iVSG™

iVSG™— *A Virtual Synchronous Generator realizing the maximum use of renewable energy*

April 1, 2024

Kawasaki Heavy Industries, Ltd.

Kawasaki
Powering your potential

Contents

Background

<u>The number of blackout cases is increasing</u>:
The power system is destabilized due to the massive deployment of renewable energy.

In South Australia, severe storms caused a cascade of renewable power plant outages, leading to statewide power outages.

Source: 2016 Reuters/David Mariuz

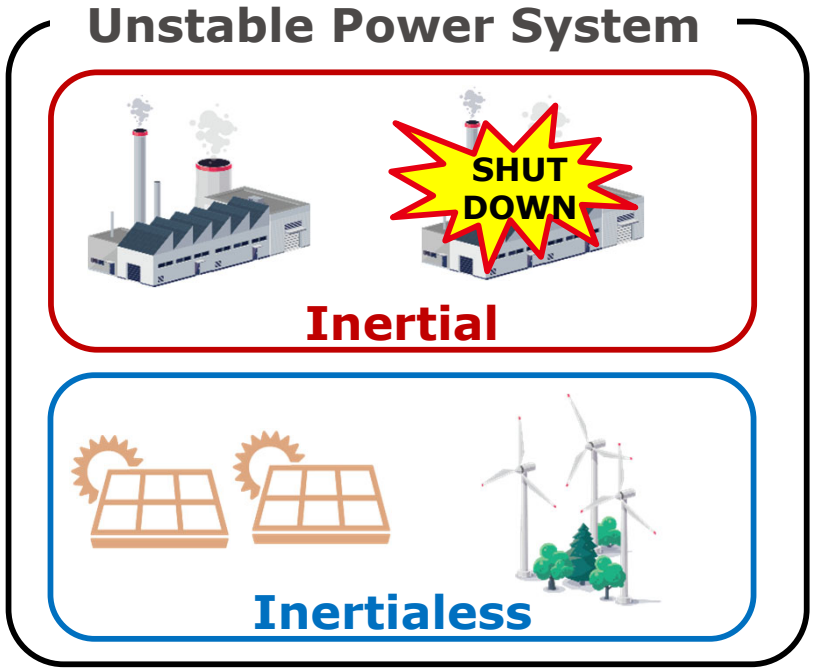
In California, it is required under the RPS law to increase the ratio of renewable energy source in electricity sales to 60% by 2030. However, gas power generation couldn't keep up with the tight electricity demand during the summer, which caused massive power outages.

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

Case Study : 2016 Australia case

Why did the blackout happen after a large-scale introduction of renewable energy?

- Synchronous generators, such as thermal power plant, possess inertia and play an important role in stabilizing the power system.
- Since renewable energy sources, such as solar power generators, are inertialess, power system stability is getting lower.



Power outage occurs at the thermal power plant.

↓

The grid frequency drops.

↓

Power system inertia is insufficient.

↓

The grid frequency drops further.

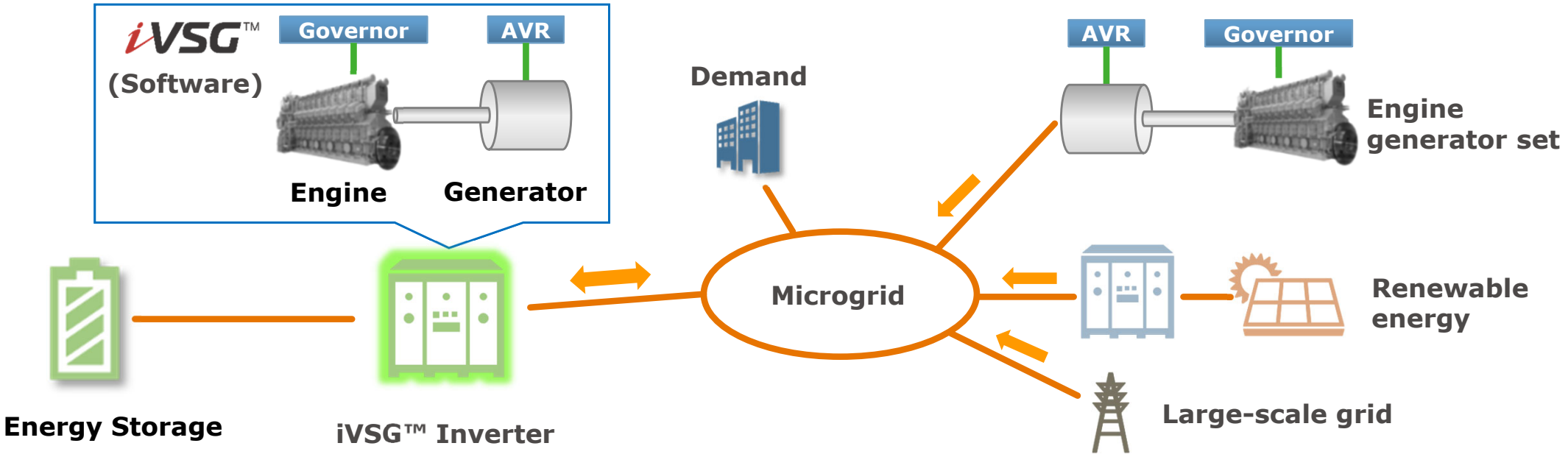
To promote a large-scale introduction of renewable energy, there is a need to address the lack of inertia.

