反映される。 Q7: (Mr. Nelson Stapleton, S) 省エネ手法の研究として始まった水素実証事業はいつごろから開始されているのか？ A7: (佐々木氏) 2021 年から開始した新しいプロジェクトである。
4 月 19 日 （水） 午後	●概要 プログラム名:東京電力グループにおけるエネルギーサービス事業について 講師:佐藤　大輔様 ●質疑応答 Q1: (Mr. Nelson Stapleton, S) ESCO 事業を提供対象となる顧客をどうやって見つけているのか？ A1: (佐藤氏) TEPCO は電力会社であり、様々な企業様と取引をしている。その中でニーズを見つけ、ESCO 事業を提案してきた。ただ対象となるのは、需要が大きなお客様、例えば工場などである。 Q2: (Mr. Horace Archer, B) 省エネ事業の推進結果を示したスライドによると、当初はその企業ではガスを使っていたもののESCO 事業を実施した後、ガスの使用量がほぼゼロになっている。これはなぜか？ A2: (佐藤氏) ガス式で使用していた設備を電気式（ヒートポンプ）へ転換したためである。 Q3: (Mr. William Hinds, B) ESCO 事業の競合他社がいるのか？どのようにビジネスモデルを保っているのか？ A3: (佐藤氏) お客様でも出来る範囲はあるが、省エネの専門家がいないので、より詳細な省エネ活動が必要な場合、そこにコンサルティングとしてのニーズがある。また、競合会社としてはガス会社や他地域の電力会社、それに加え制御機器メーカーも入ってくる。 Q4: (Mr. Nelson Stapleton, S) ESCO 事業は関東エリアだけなのか？ A4: (佐藤氏) 日本全国で展開している。コンサルタントとしても海外で展開している。 Q5: (Mr. William Hinds, B) 海外でも、例えばバルバドスでもやってもらえるのか？

月日	概要・質疑応答
4月19日 （水） 午後	A5: (佐藤氏) タイで事務所を作ってビジネスを展開し始めているが、正直苦戦している。理由としてはその国々の仕事の仕方、メンテナンス方法などが大きく異なることが原因である。しかしながら、将来的には海外展開を広げていきたい。 Q6: (Mr. Nelson Stapleton, S) 省エネ事業に係る資金や設備はどうしているのか？資金回収は予定通りできているのか？ A6: (佐藤氏) 設備はリース会社から借りており、それを省エネ事業として顧客へ貸し出し、その際、弊社グループと顧客の間の契約で決められた定額の支払いを通常 15 年で回収して、収益としている。また、資金回収率は 100%である。 Q7: (Mr. Horace Archer, B) 省エネ事業を推進すると、使用する電力量が小さくなる。そうすると、顧客は浮いた分の電力量分で稼働率を上げるなど、電気を多く使うようになるのか？ A7: (佐藤氏) そのようなことは聞いたことが無い。顧客は ESCO サービス範囲以外の電気料金を抑えるために省エネ化を進めている。
4月20日 （木） 午前	●概要 プログラム名:Energy Conservation Policies of Japan 講師:鷲見　元宏、省エネルギーセンター国際協力本部　国際調査・連携部長 ●質疑応答 Q1: (Mr. William Hinds, B) 2007 年ごろから GDP は成長しているのに、日本全体でのエネルギー使用量が下がって来ている。この原因は何か？省エネ施策によるものか？ A1: (鷲見氏) 産業分野での省エネ化が進んできたことが一因である。直接関わりがあるわけでないため明言はできないが、輸送分野でも省エネ技術の発達、導入によりエネルギー使用量が小さくなったのだと推測する。 Q2: (Mr. Robert Harewood, B) 省エネ法は誰がレビューしているのか？ A2: (鷲見氏) 政府が省エネ委員会を有しており、彼らがレビューを行っている。 Q3: (Mr. Denasio Frank, S) 省エネ計画の提出を公的機関から要請された場合、要請を守らず提出しなかった場合はペナルティはあるのか？ A3: (鷲見氏) 罰金が科される場合がある。ただし、これまで何かしらのペナルティを科されたケースは聞いたことは無い。 Q4: (Mr. Heather Sealy, B) キャリアーとコンサイナーの両者が掲げた省エネ目標を達成しなければならないのか？ A4: (鷲見氏) 目標に向かって最大限取り組むことが 1 つのゴールであり、必ずしも省エネ目標を達成しなければならない訳ではない。取り組む中で目標達成が難しいことが判明する場合もある。また、達成しなかった場合のペナルティは無い。 Q5: (Mr. Heather Sealy, B) 省エネ法の内容が改正され、新しい基準を満たさない設備が出てきた場合、新しい基準を満たすための設備導入計画を作成し、それを公的機関へ提出しなければならないのか？ A5: (鷲見氏) その通りである。ただし、これに該当するのは一定以上の大きさをもつ建物、施設が対象となる。 Q6: (Mr. William Hinds, B) カーボンリサイクリングとは何か？ A6: (鷲見氏) メタネーションという技術で、大気中の二酸化炭素をメタンに戻すものである。 Q7: (Mr. Horace Archer, B) 建築物の省エネシミュレーションソフトウェアで計算しているとあったが、それはどんなソフトか？

月日	概要・質疑応答
4 月 20 日 （木） 午前	A7: (鷲見氏) DOE2 という米国でも使用されているソフトだと聞いている。
4 月 20 日 （木） 午後	●概要 プログラム名:Renovation Technologies that Optimize Renewable Energies; Targeting a Zero-Energy Building (ZEB) 講師:塩谷　正樹、三建設備工業技術総括本部　開発グループ　つくばみらい技術センター　主任研究員 ●質疑応答 Q1: (Mr. Nelson Stapleton, S) 地下水熱について、もう少し詳しく説明してほしい。 A1: (塩谷氏) 地下水は 1 年中安定しており、16℃くらいである。よって、夏は外気より低い温度の水をくみ上げることができる。これを利用して、建物の内外の冷却に利用している。 Q2: (Mr. William Hinds, B) 省エネ推進で CO2 排出量を削減すると、再エネ導入により削減するのではどちらの方が安いのか？ A2: (塩谷氏) ZEB Ready の段階までであれば、省エネの方が安い。さらに ZEB 化を進めるためには再エネ導入が必要になってくるので、ZEB 化を進めれば進めるほど初期費用が高くなってくる。 Q3: (Mr. Horace Archer, B) このビルで採用されている太陽熱温水器は真空式か？ A3: (塩谷氏) 平板式という安価なものを使用している。空調のみに太陽熱を利用しているので、真空式ほどの蓄熱能力は必要ない。もしもっと高い温度が必要であれば、真空式の方が良い。 Q4: (Mr. Horace Archer, B) この建物の部屋の天井に設置された吸熱パネルはどのような熱を吸収するのか？ A4: (塩谷氏) 人体から出た熱で暖められた空気だけでなく、周囲の空気の熱も吸収する。 Q5: (Mr. Horace Archer, B) 自動制御で建物全体の空調を動かしているとのことだが、この部屋の窓も自動で運転されていて窓が開いて、自然換気をするようになっているのか？ A5: (塩谷氏) 窓の開け閉めは手動で行っている。制御装置で現在の状態が色で示されており、今日は緑色だったので、手動で窓を開け自然換気としている。 Q6: (Mr. Horace Archer, B) この建物は日本ならではの気候を考慮して ZEB 化されているが、他の気候でも ZEB は成立するのか？ A6: (塩谷氏) それぞれの地域に合った方法があるはずで、それを検討、色々な技術を組み合わせて試しながら取り組みことで、地域に見合った ZEB 化をできると考えている。 Q7: (Mr. Horace Archer, B) 今日紹介してもらったそれぞれの技術は、商業向けのものなのか？それとも住宅規模でも適用できるものなのか？また、それはコストに見合うのか？ A7: (塩谷氏) まずこの建物はコスト重視ではなく、色々な省エネ技術を取り入れて ZEB 化することが主な目的である。この建物でやったことをそのまま適用すると、コスト的には資金回収に 20 年以上かかると推測する。ただ、状況やコストに応じて各技術を適用できる場合もあると考える

月日	概要・質疑応答
4 月 21 日 (金) 午後	●概要 プログラム名:エリーパワー 川崎事業所(蓄電池工場) 見学先担当者:桝本 浩司、上席執行役員 営業第一部長 ●質疑応答 Q1: (Mr. William Hinds, B) 何 MW までの容量が可能か？ A1: (桝本氏) アセンブルにより容量は増やせる。 Q2: (Mr. Horace Archer, B) 7,000 サイクルの試験と、温度環境を変化させたときの試験の条件の違いは？ A2: (桝本氏) 17,000 サイクルは標準の状態。エリーパワー製は-20℃から 60℃まで安定的に使える。 Q3: (Mr. Todd Johnson, J) 次のシリーズはいつ頃市場に出されるか？ A3: (桝本氏) 2023 年 6 月以降になる。 Q4: (Mr. William Hinds, B) 1MW 当りのコストは？バッテリーのコントロール、管理システムはあるか？ A4: (桝本氏) ビジネスによる。また世帯用、産業用など、システムの規模による。中国などに比べると生産規模は大きくなく競争性は高くない。コモディティとしてではなく、高い安全性等 独特な仕様に答えることに弊社の強みがある。 Q5: (Mr. Robert Harewood, B) ダメージを受けても運転を続けられるのか？ A5: (桝本氏) 場合による。ダメージの状況、運転環境を調べ、検査する必要がある。 Q6: (Mr. Todd Johnson, J) 世帯用の容量のラインアップは？ジャマイカ最小ロットはどの程度か。Power iE5 Link の 5.4 kWh の価格は？世帯用がほとんどか？ A6: (桝本氏) 1.3 kWh から 65.1 kWh まで。ロットが小さいと輸送費が高い。コストは販路による。ダイワハウスを通しての販売が通常。ダイワハウス側のコストによる。産業用は Power Storager D20 がある。 Q7: (Mr. William Hinds, B) 輸出はしているか？EMS は？ A7: (桝本氏)現在は日本市場向け。輸出にはローカルパートナーが必要。EMS を設計するが、販売はしていない。また、EMS はボリュームや求められるシステムによる。 Q8: (Mr. William Hinds, B) 充電プロセスで特別な手順はあるか？ A8: (桝本氏) システムの要求、環境による。EMS がコントロールする。 Q9: (Mr. Robert Harewood, B) グリッド接続の典型的なアプリケーションは？PV と接続した場合の図面はあるか？ A9: (桝本氏) 今は PV のある住宅向けがメイン。系統接続の場合の設計も理論的には可能。マッチしない PV システムもある。システムのリンクが欠けて難しい場合がある。 Q10: (Mr. William Hinds, B) 系統に接続する場合の同期は？上手くいった場合のインバータの例など情報はもらえるか？ A10: (桝本氏) 設計する。ユーティリティとの調整が必要。海外の事務所がまだないので、情報提供は現時点では難しい。 Q11: (Mr. William Hinds, B) 金額が高いがどのように競争性を出すのか？ A11: (桝本氏) 高いのは承知。安全性と長い寿命が売りである。地震の懸念や高温などシビアな環境で用いる用途の市場ニーズに答えている。寿命が長い為トータルライフコストでは競争性が出てくる。中国製は 5000 サイクル以下。

月日	概要・質疑応答
4 月 21 日 (金) 午後	Q12: (Mr. Robert Harewood, B) 10 年後の充放電効率へ影響は？ A12: (桝本氏) 充放電効率は秘密事項なので開示には NDA が必要。 Q13: (Mr. Todd Johnson, J) バイクのマーケットはどこを対象にしているか。プロダクトはとても良い。カリブ、米国、豪州をマーケットとするのには、コストが鍵では？ A13: (桝本氏) 日本だけではなく欧州もターゲットだがコストが鍵。もちろんその点は認識している。良いローカルパートナーがいれば共に考えたい。 Q14: (Mr. William Hinds, B) ToU (Time of use) はあるか？それを利用したマーケットは？一般家庭には蓄電池は高価だ購入者はどうやって投資しているのか。 A14: (中川、JET) 契約オプションにより深夜料金がある契約もある。将来的にはそのマーケットがあると考えている。一般家庭の新築コストに盛り込んでローンに含め、ライフサイクルコストとして考えて対応している。