What is iVSG™?

VSG: Virtual Synchronous Generator

iVSG™ is the trademark of Kawasaki Heavy Industries, Ltd.

- iVSG™ is control software for inverter with energy storage, simulating behavior of an engine generator.
- iVSG™ enables maximum utilization of renewable energy, realizing flexible and economical operation of microgrid with energy storage and engine generator.
- KHI(Kawasaki Heavy Industries) is licensing iVSG™ software.



Comparison with Conventional Technologies

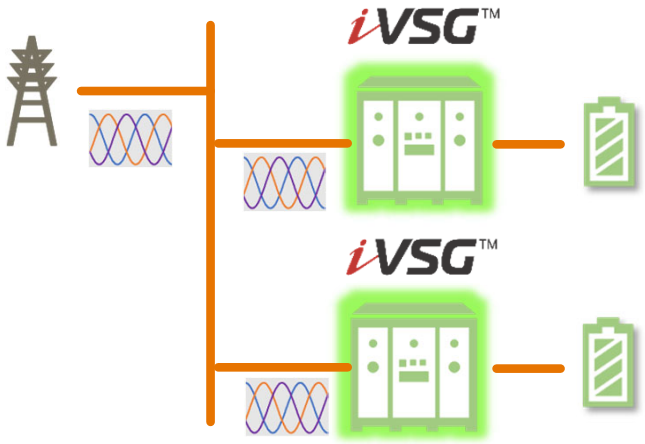
iVSG™

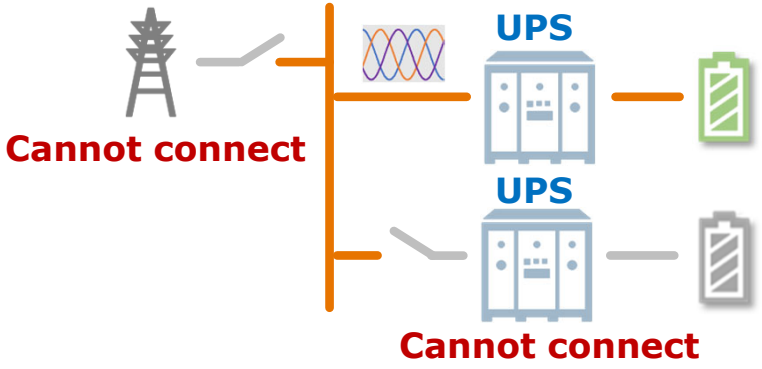
■ iVSG™
- ✓ Grid forming
- ✓ Droop (autonomous load sharing)
- ✓ Inertia (stabilizing grid)
- ✓ Parallel with a large-scale grid(*) or gensets
  (*) Compliant to grid code of Japan

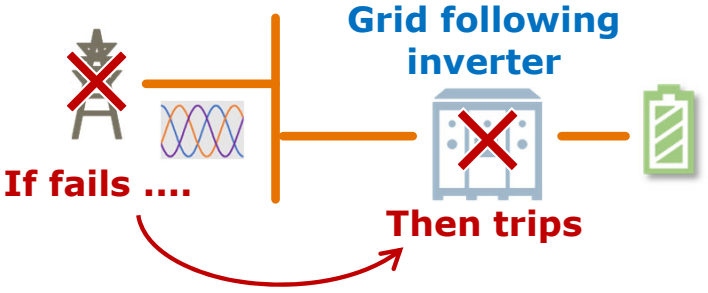
■ UPS
- ✓ Grid forming
- × No droop
- × No inertia
- × No ability to connect to a large-scale grid nor other UPS

■ Grid following inverter
- × No grid forming
  (No ability to maintain frequency or voltage)

✓ :merits × :demerits



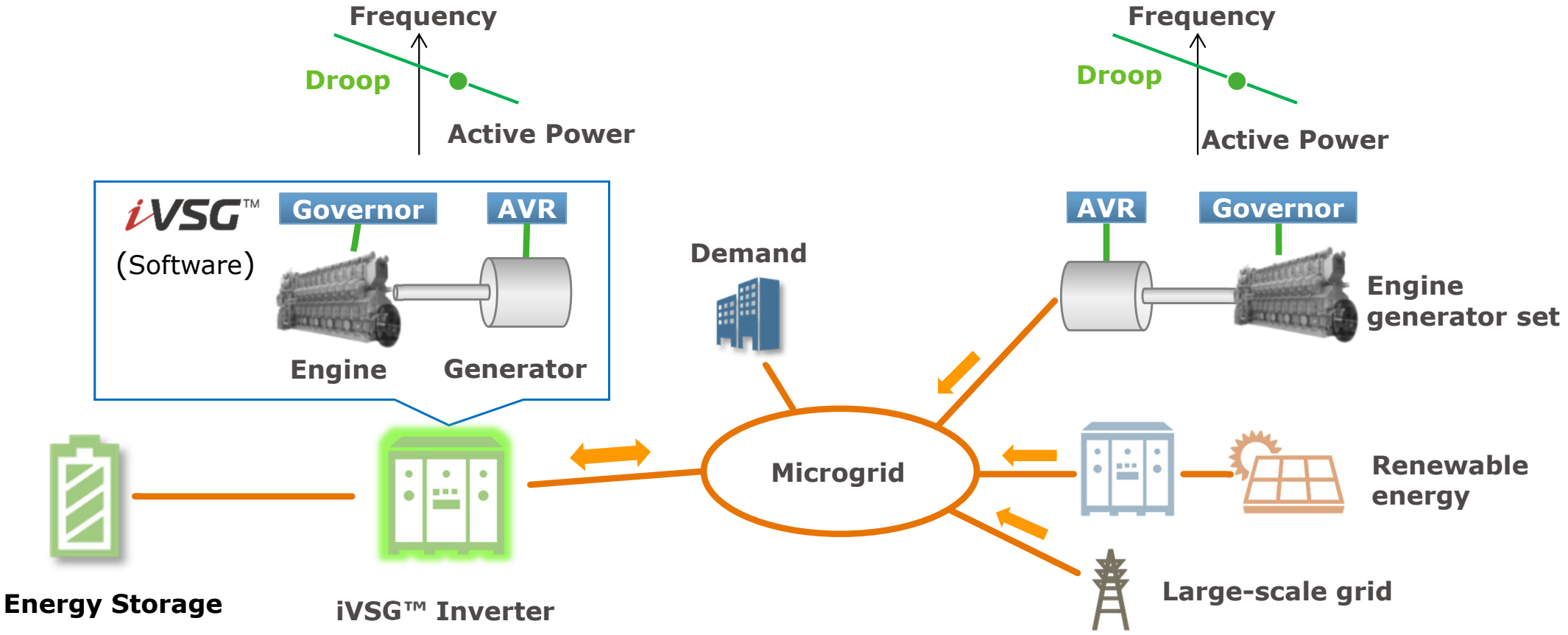




Features of iVSG™

Features
(1) Grid forming
(2) Droop control
(3) Simulated inertia
(4) Charge and discharge