出所:JET 作成

2.2 研修成果発表会

研修最終日に、研修成果発表会、閉講式を実施した。研修成果発表会では、各研修員から 1 人 5 分程度、パワーポイント 5 スライド程度で、

① 自国の再エネもしくは省エネに関する課題

② 本邦研修を受けて、自国の課題解決のために取り入れたい日本の技術や知見

③ 今後 JICA や日本政府から支援を受けたい分野や取り組み

について発表した。

2.2.1 研修成果発表の質疑応答

発表内容を基に JET や JICA から質疑応答を行った。その質疑応答を以下に示す。なお、研修員全員が発表を行い、質疑応答を以下に記載する。

表 2-2 研修報告会 質疑応答

質疑応答、コメント
●発表者：Mr. Todd Johnson, MSET, Jamaica Q1: (中川、JET) IRP2 の最終化の予定は？ノンテクニカルロスが大きな課題だが IRP2 ではノンテクニカルロスを減じるための対策を含めているか。また IPR3 を実施する方針の場合、今後のスケジュールは？ A1: (Mr. Todd Johnson, J) IRP2 はステークホルダー協議中。IRP2 にノンテクニカルロス対策は入っていない。IRP3 で含めるのが良い。IRP3 は必要と認識しているが、IRP2 の最終化がまず先。スケジュールなどはまだ決めていない。 Q2: (蝦名、JET) ノンテクニカルロスの解決策や展望はあるか？ A2: (Mr. Todd Johnson, J) 1 つは系統側の対策で地中にケーブルや電線を埋めてしまえば、容易に盗電できないと考えている。もう 1 つは、マイクログリッド化することである。マイクログリッドにすれば、接続箇所と計器が管理できるので、盗電している場所を検知しやすくなる。検知したら、その箇所を切り離せば盗電対策になると考える。

質疑応答、コメント

●発表者：Ms. Leneka Rhoden, MSET, Jamaica

C1: (坂本、JET)
本プロジェクトで提供したデータロガーを活用して電力消費量、特に家電製品を計測してほしい。計測対象地域、家族構成、対象機器など、実行計画を立案して頂きたい。

Q1: (中川、JET)
CO2 排出削減量を満たすために日本のユーティリティが排出削減量取引に関心を抱いている。ジャマイカの排出権取引を行う方向性か？

A1: (Ms. Leneka Rhoden, J)
CO2 削減として一案だと考える。

●発表者：Mr. Nelson Stapleton, NEVLEC, St. Kitts and Nevis

Q1: (Mr. William Hinds, B)
地熱プロジェクトの進捗状況はどうか？

A1: (Mr. Nelson Stapleton, S)
最初の 10MW について現在試掘の調達中。Phase 2 で、地熱発電で発電した余剰電力をセントキッツ側へ送る。次の Phase 3 は、余った地熱の電力を水素などに変換して海外へどうやって輸出するかを検討する段階になる。

●発表者：Mr. Denasio Frank, MPI, St. Kitts and Nevis

Q1: (Mr. William Hinds、B)
St. Kitts にも地熱のポテンシャルがあるが。Nevis と連系する方針なのか。

A1: (Mr. Denasio Frank, S)
St. Kitts は試掘もまだである。Nevis の方が地熱開発ポテンシャルは大きい。

Q2: (中川、JET)
St. Kitts 島と Nevis 島の連系計画についての公的文書はあるか。JICA や他のファイナンスの可能性の為には政府計画として示されていることを明示する必要がある。

A2: (Ms. Michelle Walters, S)
10 数年前に F/S を実施したことはある。

●発表者：Mr. Robert Harewood, BLPC, Barbados

Q1: (中川、JET)
現在調達中の 10 MWx6 か所の BESS について、1Cycle/day の想定とのことだが、バルバドスは通常より変動が激しくサイクル数に影響する可能性がある。サイクルへの影響について考慮して調達したのか？

A1: (Mr. Robert Harewood, B)
キャパシティギャランティを適用して、寿命までの要求した能力を出すことを保証する機器を調達し契約する予定である。

Q2: (蝦名、JET)
スマートメーターは導入しているか？

A2: (Mr. Robert Harewood, B)
直近で始まったばかりの計画にスマートメーターの導入が入っていると思う。

●発表者：Ms. Heather Sealy, GEED, Barbados

Q1: (中川、JET)
世帯のオーナーにとって BESS のコストが高く購入が難しいとあった。IPP の集中型には接続要件で義務付ければよいが、分散型のオーナーに系統安定化を求める仕組みや方針はあるか？

A1: (Mr. Horace Archer, B)
彼女の代わりに回答する。来間島 MG のように太陽光発電設備とバッテリーの両方を踏まえた料金設定とし電気料金から回収する形のサービスを提供できれば、分散型 PV からも系統安定化に寄与できると考える。

●発表者：Mr. Horace Archer, MEB, Barbados

C1: (坂本、JET)
東京都の例を挙げると、20 年ほど前、東京都の省エネ活動は 2、3 名の職員から活動が始まった。限られた職員がエネルギー消費の実態把握のために現場を訪問しデータ収集を行った。2-3 年前に東京都の職員と話した際、この時のデータ収集が後の省エネ政策立案に極めて役に立った、と言っていたことを共有したい。

出所:JET 作成

2.2.2 今後 JICA や日本政府から支援を受けたい分野や取り組み

各国の課題や本邦研修で特に各国への活用性が高かった点など踏まえ、各研修員は今後 JICA や日本政府に期待する分野、支援ニーズがある分野について発表した。それらについて、以下にまとめる。

(1) ジャマイカ

- 省エネルギー推進

ジャマイカの研修員は、同国の省エネルギー推進に係る課題／現状として以下を挙げた。

- 旺盛な電力需要と高いエネルギーコスト
- エネルギー効率や省エネルギーに関する意識が低く、また、省エネ活動が実践されていない
- 省エネ推進はこれまで規制対象外であった

省エネ推進には、高効率技術の積極的な市場投入によるユーザーの増加、公共部門向け省エネルギー基準ガイド策定、既存政策 National Energy Policy の推進、省エネビルディング化（民間企業/NGO/学校）が重要。

また、研修員は JICA や日本に対して、以下のニーズや期待する項目があることを説明した。

- 省エネビルのさらなる開発支援
- 省エネモデルビルへの評価・表彰制度策定
- ZEB および省エネ業界のリーダー向け技術力強化・育成
- 省エネビルに係る規制と（規制制度の）執行
- 家電製品のラベリング・評価システム開発
- （省エネ運転自動化を実現する）スマート家電製品導入
- 官公庁向けエネルギー管理システムの導入推進
- エネルギー管理者の育成（パイロットプログラム）
- 省エネプロモーションや省エネ技術普及啓発アニメーション作成支援

- 再生可能エネルギー導入

ジャマイカの研修員は、同国の電力セクターの課題として以下を挙げた。

- ピーク需要が減少トレンドであること
- 産業需要家をはじめ、系統の大規模消費者が自家発電へ移っている
- 高いノンテクニカルロス
- 政策と規制の枠組みが発展段階にある（2023 年 12 月までに政策の完成を目指す）

なお、ジャマイカ現政権内閣は、すべての化石燃料の発電は再生可能エネルギー技術に置き換える方針を述べたことを付記した。

また、研修員は JICA や日本に対して、以下のニーズや期待する項目があることを説明した。

- エネルギーデータの収集、管理、分析、Web モニタリング
- ジャマイカの電力セクター移行に関する分析（JPS のライセンスは 2027 年に失効する）
- 電力部門の市場・規制改革分析、分散型エネルギーソリューションを促進するための RE グリッド統合、発電計画・差的化、送配電の近代化
- 水素他、エネルギー貯蔵オプションの適切なロードマップ策定
- 石油の上流・下流政策の立案
- 電力会社・IPP の従来グリッドの送配電サービスからの移行
- 料金制度の改定：ネットビリングからネットゼロへ。余剰分を発電しない場合はゼロトレランスとする。分散型エネルギーのグリッド統合とレジリエンスを高めること
- 研究・開発パートナーシップ：FREA などを通じ、秘密保持契約を締結した上で、ジャマイカの送電網に対する技術的サポート、技術研究の実施
- Integrated Resource Plan-3 （IRP-3）の支援：スピニング・リザーブの必要量を計算するための予備力調査、電力コスト削減モデル化、オフショア風力発電のフィージビリティをユーティリティ規模に高める方法、など

特に IRP-3 は現在改定中の IRP-2 の次の電源・送配電開発計画ともなるもので、上の項目がその中にスコープとして含まれると思われる。技術協力プロジェクトとして IRP-3 を実施することが可能であれば、ジャマイカの電力開発へのインパクトは大きいと考えられる。

(2) バルバドス

● 省エネルギー推進

バルバドスの研修員は、同国の省エネルギー推進に係る課題として以下を挙げた。

- エネルギー効率フレームワークの開発
- バルバドスにフィットする省エネソリューションを提供するための現地調査の仕組み
- 非効率エアコン大量廃棄に係る冷媒処理計画、基準、方法
- 建物や運輸部門におけるエネルギー効率を規定する基準や法律が未整備
- 非効率照明に関する法律はあるものの、省エネに係る包括的法律が未整備
- スマートビルディングのメーカー（供給者）不足

省エネ推進のためには、ヒートポンプの導入、省エネルギー関連法律の充実、建物の ZEB 化、省エネ政策の（策定も含め）定期的な見直し、実証事例に基づく省エネサービス事業の創出、省エネ家

電導入による旧式製品の処分方法の確立、日本のベストプラクティスに倣った包括的省エネ法策定、建物のエネルギー効率算定用ソフトウェア開発が重要であると述べた。

また、研修員は JICA や日本に対して、以下のニーズや期待する項目があることを説明した。

- ヒートポンプの供給に係る支援
- 省エネへの取り組み
- 効率的かつ持続可能な省エネビルディングコードおよび政策の開発支援
- バルバドスに適した現地調査の仕組みの開発
- エネルギー・サービス・モデルの検討
- バルバドスの地質と地中熱利用ヒートポンプの適用研究、開発
- スマートビルディングに係る日本企業と現地企業の提携、開発、教育

- 再生可能エネルギー導入

バルバドスの研修員は、同国の再生可能エネルギー導入に係る課題として以下を挙げた。

- 現状の送配電設備が変動型再エネ(VRE)の大量導入を踏まえたものとなっていない。逆潮流を前提としていない。活用できる蓄電池の不足。これらを至急に改善する必要があること。
- バルバドスのグリッドに特化して認証されたインバーターシステムの不在
- BESS のコスト回収。また、バルバドスの一般世帯(の PV オーナー)は財務的に BESS を設置することは不可能であること。また蓄電池の廃棄について。電池が寿命に達した場合の廃棄計画や方針。
- 変圧器の設置に 2 年以上の長いリードタイムが必要であること。このため一部の住宅・商業用 RE の接続を遅らせる必要がある。
- 大規模な風力発電プロジェクトの許可に長い年月がかかること。その間に技術が陳腐化する可能性がある
- 政策の実施目標。100%RE 達成に重点を置いているが、これが最も効率的で持続可能なアプローチとは限らないこと。
- 自然災害影響を軽減するためのレジリエントな建設に関する枠組みやガイドラインの不在

研修で特に印象的だった点、日本の教訓をバルバドスに活用したい点として、以下を挙げた。

- 宮古島の VPP を含む技術により、島内で高い RE 比率を達成していること、
- 系統シミュレーションモデル
- 風力発電プロジェクト:寿命を確保するために維持管理が必須であること。特に島嶼部では腐食の緩和を考慮する必要がある。タービンの風荷重を理解し、自然災害時の緩和策を講じることで、確実に寿命を達成する必要がある。また、風力発電の開発を可能にし、より迅速な許認可を可能にする政策が必要。技術の進歩は速く、スコープの決定や承認を加速する必要がある。

- マイクログリッド：マイクログリッドにおける負荷バランシングには計画が必要。特にグリッド電源と接続していない場合、顧客への信頼性の高い供給を維持するための容量と BESS の必要性という点で非常に具体的な検討が必要。BESS と PV の制御と監視が必要。
- 研究開発：産総研などの研究が、その国の資源に特化した技術の機会を提供し、その国の課題解決を行っていること。例えばインバータの認証と開発、塩水バッテリー、住宅用地熱、グリッド管理におけるニューラルネットワークの使用、風力サイトの実行可能性を決定するためのドップラーライダーの使用、RE 効率と貯蔵能力のための新しい材料と複合材料の開発など。

さらに、本邦や JICA へ期待する支援の項目として以下を上げた。

- 水素やアンモニア技術、エネルギー貯蔵媒体研究開発、BLPC と MEB の研究機会と本邦研究機関とのネットワーク
- バルバドスのグリッドに接続するインバータについて、機能のテスト・動作確認・検証を通じた適合性認証プロセスの開発
- 出力抑制の取り組み
- 日本のメーカー技術を用いたパイロットプロジェクト、かかる本邦企業とバルバドス企業とのパートナーシップや、BESS や変圧器メーカーとのネットワークの構築。
- レジリエントで効率的で持続可能な建設基準および政策の開発支援

バルバドスは RE100%を政策目標として掲げているが、地熱や水力など安定型再エネポテンシャルが無い。RE100%達成するためには、VRE の大量導入が必要となるが、通常のスマートインバータでは VRE 増加につれて慣性力や同期化力の不足が顕著になる。よって今後、グリッドフォーミングインバータを BESS と共に導入していくことが、RE100%の達成に不可欠となる。インバータの認証に関して、実証事業としてのグリッドフォーミングインバータの本邦企業の参画と、バルバドスの認証制度設立にかかる支援、系統解析と出力抑制の枠組み構築、蓄電池廃棄とリサイクルにかかる支援が、同国の RE100%実現に大きく寄与すると考えられる。また本邦企業に島嶼国 RE 主要電源化の機器供給や事業実施機会を与えることとなる。

- その他

研修員は脱炭素という観点から、以下のニーズがあることを説明した。

- セメント事業のエネルギー投入量削減に対するアプローチ
- 省エネ型輸送技術選択肢に関する研究
- 水素自動車の導入、供給に係る支援

(3) セントクリストファー・ネービス

- 省エネルギー推進

セントキッツ・ネービスの研修員は、同国の省エネルギー推進に係る課題として以下を挙げた。

- CREEBC (CARICOM Regional Energy Efficiency Building Code) の適用が必須ではないこと

- 省エネルギーやその検査基準（確認申請、立入検査）が含まれたビルディングコードの策定
- 省エネルギーに係るデータ収集・管理体制のリソース不足

省エネ推進のためには、高効率空調設備の導入、ZEB 技術とその導入戦略、エネルギーマネジメントシステムの構築、省エネルギー規制と執行、高効率家電の導入、省エネルギー診断が重要であると述べた。

また、研修員は JICA や日本に対して、以下のニーズや期待する項目があることを説明した。

- データ収集に係るキャパシティビルディング
- 省エネルギー政策の策定支援
- 省エネに係る各種規制策定に向けた検討支援
- 省エネルギーに関連する法律のレビュー
- 省エネルギー（3E+S）の推進
  * 3E+S: (i) Energy Security-Self Sufficient, (ii) Energy Efficiency-Energy Cost, (iii) Environment-Greenhouse Gas Emissions), (iv) Safety

● 再生可能エネルギー導入

セントキッツ・ネービスの研修員は、同国の再生可能エネルギー導入に係る課題として以下を挙げた。

- RE 導入強化・促進、電気料金にかかる政府政策、手続き、規則の不在 (エネルギー政策が古く、交通セクターが考慮されていない、グリッドコードが制定されていない、FIT が無い、規制機関がない等)
- 規格外 RE 製品の輸入
- 系統に係るデータ収集・管理体制の弱さ
- 燃料への補助金
- SCADA, AMI を含む系統制御の近代化
- 系統安定度とブラックスタートを可能にする蓄電池の採用
- 既設発電機の老朽化と低い効率
- IPP との契約交渉の能力、プロマネ・エンジニアリング能力
- 高い GDP に比して、電力会社の低いキャッシュフロー

本邦研修の内容で、技術の標準化、RE 導入の為の系統解析、水素研究、技術標準化、洋上風力の保険や天候の影響、台風による PV の破壊、RE の観測システムなどは特に関心が深かったと述べた。

また、研修員は JICA や日本に対して、以下のニーズや期待する項目があることを説明した。

- 政策・規則、インセンティブやペナルティ策 の支援
- グリーン水素生産の計画、水素輸送媒体の検討

- スマートインバータ(グリッドフォーミングインバータ)
- RE Infusion Study の更新 (FIT インパクト調査を含む)
- セントキッツ島とネービス島の系統連系
- リソースマッピング
- BESS のパイロットプロジェクト

上の内、セントキッツ島・ネービス島の系統連系は演習として単純化したモデルで検討をしたが、今後詳細な F/S が必要である。これと、政策・規則面を含んだ RE Infusion Study(RE 導入を含む電力開発計画)の更新版を支援することは意義が大きい。また、グリッドフォーミングインバータや BESS にかかるパイロットプロジェクトの実施が可能であれば、本邦企業が当該分野で進出し島嶼国における低炭素化をリードするための実績が蓄積できることとなる。

Energy Efficiency & Conservation (EEC) Materiel Technical Cooperation to Promote Energy Efficiency in Caribbean Countries

- Energy Consumption Analysis & EE Roadmap -

Barbados, November 2022

Nippon Koei Co., Ltd.
PADECO Co., Ltd.

Contents

1. Energy Consumption Analysis from Energy Balance Table

Energy Consumption Analysis from Energy Balance Table

- **Current situation :Energy consumption outlook by sector and energy source**
  - Transportation is the largest energy consuming sector (33%) followed by Commercial & public service sector (28%) and residential sector (19%).
  - Electricity is the largest energy source (52%) followed by oil (43%).

Energy consumption by sector and energy source on primary energy basis (2019, ktoe)

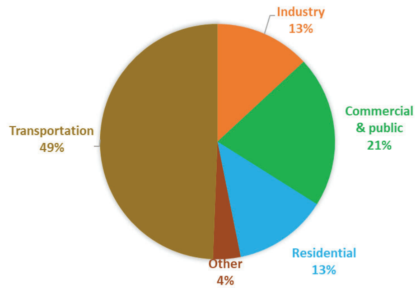
	Industry	Commercial & public	Residential	Other	Transportation	Total	
Oil	20	15	8	1	141	185	43%
Natural gas	1	10	2	0	0	12	3%
Bio/waste	7	0	0	1	0	8	2%
Charcoal	0.0	0.0	0.2	0.0	0.0	0.2	0%
Electricity (Primary energy basis)	28	97	72	26	0	223	52%
Total	55	122	83	27	141	428	100%
	13%	28%	19%	6%	33%	100%	

Note 1: Primary energy conversion factor of electricity is utilized to evaluate the effect of energy saving by reduction of 1kWh of electricity consumption at demand side.
Note 2: To calculate primary energy consumption of electricity, energy efficiency at end use (36.3%) was used based on the material by Government of Barbados.
Source: JET with reference to energy balances (2019) by United Nations Statistics Division for overall energy balance and the material above mentioned (Note 2) for primary energy conversion factor calculation of electricity.
https://unstats.un.org/unsd/energystats/dataPortal/

Energy Consumption Analysis from Energy Balance Table

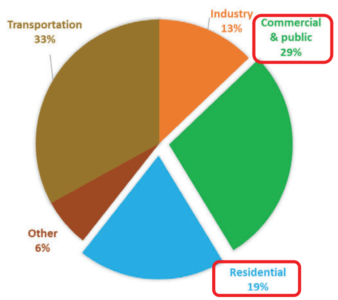
- Energy consumption **should be evaluated on primary energy basis.**
- **Commercial & residential sectors** share about half of the primary energy consumption.

Energy consumption by sector on final consumption basis (2019)



1 kWh consumption corresponds to 2.75 kWh as primary energy supply.
- 1 kWh / 0.363 =2.75 kWh

Energy consumption by sector on primary energy basis (2019)

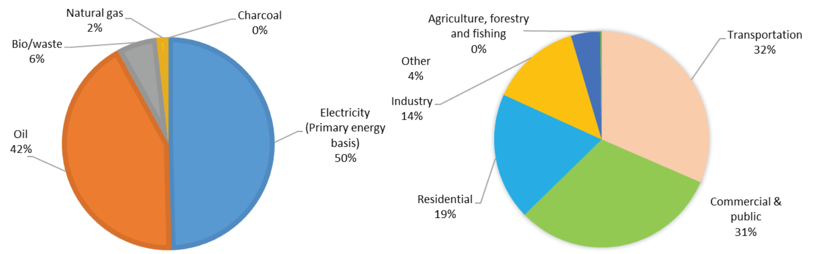


Source: JET with reference to energy balances (2019) by United Nations Statistics Division for overall energy balance.

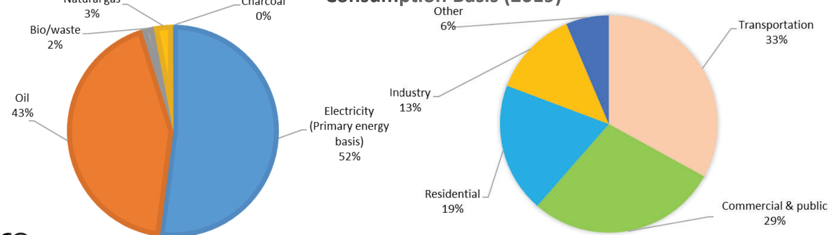
Energy Consumption Analysis from Energy Balance Table

- No particular change has been observed in energy consumption by fuel nor by sector between 2010 and 2019 on primary basis.