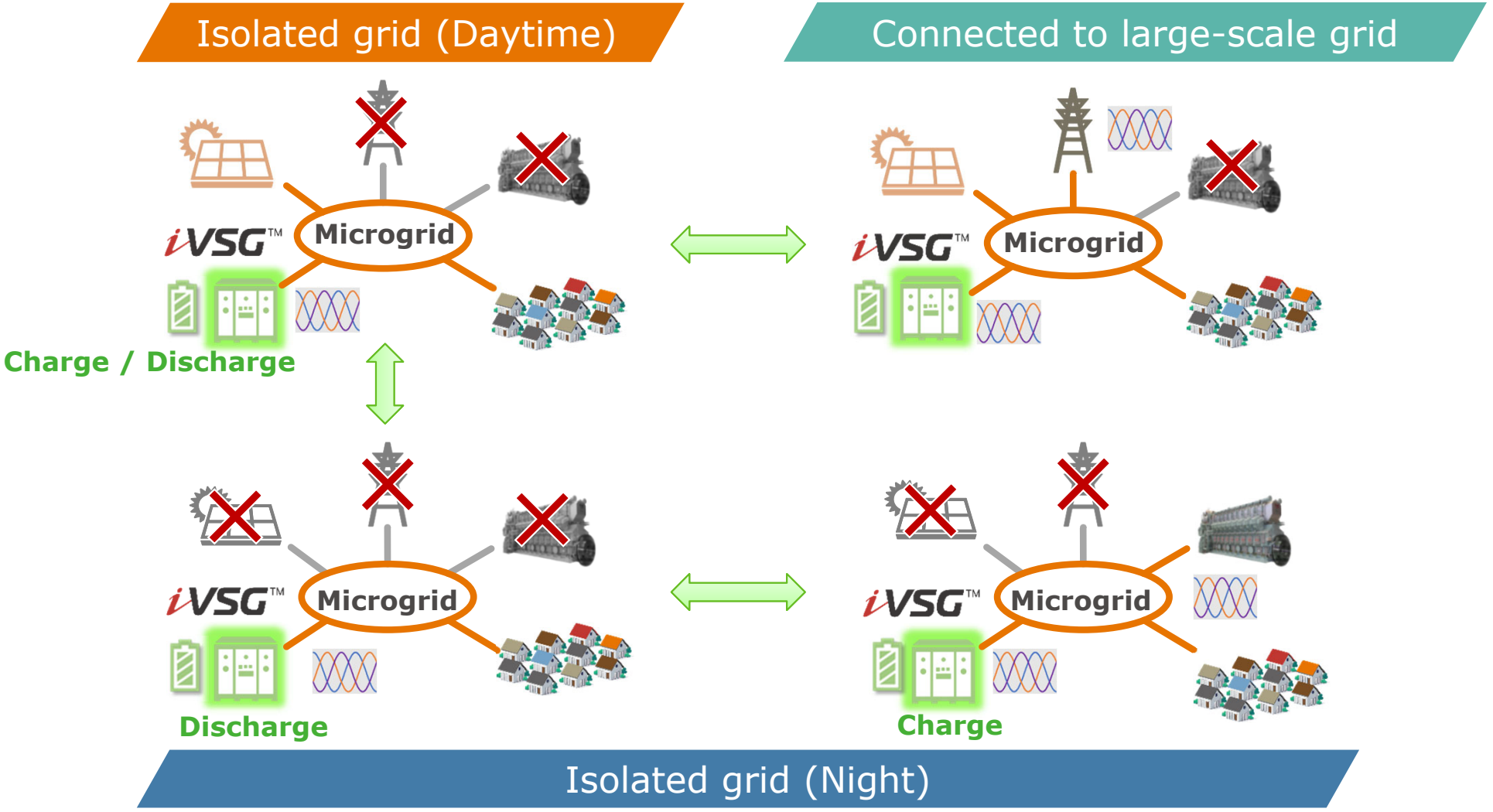
Benefits
(a) Minimal use of engine
(b) Autonomous load sharing
(c) Improving grid stability



Flexible Grid Operations

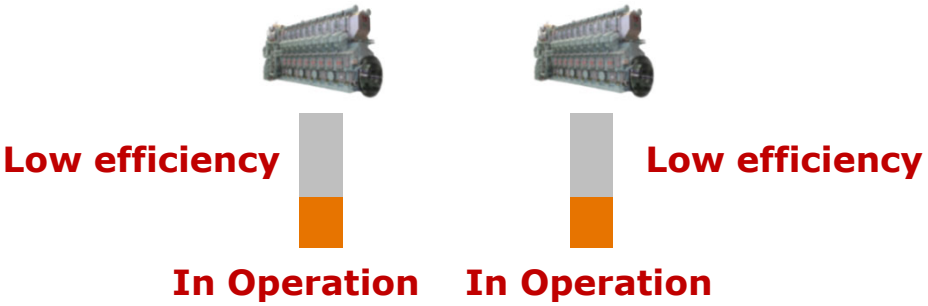
iVSG™

- iVSG™ enables flexible microgrid operation without blackouts.

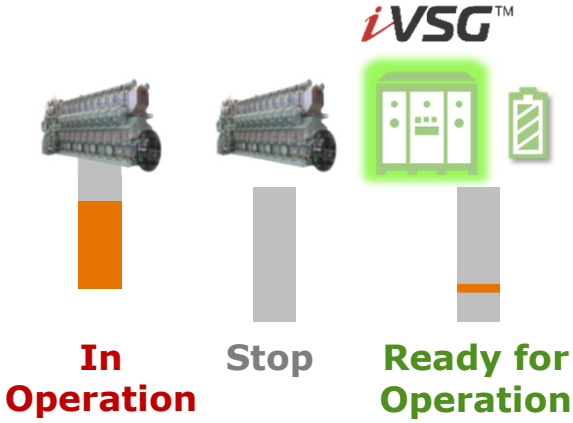


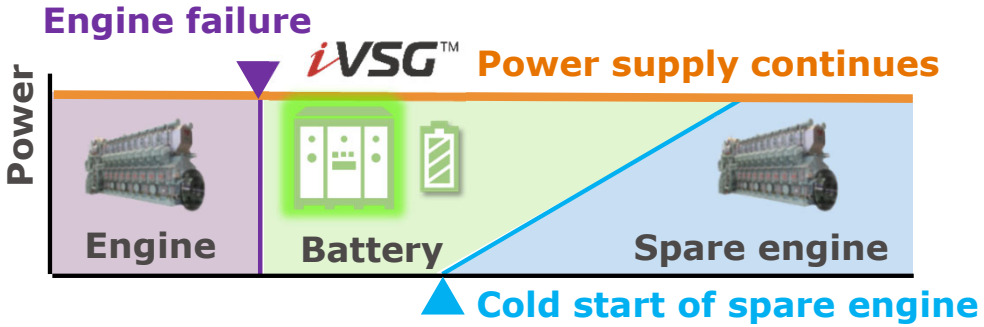
Maintaining Redundancy

- Multiple generators must be in operation to maintain redundancy.
- Partial load operation causes low efficiency.



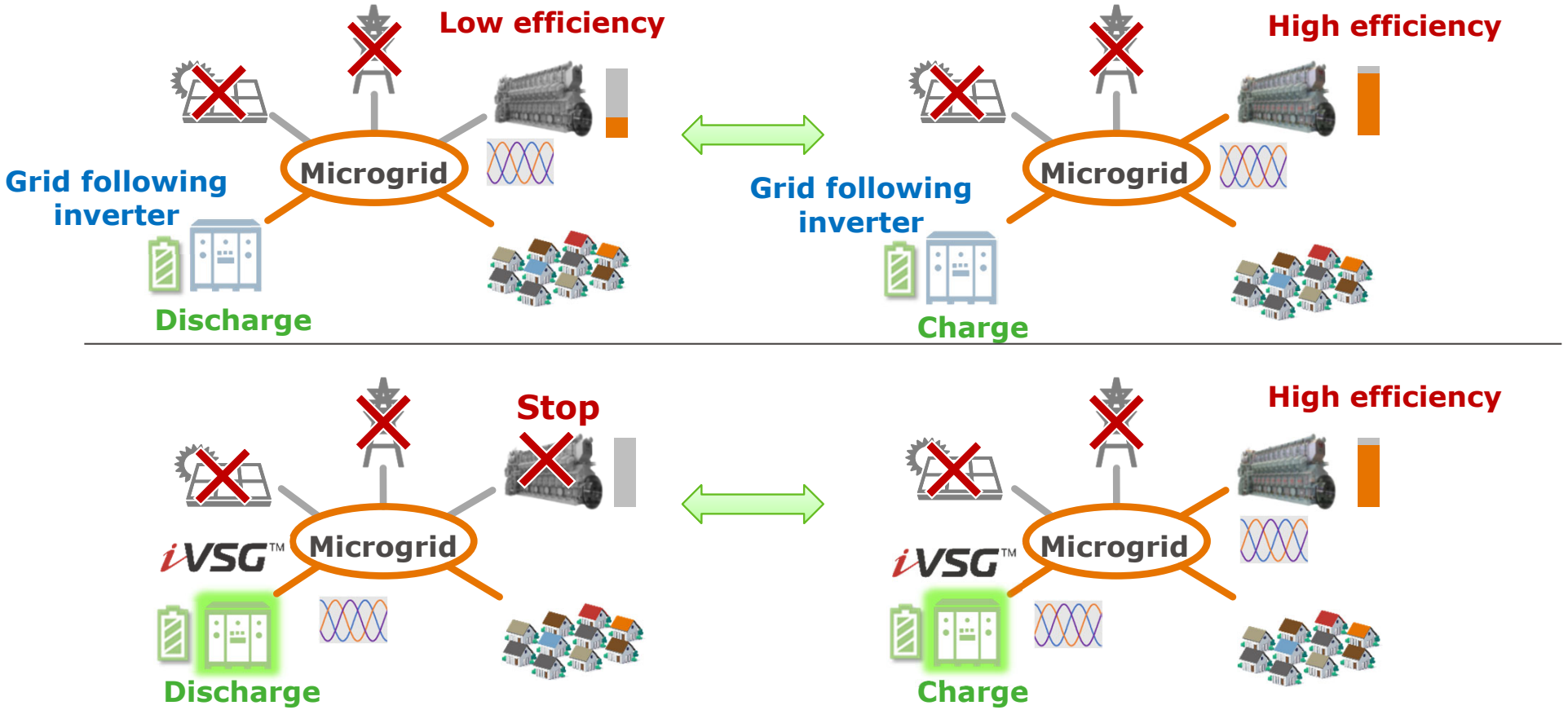
- iVSG™ maintains redundancy even in single generator operation.
- iVSG™ improves efficiency by using generators at higher load.