Energy Consumption by Fuel (left) and by Sector (right) on Primary Energy Consumption Basis (2010)



Energy Consumption by Fuel (left) and by Sector (right) on Primary Energy Consumption Basis (2019)



Energy Consumption Analysis from Energy Balance Table

Energy Consumption by Fuel and by Sector on Primary Energy Consumption Basis (2010)

	Industry	Commercial & public	Residential	Other	Transportation	Agriculture, forestry and fishing	Total	
Oil	820	723	487	25	6,045	47	8,147	42%
Natural gas	25	240	80	0	0	0	345	2%
Bio/waste	1,146	0	11	29	0	0	1,186	6%
Charcoal	0	0	0	0	0	0	0	0%
Electricity (Primary energy basis)	623	5,036	3,077	785	0	0	9,521	50%
Total	2,614	5,999	3,655	839	6,045	47	19,199	100%
	14%	31%	19%	4%	31%	0%	100%	

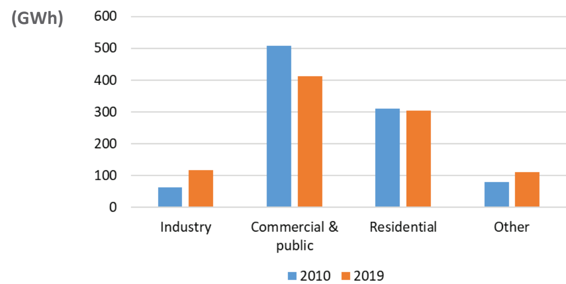
Energy Consumption by Fuel and by Sector on Primary Energy Consumption Basis (2019)

	Industry	Commercial & public	Residential	Other	Transportation	Total	
Oil	821	616	351	36	5,937	7,761	43%
Natural gas	22	402	94	0	0	518	3%
Bio/waste	312	0	0	27	0	339	2%
Charcoal	0	0	9	0	0	9	0%
Electricity (Primary energy basis)	1,163	4,091	3,019	1,085	0	9,358	52%
Total	2,318	5,109	3,473	1,148	5,937	17,985	100%
	13%	28%	19%	6%	33%	100%	

Energy Consumption Analysis from Energy Balance Table

- Electric power consumption was reduced by 2% between 2010 and 2019, some changes have been observed by sector:
  - Industry: Increased by 87%
  - Commercial: Decreased by 19%
  - Residential: Decreased by 2%

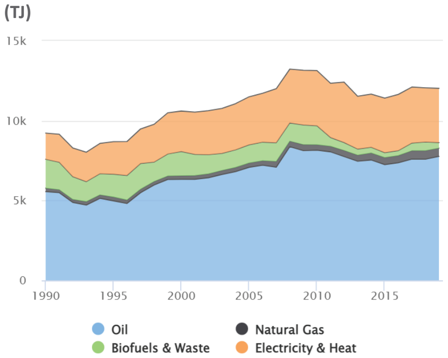
Changes in Electric Power Consumption by Sector from 2010 to 2019



Energy Consumption Analysis from Energy Balance Table

- Electricity and oil consumption have decreased slightly while natural gas consumption have been increasing during 2010 – 2019.
- Biofuel & waste consumption has decreased significantly.
- As total, final consumption was reduced by 1.0 % in the past 9 years.

Final Consumption by Fuel



Trend of Final Consumption by Fuel (2010 – 2019)

(TJ)

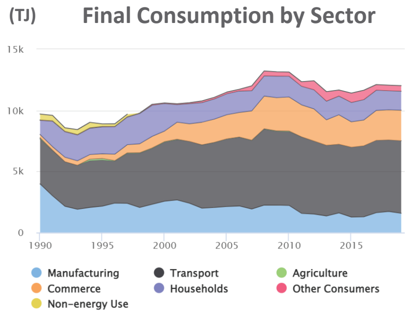
	2010	Share	2019	Share	AAGR
Electricity	3456	26%	3398	28%	-0.2%
Biofuels & Waste	1186	9%	348	3%	-12.7%
Natural Gas	346	3%	518	4%	4.6%
Oil	8148	62%	7761	65%	-0.5%
Total	13136	100%	12025	100%	-1.0%

Note: AAGR = Annual Average Growth Rate

Energy Consumption Analysis from Energy Balance Table

- Most of major sectors reduced final energy consumption and the industry sector is the largest among all (AAGR = -3.9%) during 2010 – 2019.

Final Consumption by Sector



Trend of Final Consumption by Sector (2010 – 2019)

	2010	Share	2019	Share	AAGR
Transport	6045	46%	5937	49%	-0.2%
Commerce	2791	21%	2503	21%	-1.2%
Households	1695	13%	1550	13%	-1.0%
Industry	2217	17%	1557	13%	-3.9%
Agriculture	47	0%	0	0%	-100.0%
Other consumers	340	3%	457	4%	3.3%
Total	13135	100%	12004	100%	-1.0%

2. Energy Efficiency & Conservation (EEC) Roadmap

Energy Efficiency & Conservation (EEC) Roadmap

Inputs

- Actual record of power consumption
- Power consumption ratio of each device (%)
- Service life of each device (e.g. 15 years)
- Input of MEPS future values step-by-step for 3 target devices (Average efficiency of currently used equipment = 1)

(1) Electricity demand assumptions up to 2036 (by demand type and use)(i)

Scenario a: Average efficiency of each device currently in use = natural (no energy conservation measures) case (i.e. Business As Usual (BAU) case)

(2) Energy demand assumptions by 2036 (by demand type and use)

Scenario b: Improvement of average efficiency of each product through introduction of S&L program / MEPS = Energy saving measure case

(3) Calculation of electricity consumption in each scenario (by demand type and use)

(4) Calculation of electricity consumption reduction potential for each scenario (by demand type and use) [(1)-(3)]

Primary energy conversion factor electricity

CO_2 emission factors for electricity

(5) Primary Energy Reduction Potential

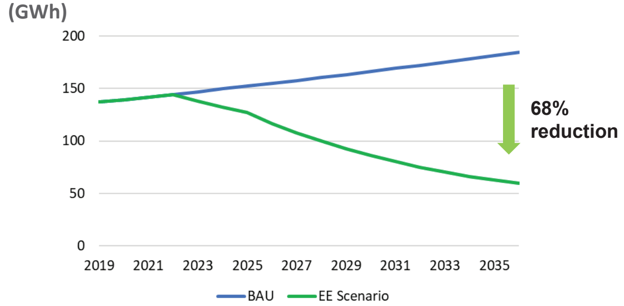
(6) CO_2 Emission Reduction Potential

(i) Source:1 Barbados Country Energy Balance Table (UN),
Source 2: Long-Term Peak Power Outlook: Report submitted to Prime Minister's Office, Government of Barbados (Mar 2017),
Note: the report does not present EEC measure scenarios.

Energy Efficiency & Conservation (EEC) Roadmap

- Electric power consumption of refrigerator has been estimated to be **reduced by 68%** with EE Scenario compared with BAU Scenario.
- Energy efficiency of refrigerator in use at households will be **3.1 times more efficient** compared with that of currently used in 2036 in EE Scenario with Introduction of MEPS.

Electric Power Consumption by Refrigerator up to 2036 (BAU and EE Scenario)



Assumed MEPS (EE Index) introduction for refrigerator in EE Scenario

EE index	
Present	1
2023	2
2026	3
2029	3.5
2032	4

Average EE index currently used at all households (Present)

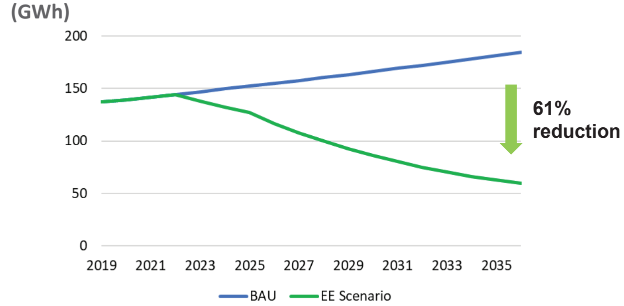
Assumed stepwise introduction of MEPS (2023–2032)

Average EE index will be 3.1 in 2036 used at all households

Energy Efficiency & Conservation (EEC) Roadmap

- Electric power consumption of air conditioner has been estimated to be **reduced by 61%** with EE Scenario compared with BAU Scenario.
- Energy efficiency of air conditioner in use at households will be **2.6 times more efficient** compared with that of currently used in 2036 in EE Scenario with Introduction of MEPS.

Electric Power Consumption by Air Conditioner up to 2036 (BAU and EE Scenario)



Assumed MEPS (EE Index) introduction for air conditioner in EE Scenario

EE index	
Present	1
2023	2
2026	2.5
2029	3

Average EE index currently used at all households (Present)

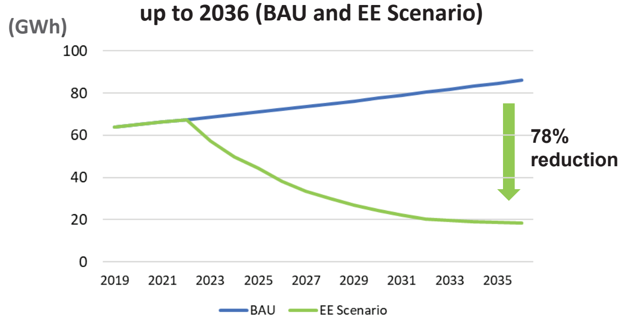
Assumed stepwise introduction of MEPS (2023–2029)

Average EE index will be 2.6 in 2036 used at all households

Energy Efficiency & Conservation (EEC) Roadmap

- Electric power consumption of lighting equipment has been estimated to be **reduced by 78%** with EE Scenario compared with BAU Scenario.
- Energy efficiency of lighting equipment in use at households will be **4.7 times more efficient** compared with that of currently used in 2036 in EE Scenario with Introduction of MEPS.

Electric Power Consumption by Lighting Equipment up to 2036 (BAU and EE Scenario)



Assumed MEPS (EE Index) introduction for lighting equipment in EE Scenario

EE index	
Present	1
2023	3
2026	4
2029	4.5
2032	5

Average EE index currently used at all households (Present)

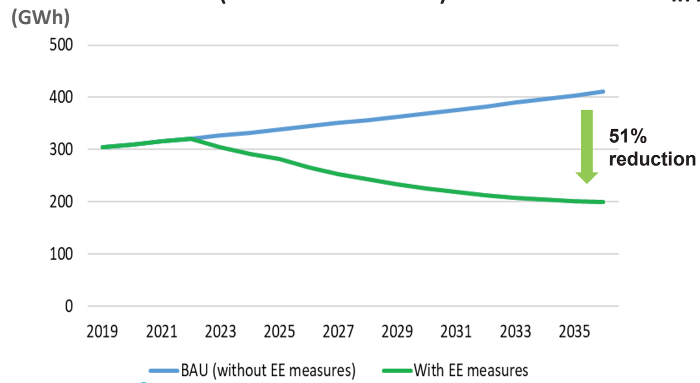
Assumed stepwise introduction of MEPS (2023–2032)

Average EE index will be 4.65 in 2036 used at all households

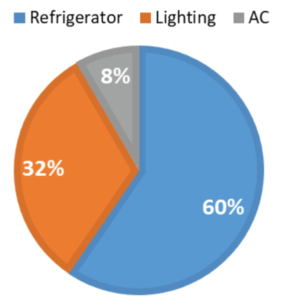
Energy Efficiency & Conservation(EEC) Roadmap

- With MEPS introduction targeting refrigerator, lighting equipment and air conditioner, it has been estimated power consumption will be **reduced by 51% in 2036.**

Energy Saving Potential in Residential Sector up to 2036 (BAU and EE Scenario)

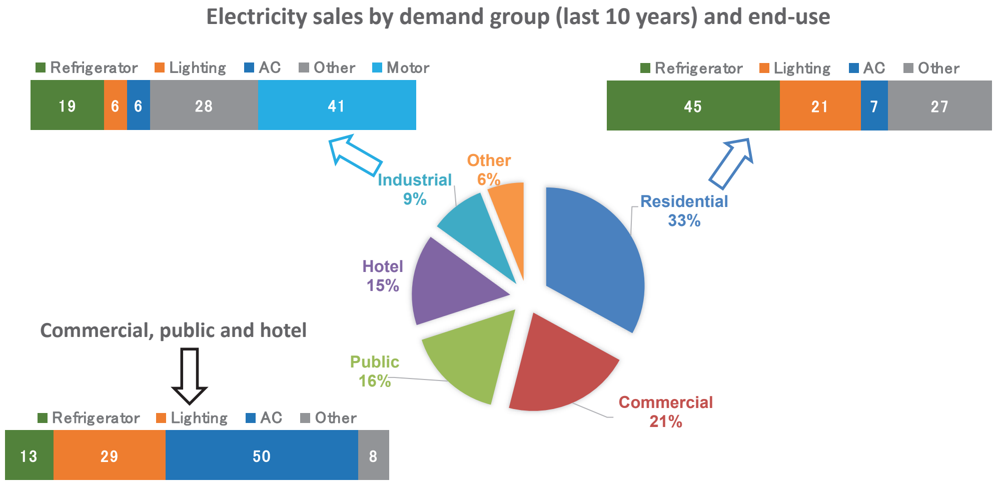


Energy Saving Ratio by Appliance in 2036 (EE Scenario)