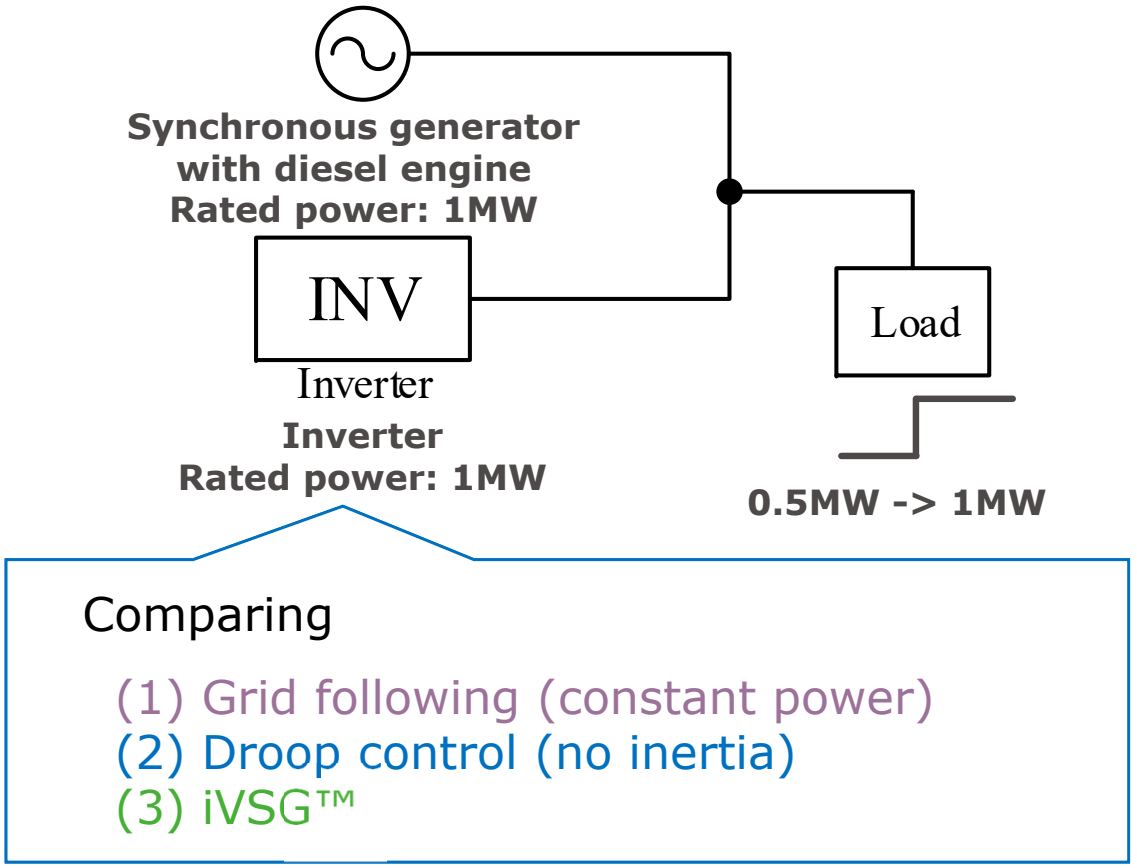
Reduction of Fuel Consumption

- A microgrid with a grid following inverter requires the engine to run all the time.
- At a microgrid with iVSG™, the engine can be operated intermittently to avoid low efficiency operation.