Energy Efficiency & Conservation(EEC) Roadmap

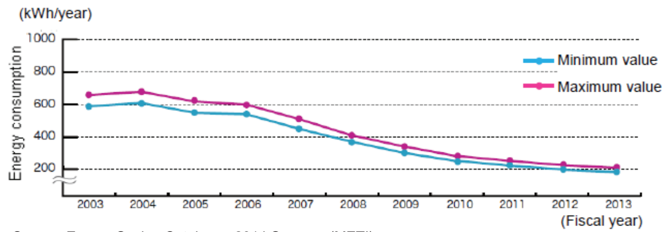
- **Current situation: Electricity consumption by sector and end-use**



Source: JET with reference to Barbados NATIONAL ENEGY POLICY (2019-2030) and material by the Government of Barbados

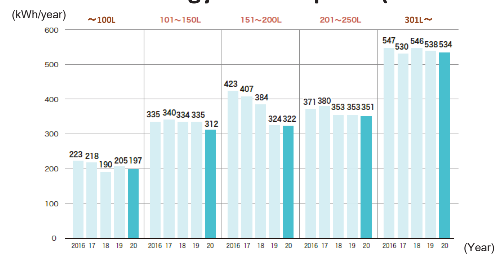
Ref: Trends of EE Improvement of Refrigerator, Japan

Trends in Annual Energy Consumption of Refrigerator (401 –450ℓ, 2003 - 2013)



Source: Energy Saving Catalogue 2014 Summer (METI)

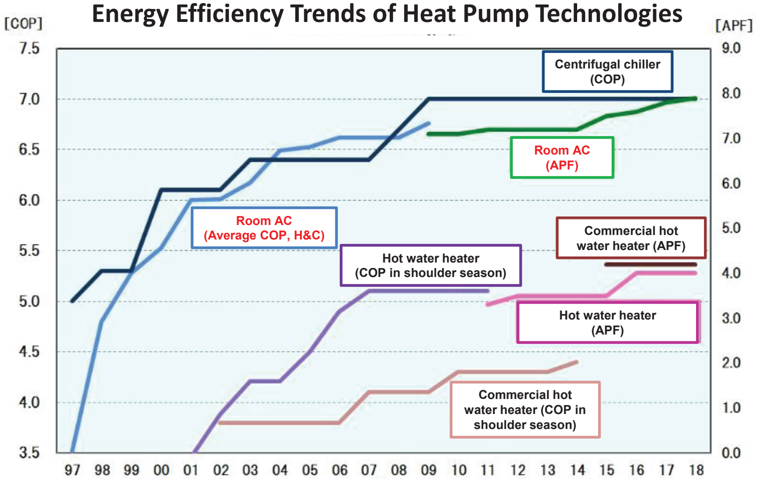
Trends in Annual Energy Consumption (2016 – 2020)



Source: Energy Saving Catalogue 2021 (METI)

Ref: Trends of EE Improvement of AC, Japan

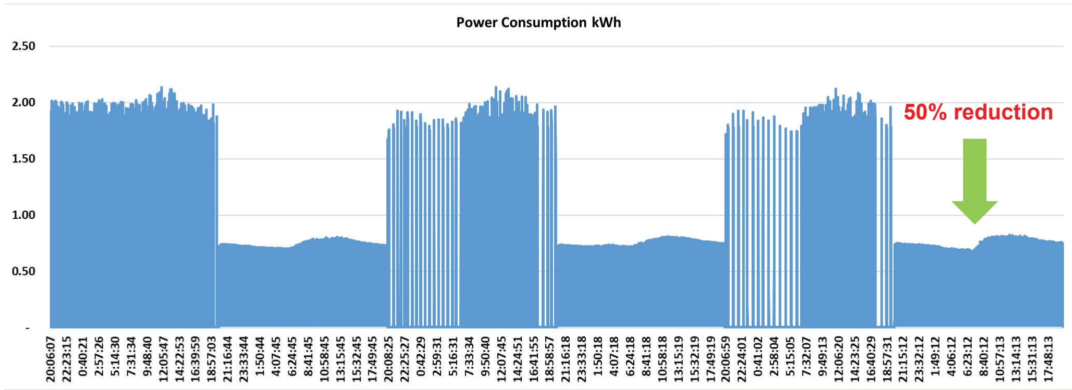
Energy Efficiency Trends of Heat Pump Technologies

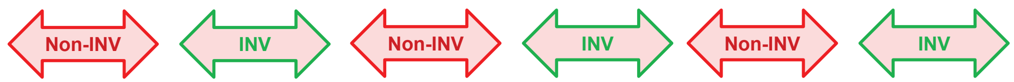


Source: Manufactures' Catalogue, Energy Saving Catalogue (METI)

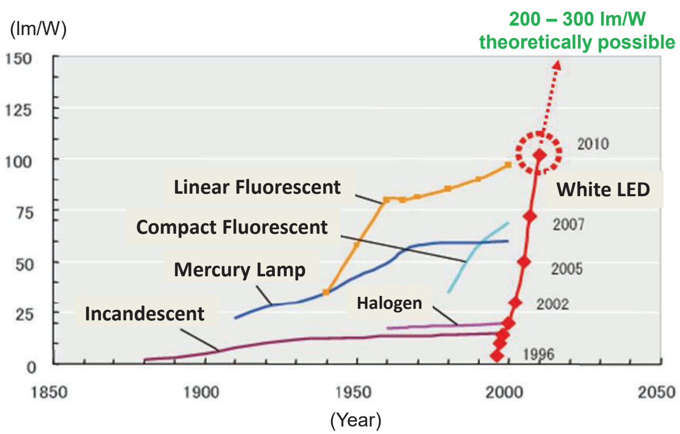
Note 1: COP stands for Coefficient of Performance, energy efficiency at rated operation (kWh/kWh)
Note 2: APF stands for Annual Performance Factor, energy efficiency throughout a year (kWh/kWh)

■ Ref: Results of Comparison Experiment, INV vs Non-INV AC



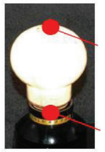


Trends of Luminous Efficiency



Source: Ministry of Economy and Trade and Industry, METI

Comparison of heat generation (Incandescent lamp vs LED lamp)

Incandescent Lamp (810 lm, 54W)	LED lamp (810 lm, 9W)
30 minutes after lighting	
 80 ℃ 110 ℃	26 ℃ 55℃ 

Contributes less AC demand

Thank you very much for your kind attention !

Energy Efficiency & Conservation (EEC) Materiel Technical Cooperation to Promote Energy Efficiency in Caribbean Countries

Information and knowledge sharing material - Energy Management & Energy Audit -

Barbados, November 2022

Nippon Koei Co., Ltd.
PADECO Co., Ltd.

1. Energy Management System (EnMS), ISO 50001, and its Case Study

Key Points of ISO 50001 (EnMS)

Key Points

- ISO 50001 specifies the energy management system (EnMS) requirements for an organization. Successful implementation of an EnMS supports a culture of energy performance improvement that depends upon **commitment from all levels of the organization, especially top management**. In many instances, this involves **cultural changes** within an organization.
- EnMS includes an **energy policy, objectives, energy targets and action plans** related to its energy efficiency, energy use, and energy consumption.
- Energy performance is a concept which is related to energy efficiency, energy use and energy consumption. Energy performance indicators **(EnPIs)** and energy baselines **(EnBs)** are two interrelated elements to enable organizations to demonstrate energy performance improvement.
  - **Energy performance indicators (EnPIs)**
    The organization shall determine EnPIs that:
    - are appropriate for measuring and monitoring its energy performance;
    - enable the organization to demonstrate energy performance improvement.
  - **Energy baseline (EnBs)**
    The organization shall establish (an) EnB(s) using the information from the energy review(s), taking into account a suitable period of time.

Key Points of ISO 50001 (EnMS)

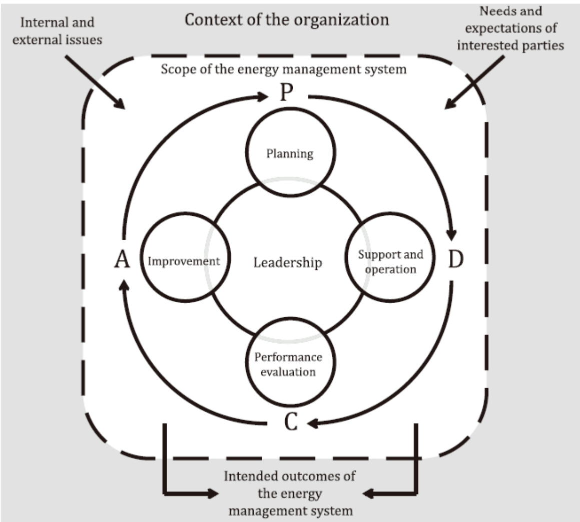
Plan-Do-Check-Act (PDCA) cycle

- The EnMS described is based on the Plan-Do-Check-Act (PDCA) continual improvement framework and incorporates energy management into existing organizational practices.

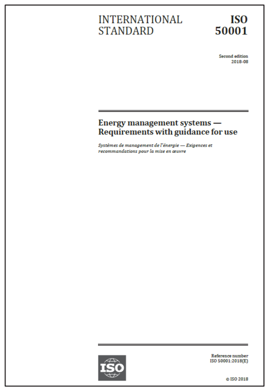
  In the context of energy management, the PDCA approach can be outlined as table below.

Plan	Understand the context of the organization, establish an **energy policy** and an **energy management team**, consider actions to address risks and opportunities, conduct an **energy review**, identify **significant energy uses (SEUs)** and establish energy performance indicators (EnPIs), energy baseline(s) (EnBs), objectives and energy targets, and action plans necessary to deliver results that will improve energy performance in accordance with the organization's energy policy.
Do	Implement the action plans, operational and maintenance controls, and communication, ensure competence and consider energy performance in design and procurement.
Check	Monitor, measure, analyze, evaluate, audit and conduct management review(s) of energy performance and the EnMS.
Act	Take actions to address nonconformities and continually improve energy performance and the EnMS.

Key Points of ISO 50001 (EnMS)



Plan-Do-Check-Act (PDCA) cycle



Case Study of EnMS -ISO 50001-

1. Planning for Collection of Energy Data

- The organization shall ensure that key characteristics of its operations affecting energy performance are identified, measured, monitored and analyzed at planned intervals. The organization shall define and implement an **energy data collection plan** appropriate to its size, its complexity, its resources and its measurement and monitoring equipment.
- The plan shall specify the data necessary to monitor the key characteristics and state how and at what frequency the data shall be collected and retained.
- Data to be collected (or acquired by measurement as applicable) and retained documented information shall include:
  - the relevant variables for **SEUs**;
  - energy consumption related to **SEUs** and to the organization;
  - operational criteria related to **SEUs**;
  - static factors, if applicable;
  - data specified in action plans.
- The energy data collection plan shall be reviewed at defined intervals and updated as appropriate.

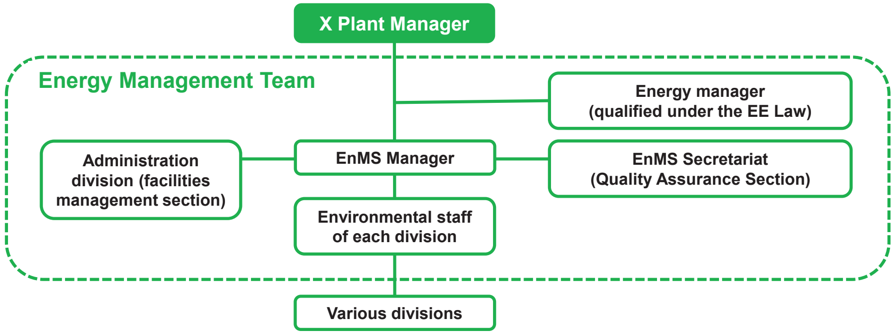
Case Study of EnMS -ISO 50001-

2. Scope of EnMS

The scope of ISO 50001 certification covers the manufacture of automotive undercarriage parts at the X Plant.

3. Promotion Structure

The X Plant Manager was appointed as top management to establish an EnMS based on ISO 50001, including an energy manager in accordance with the EE Law, a facility management section in the administration division, and a person in charge of promotion in each division.



EnMS Promotion Structure at X Plant

Case Study of EnMS -ISO 50001-

4. Energy Policy

Energy Philosophy

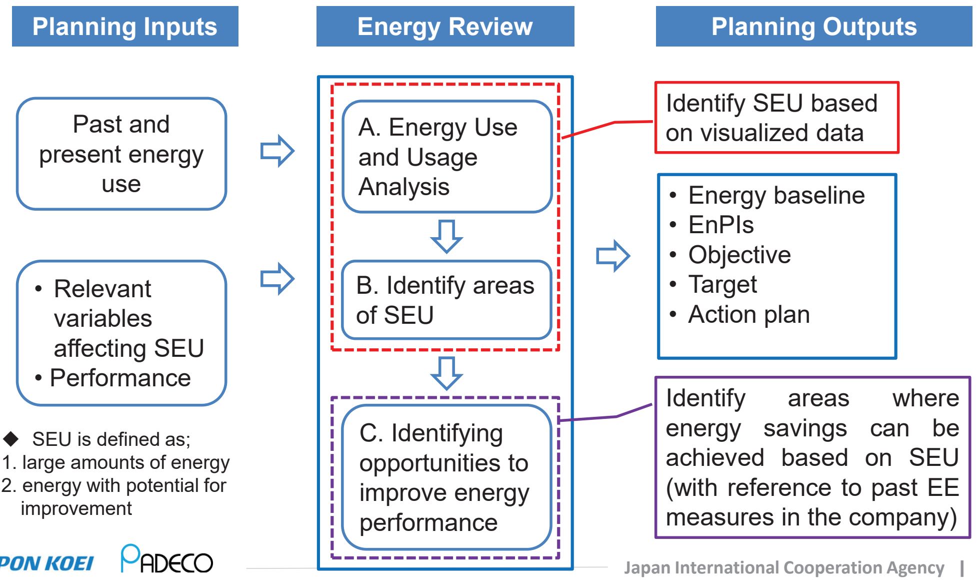
We aim to be the top environmental runner in the automotive industry, and we will do our utmost to build a low-carbon and nature-rich future by deepening each employee's correct understanding of global environmental issues and actively engaging in ongoing environmental conservation activities in all areas of our corporate activities.

Basic policy

- We will continuously implement energy conservation activities in our production activities.
- Collect appropriate information to achieve our goals and objectives
- We will strive to use appropriate resources to achieve our goals and objectives
- We will comply with all laws and regulations related to energy use and other agreed upon requirements.
- Set objectives and review them regularly.
- We will strive to install energy-efficient product equipment and utilize energy-efficient services
- We will develop environmentally conscious people through energy conservation activities.

Case Study of EnMS -ISO 50001-

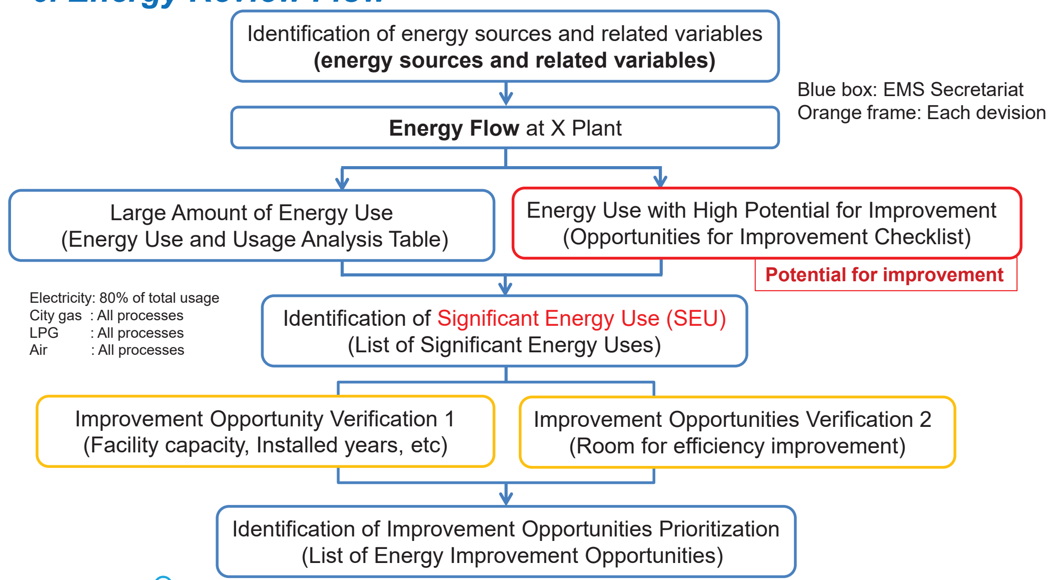
5. Overall Energy Review



◆ SEU is defined as;
1. large amounts of energy
2. energy with potential for improvement

Case Study of EnMS -ISO 50001-

6. Energy Review Flow



7. Methodology for Setting Energy Baselines and Energy Performance Indicators

- The energy baseline was based on FY 2010, when operations were relatively normal.
- The energy performance indicators (EnPIs) are basic units obtained by dividing the respective energy consumption (total amount) by a more closely related variable.
- The intensity is set more precisely than that used for reporting under the EE Law, so that energy usage can be more clearly understood.

Energy Baselines and Energy Performance Indicators (EnPIs)

	Electricity	City gas	LPG	Air
Baseline	FY2010	FY2010	FY2010	FY2012
EnPIs	• Total amount • Intensity (Value added)	• Total amount • Intensity (Production)	• Total amount • Intensity (Average temperature)	• Total amount • Intensity (Value added)

Note: Parameter of intensity in parentheses

8. Energy Objectives and Targets

- Targets were set for a single year (FY2012) and for the medium term (through FY2015).
- In setting the targets, target values were set for each energy source without CO2 conversion or crude oil conversion in order to clarify the effect of energy improvement.

Energy Objectives and Targets (Mid term and FY2012)

		Electricity	City gas	LPG	Air
Intensity	FY2015	5% improvement	5% improvement	Less than FY2012	3% improvement
	FY2012	3% improvement	3% improvement	Less than FY2012	1% improvement
Total amount	FY2015	30% reduction	5% reduction	15% reduction	3% reduction
	FY2012	10% reduction	Less than FY2010	15% reduction	1% reduction

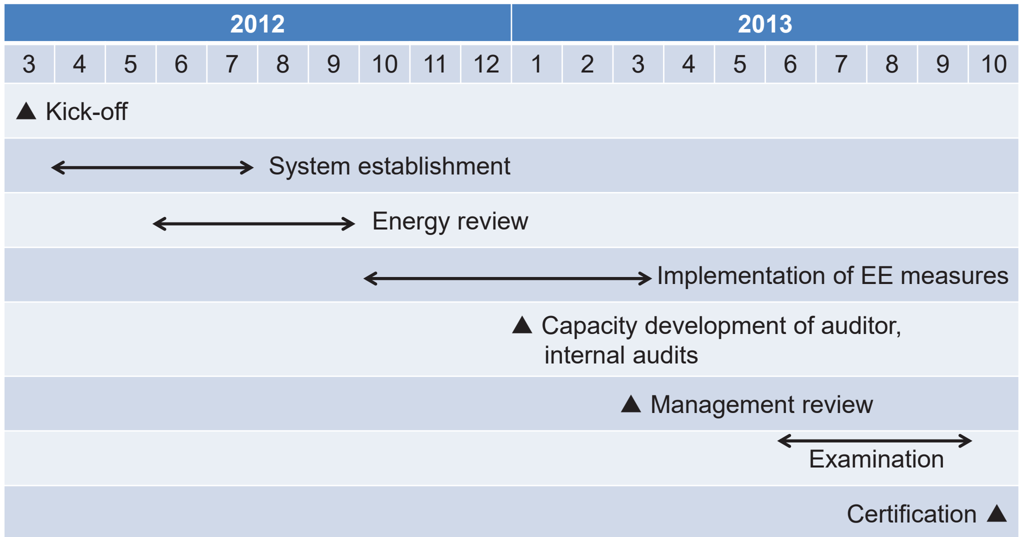
9. Preparation of Energy Management System Documents

- The following management system documents were prepared as applicable to the X plant.
  - Energy Management System Manual
  - Energy Review Implementation Procedures
  - Environmental Meeting Procedures
- In addition, several forms mainly related to energy reviews were newly prepared, including an "Efficiency Improvement Feasibility Check Sheet" and an "Energy Review Survey Sheet" that lists;
  - Energy use classification of each process facility
  - Determination of equipment capacity suitability
  - Determination of renewal timing
  - EE improvement items
  - Implementation status of measures.

10. Management Review Outputs

The management review included detailed reports on the improvement of energy performance through the efforts of each division. Specific instructions were given to include total energy consumption in an energy performance indicators / targets, and "improving the energy management team's data analysis" and “improvements in implementation capabilities” were suggested.

11. Schedule for ISO 50001 – from System Establishment to Certification



Case Study of EnMS -ISO 50001-

12. Results of Activities

Identified specific outcomes of the ISO 50001 are as follows;

- Regrading data collected by the energy management system, the steps formulation (e.g. data analysis, EE measures planning, implementation and effectiveness verification) has been standardized. This will enable permanent and systematic EE&C implementation.
- Persons in charge of implementation in each division improved skills in analyzing energy management data.
- Know-how on EE&C measures has been accumulated.
- Morale / passion for EE&C increased at the plant.
- Improved energy performance.

Improved Energy Performance Results

Total effect by measures conducted in FY2012	CO2 reductions (total)	81.2 t-CO2
	Reduction cost (total)	JPY 2,844,000
Total effect by measures conducted in FY2013 (estimates)	CO2 reductions (total)	130.3 t-CO2
	Reduction cost (total)	JPY 4,801,000

Case Study of EnMS -ISO 50001-

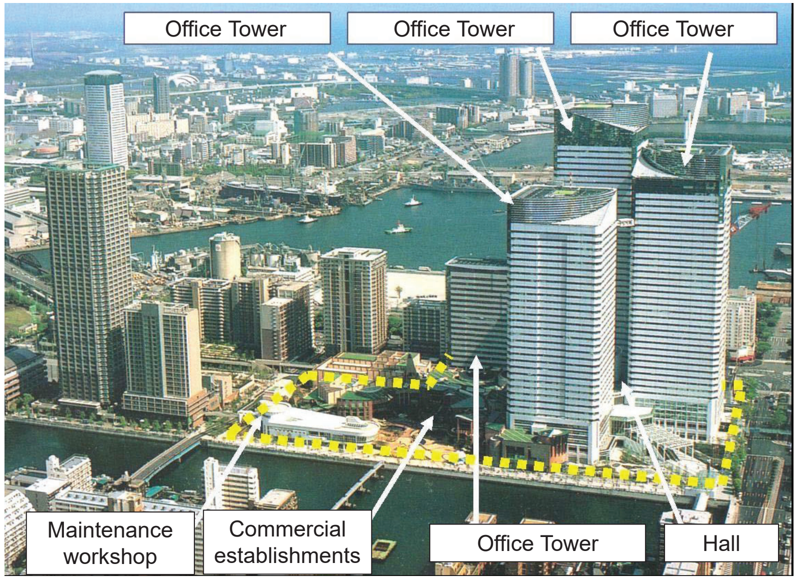
13. Potential for Future Improvement

Future issues for the development of ENMS improvements include the following.