Grid Stabilization

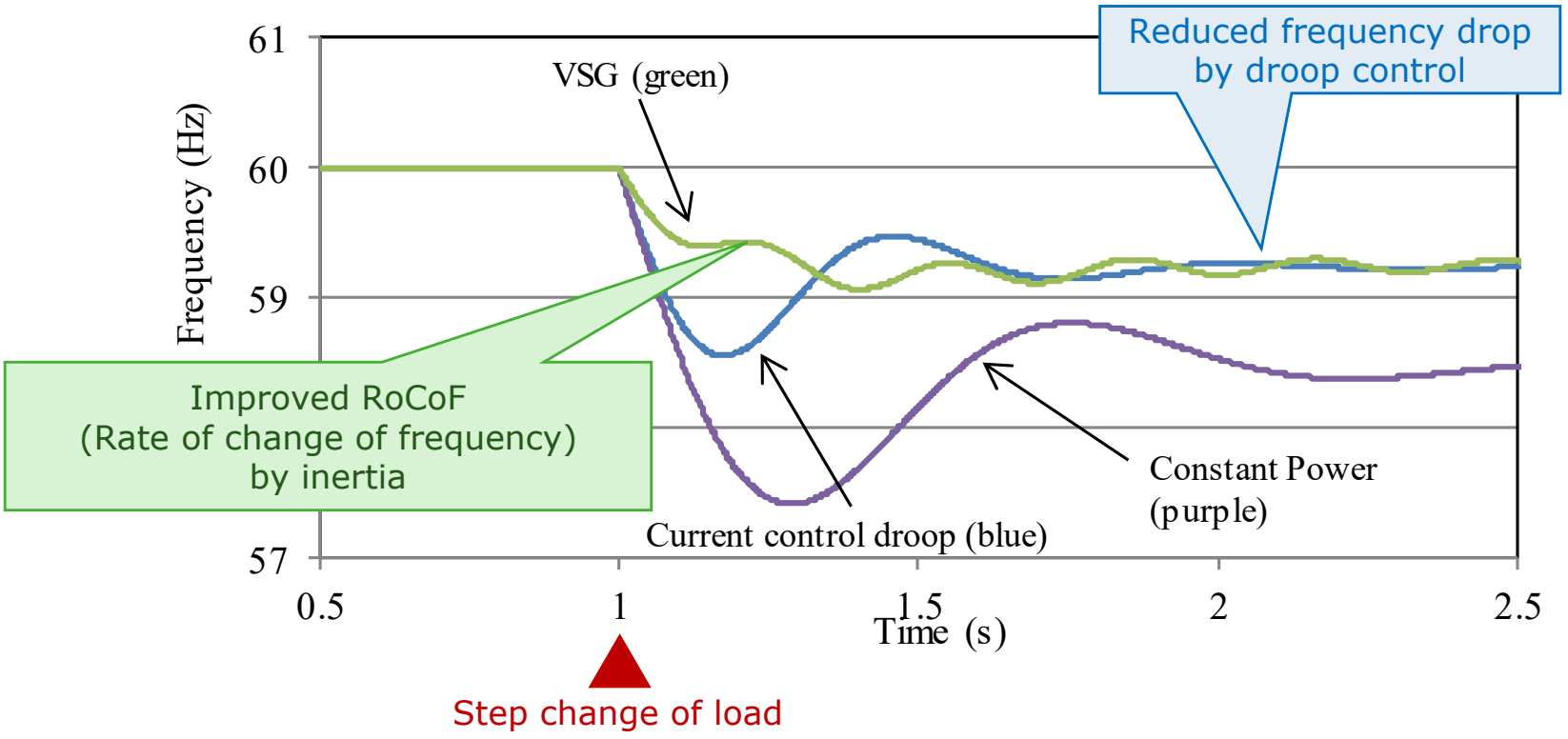
- Evaluation of the fluctuation of power system frequency when the load has step change by simulation.



Grid Stabilization

iVSG™

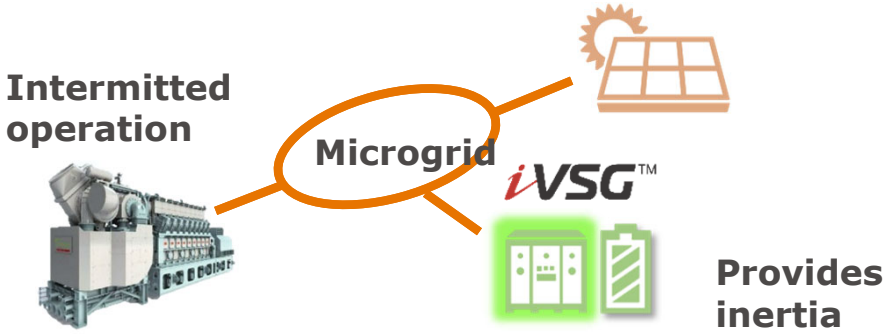
	Grid following (Constant power)	Droop control	iVSG™
Load sharing with generator	×	✓ **Load sharing by droop**	✓ **Load sharing by droop**
Maintain frequency during transient load changes	×	×	✓ **Maintain Frequency by Inertia**



Applications of iVSG™

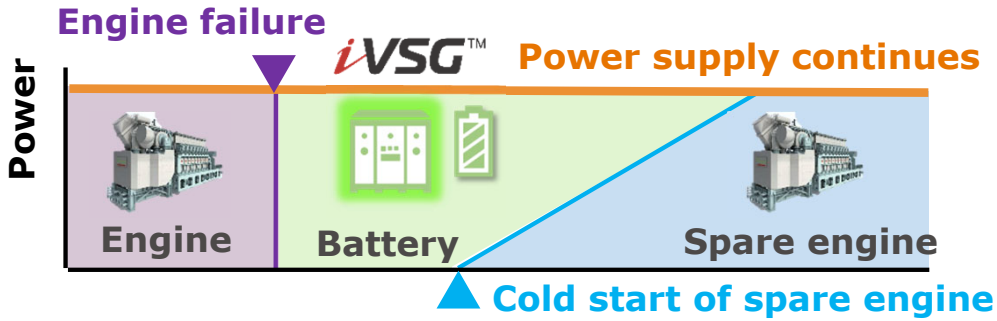
Remote Island / Resilience

iVSG™ provides inertia to micro-grid.
Power companies can increase the introduction of renewable energy and reduce fuel cost.



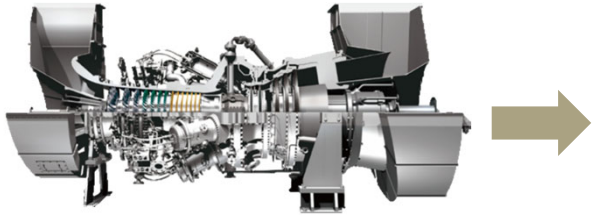
Marine

iVSG™ backs up power supply at engine failure.
Both efficiency and redundancy can be improved at single generator operation.