- Further strengthen data analytical capabilities of energy management system as well as implementation capabilities.
- Accumulation of improvement know-how through energy use visualization.
- Support for ISO 50001 certification for overseas subsidiaries as a global mother.

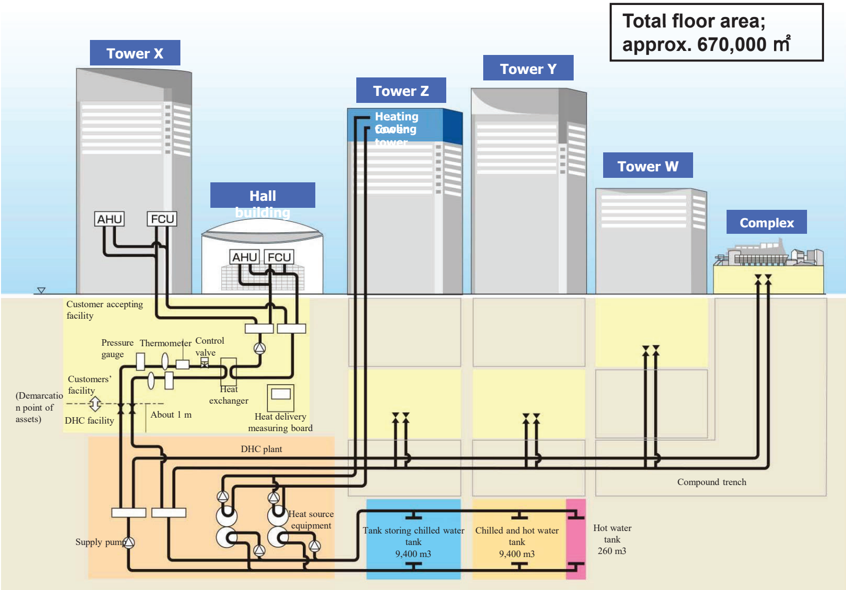
2. Energy Management Best Practice at District Heating & Cooling (DHC) plant in Japan

Outline of District Heating & Cooling System



Harumi Island District Heating & Cooling, DHC

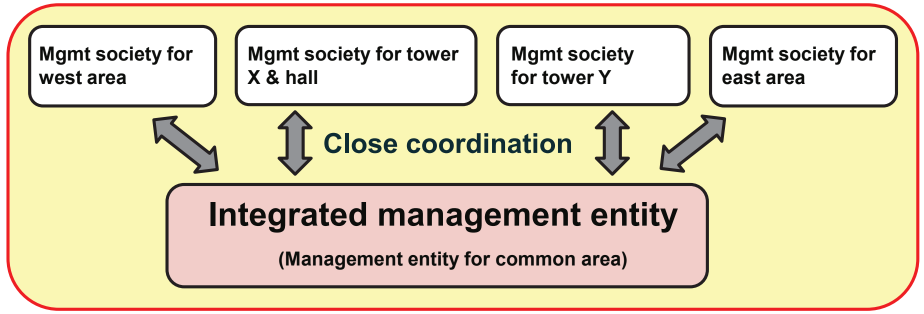
Outline of District Heating & Cooling System



Energy flow diagram of chilled and hot water supply

Outline of District Heating & Cooling System

➢ **Energy / Environment Management Structure**



■Periodical meeting
(Every other month)
✓ Comprehensive data examination
✓ Each operational improvement
✓ Feedback of the outcome

Record in FY'10

CO_2 emissions
= 32,355 t-CO_2
(▲10.5% !)

Base line= Annual average emissions from FY'04 through FY'06

Key Points 1 for Achieving EEC

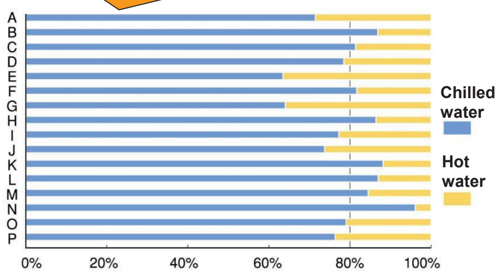
Adoption of the most efficient chiller

Space cooling demand exceeds space heating demand in the offices, etc.
In order to increase the overall system efficiency, it is crucial to adopt the equipment that produces chilled water efficiently.

⬇

The most efficient centrifugal chillers at the time of design and construction were adopted.

As for heat demand for air-conditioning in offices, etc., demand for chilled water largely exceeds that for hot water.

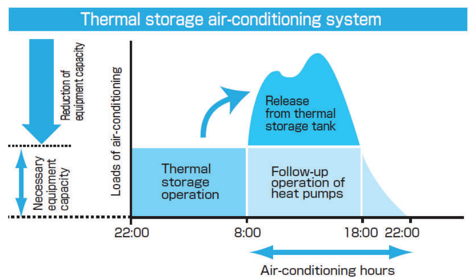


Demand for chilled water and hot water in offices, etc. (actual data)

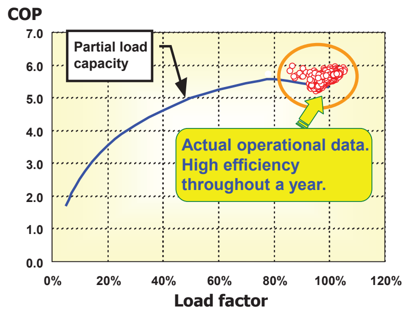
Key Points 2 for Achieving EEC

Adoption of Thermal Storage Systems

Heat pumps (chillers) can **operate at high load factor where its efficiency is high with thermal storage system**. Thus, large-scale thermal storage tank was adopted (19,060 m³).
Note: Thermal storage system has similar effects with inverter in terms of improving operational efficiency.



Operation of thermal storage air-conditioning system

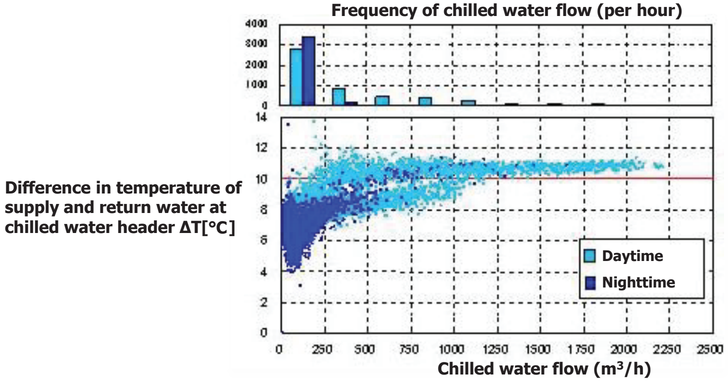


Operational records of chiller

Key Points 3 for Achieving EEC

Adoption of large temperature difference water

To reduce the power consumption by pumps, the temperature difference of supply and return water was designed at 10 degrees, while the standard is typically 7 degrees.



Weighted average ΔT
Daytime : 9.9°C
Nighttime : 7.5°C

Annual Results of difference in temperature of coming and going water

Key Points 4 for Achieving EEC

Adoption of heat recovery heat pumps

Heat recovery heat pumps save energy drastically by recycling waste heat from cooling operation. Most of the waste heat is recovered and utilized as heat for space heating.

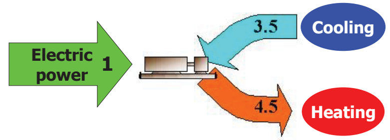
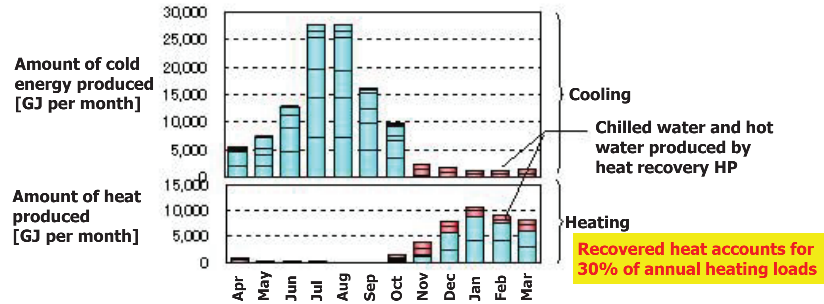


Image of heat recovery heat pump (COP=8)



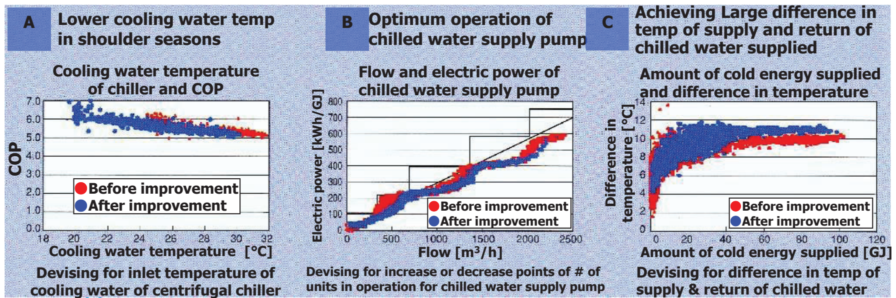
Data of waste heat recovery through a year

Key Points 5 for Achieving EEC

Implementation of continuous commissioning

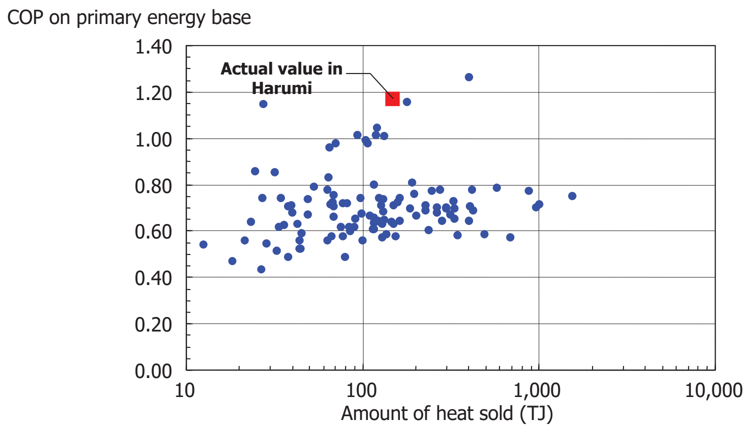
Creation of "performance evaluation and review committee" including people of academic standing, designer and constructor. It lasted 3 years after completion of construction.

- Understanding situation of operation through close and careful measurements and analyses.
- Evaluation of performance and identification of issues.
- Implementation of measures toward better performance and review of the effects thereof.



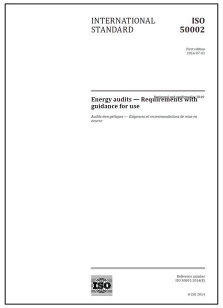
Achieved Top Energy Efficiency Rating

✓ Among high-efficiency DHC systems, Harumi DHC achieved a top energy efficiency rating in Japan.



COP on the primary energy basis for DHC in Japan

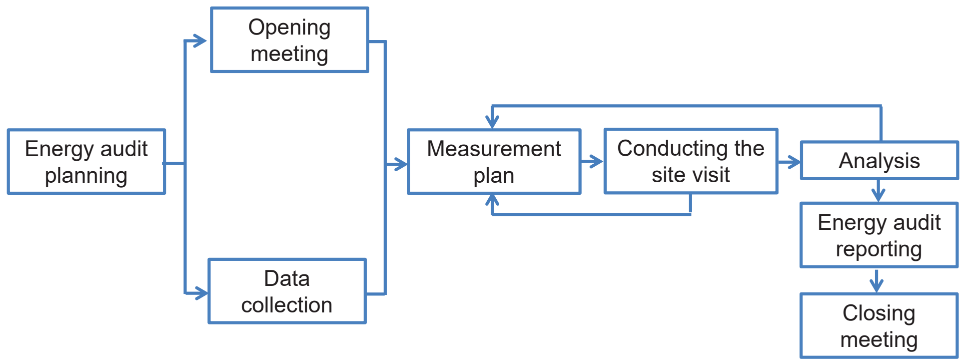
3. Energy Audits, ISO 50002, and its Case Study



Key Points of ISO 50002 (Energy audits)

Energy Audit Process Flow

- ISO 50002 stipulates the energy audit process consists of the following stages.



Energy Audit Process Flow Diagram

Key Points of ISO 50002 (Energy audits)

Data Collection

Where available, the energy auditor shall collect, collate and record the appropriate energy data that support the audit objectives. This includes the following information:

A) a list of energy consuming systems, processes and equipment;

B) detailed characteristics of the energy uses within the defined energy audit scope, including relevant variables and how the organization believes they influence energy performance;

C) historical and current energy performance data, including:

  i. energy consumption, relevant variables, relevant related measurements (e.g. power factor measurements; results from a thermographic or compressed air survey);

  ii. operational history and past events that could have affected energy consumption in the period covered by the data collected;

D) monitoring equipment, configuration and analysis information (e.g. local gauges, distributed control systems, instrumentation types);

E) future plans, design, operation and maintenance documents;

F) energy audits or previous studies related to energy performance;

G) current energy rate schedule(s) (or tariffs) or a reference rate (or tariff) to be used for financial analysis;

Key Points of ISO 50002 (Energy audits)

Analysis of Current Energy Performance

The current energy performance provides the basis for evaluating improvements and shall include:

A) a breakdown of the energy consumption by use and source;

B) energy uses accounting for substantial energy consumption;

C) where available and comparable, comparison with reference values of similar processes;

D) a historical pattern of energy performance;

E) expected improvements for energy performance.

F) where appropriate, relationships between energy performance and relevant variables;

G) an evaluation of the existing energy performance indicator(s) and, if necessary, proposals for (a) new energy performance indicator(s).

Key Points of ISO 50002 (Energy audits)

Identification of Improvement Opportunities

The energy auditor shall identify energy performance improvement opportunities based on analysis and the following:

A) their own competency and expertise;
B) evaluation of the design and configuration options to address the system needs;
C) the operating lifetime, condition, operation and level of maintenance of the audited objects;
D) the technology of existing energy uses in comparison to the most efficient on the market;
E) best practices, including operational controls and behaviours;
F) future energy use and changes in operation.

Key Points of ISO 50002 (Energy audit)

Evaluation of Improvement Opportunities

The energy auditor shall evaluate the impact of each opportunity on the current energy performance based on the following:

A) energy savings over an agreed time period or expected operating lifetime; (e.g. Energy savings, improvements in specific energy consumption).
B) financial savings anticipated from each improvement opportunity;
C) necessary investments;
D) agreed economic and other criteria identified in the energy audit planning;
E) other non-energy gains (such as productivity or maintenance);
F) the ranking of energy performance opportunities;
G) potential interactions between various opportunities.

Key Points of ISO 50002 (Energy audits)

Energy Audit Report Contents

The energy audit report shall include the following topics:

A) Executive summary:

i. summary of energy use and consumption;
ii. ranking of opportunities for improving energy performance;
iii. suggested implementation programme;

B) Background:

i. general information on the organization, energy auditor and energy audit methods;
ii. relevant legal and other requirements applicable to the energy audit;
iii. statement of confidentiality;
iv. context of the energy audit;
v. energy audit description, defined scope and boundaries, audited objective(s) and timeframe;

Key Points of ISO 50002 (Energy audits)

C) Energy audit details

i. information on data collection:
ii. analysis of energy performance and any energy performance indicator(s);
iii. basis for calculations, estimates and assumptions and the resulting accuracy;
iv. criteria for ranking opportunities for improving energy performance.

D) Opportunities for improving energy performance

i. recommendations and the suggested implementation programme;
ii. assumptions and methods used in calculating energy savings, and the resulting accuracy of calculated energy savings and benefits;
iii. assumptions used in calculating costs of implementation, and the resulting accuracy;
iv. appropriate economic analysis, including known financial incentives and any non-energy gains;
v. potential interactions with other proposed recommendations;
vi. measurement and verification methods recommended for use in post-implementation assessment of the recommended opportunities;

E) Conclusions and recommendations.

Key Points of ISO 50002 (Energy audits)

< Reference> Energy Audit Principles

The energy audit shall be conducted according to the following principles:

A) the audit is consistent with the agreed energy audit scope, boundary and audit objective(s);

B) the measurements and observations are appropriate to the energy uses and consumption;

C) the collected energy performance data are representative of the activities, processes, equipment and systems;

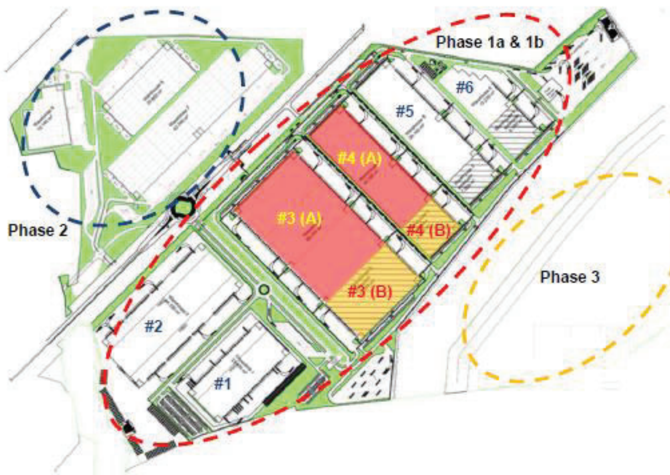
D) the used data for quantifying energy performance and identifying improvement opportunities are consistent and unique;

E) the process of collecting, validating and analysing data is traceable;

F) the energy audit report provides energy performance improvement opportunities based on appropriate technical and economic analysis.

Case Study of Energy Audits (1)

Logistics Center Project (2 large warehouses + offices)



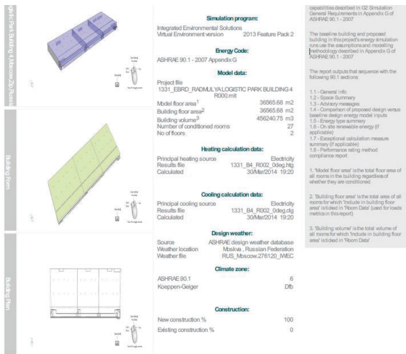
Case Study of Energy Audits (1)

Energy Dynamic Simulation

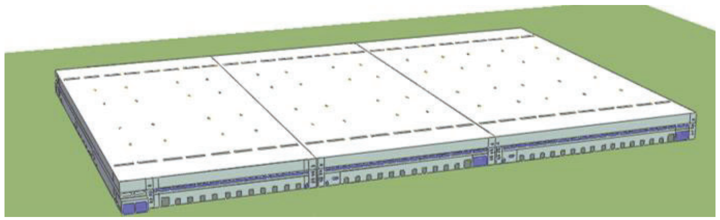
Part of Building Design Data (Project Data)

Design data (Assumptions&Project data)					
Areas	Lighting (installed)		People	Shifts	T ©
	GL	FF			
	kW	kW			
Warehouse 1	13176	96336	70	3	14
Warehouse 2	13608	100224	70	3	14
Warehouse 3	17496	123552	80	3	14
Office 1_1	15	W/m2	13	2	18
Office 1_2	15	W/m2	13	2	18
Office 2_1	15	W/m2	13	2	18
Office 2_2	15	W/m2	13	2	18
Office 3_1	15	W/m2	24	2	18
Office 3_2	15	W/m2	24	2	18
Toilets 1	15	W/m2	24	2	18
Toilets 2	15	W/m2			
Toilets 3	15	W/m2			
Toilets 4	15	W/m2			
Toilets 5	15	W/m2			
Toilets 6	15	W/m2			
Plantrooms	8	W/m2			16

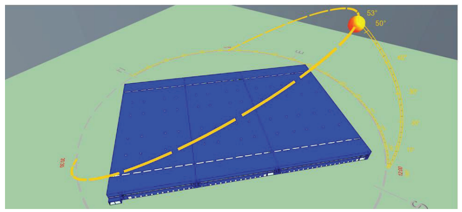
Screen of General Information of Dynamic Energy Calculation



Case Study of Energy Audits (1)



Facade and Roof of Warehouse



Sun Trajectory

Case Study of Energy Audits (1)

Summary of Dynamic Energy Calculation of the Building for BREEAM Assessment

Indicator	Baseline	The Project
Overall final energy performance (electricity + fuel) (kWh/m²/year)	215	95
Overall final energy consumption (electricity + fuel) (MWh/year)	7,856	3,474
Energy savings of electricity (kWh/m²/year)	-	31
Energy savings of electricity (MWh/year)	-	1,132
Energy savings of heat and fuel (kWh/m²/year)	-	89
Energy savings of heat and fuel (MWh/year)	-	3,250
Primary energy savings (KJ/m²/year)	-	2,754
Primary energy savings (MJ/year)	-	100,697

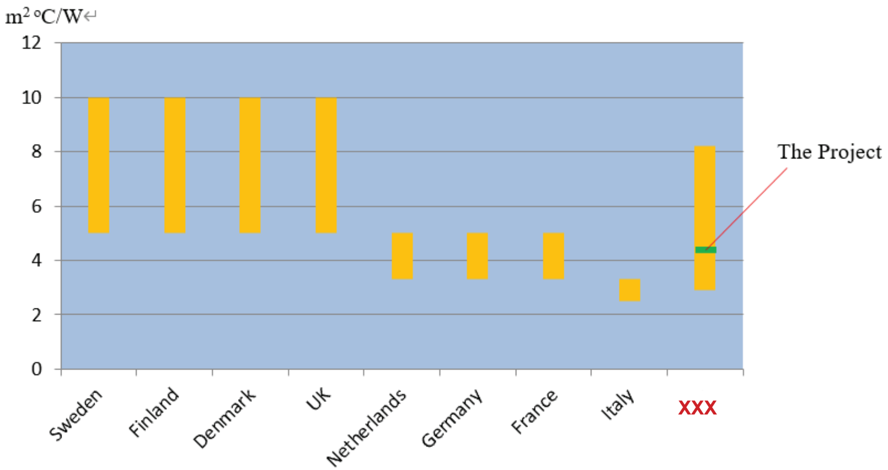
Case Study of Energy Audits (1)

Examined EE&C Technologies (additional study)

Examined technologies	Examination / Evaluation	Financial Analysis
Combined Heat & Power (co-generation)	Proposed	• Investment cost • Cash-flow • Pay back period • IRR • NPV
Variable speed control units (inverters)	Proposed	
Efficient transformer	Proposed	
Renewable energy	Already included	-
Peak shaving	Not necessary (high load factor)	-
Building envelope performance	Good (see next slide)	-

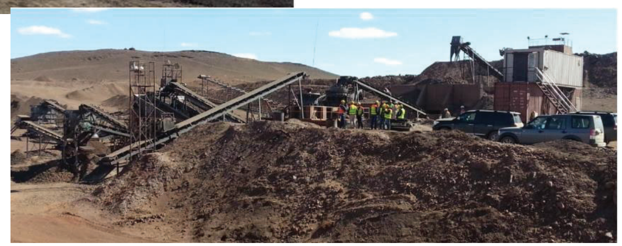
Case Study of Energy Audits (1)

Evaluation of Building Thermal Properties



Case Study of Energy Audits (2)

Mining Plant Project



Complete view of the existing crushing plant