Fast Adjustment

If a thermal power plant cannot be shut down due to the need for fast demand/supply adjustment despite low demand at night, iVSG™ energy storage system can be used instead.



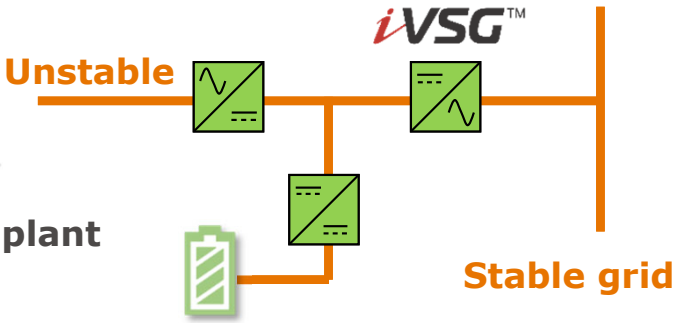
100MW thermal power plant has only a few MW adjustment ability.

A few MW VSG storage system can be used instead.

Improving Power Quality

Even if the renewable energy power generation equipment itself does not have sufficient stability, iVSG™ can form a stable grid.

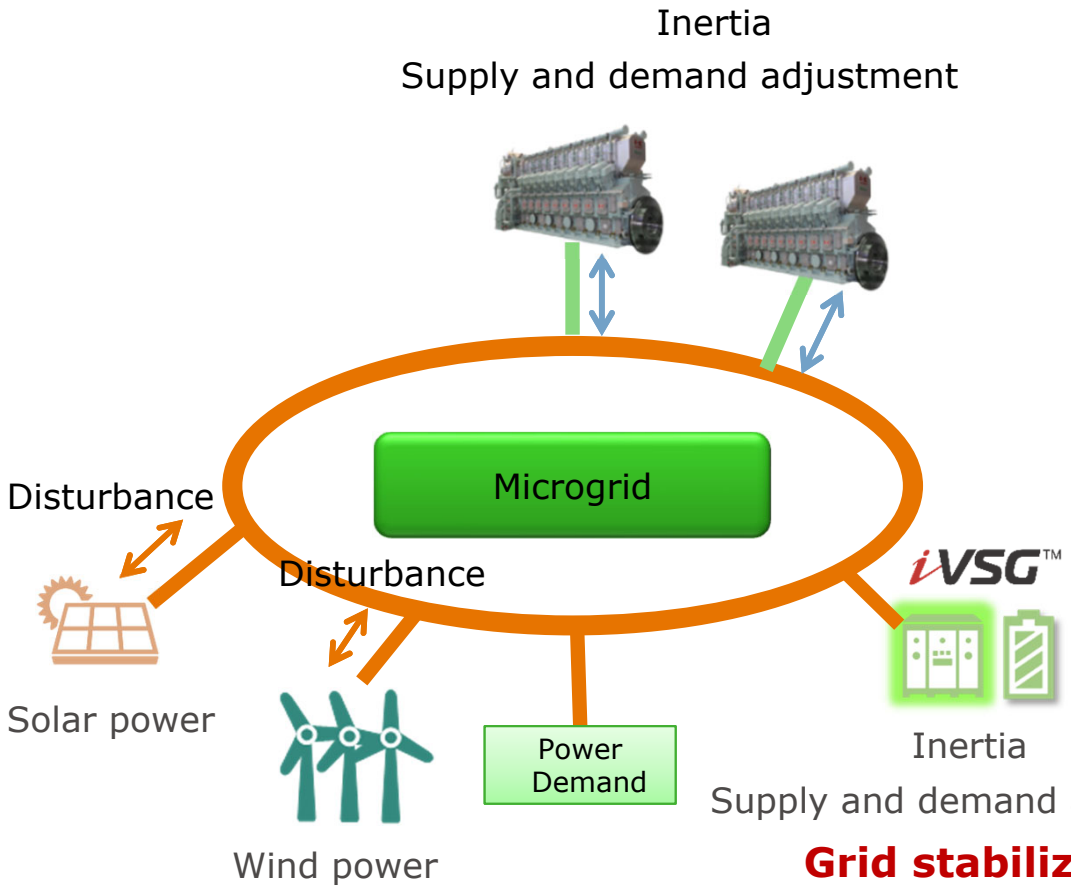
Geothermal power plant etc.



(1) Remote Islands / Resilience

iVSG™

Application	• Remote island grid systems that are not connected to power systems on the mainland
Benefits	• Promotion of introduction of renewable energy • Improving the stability of a self-sustaining system

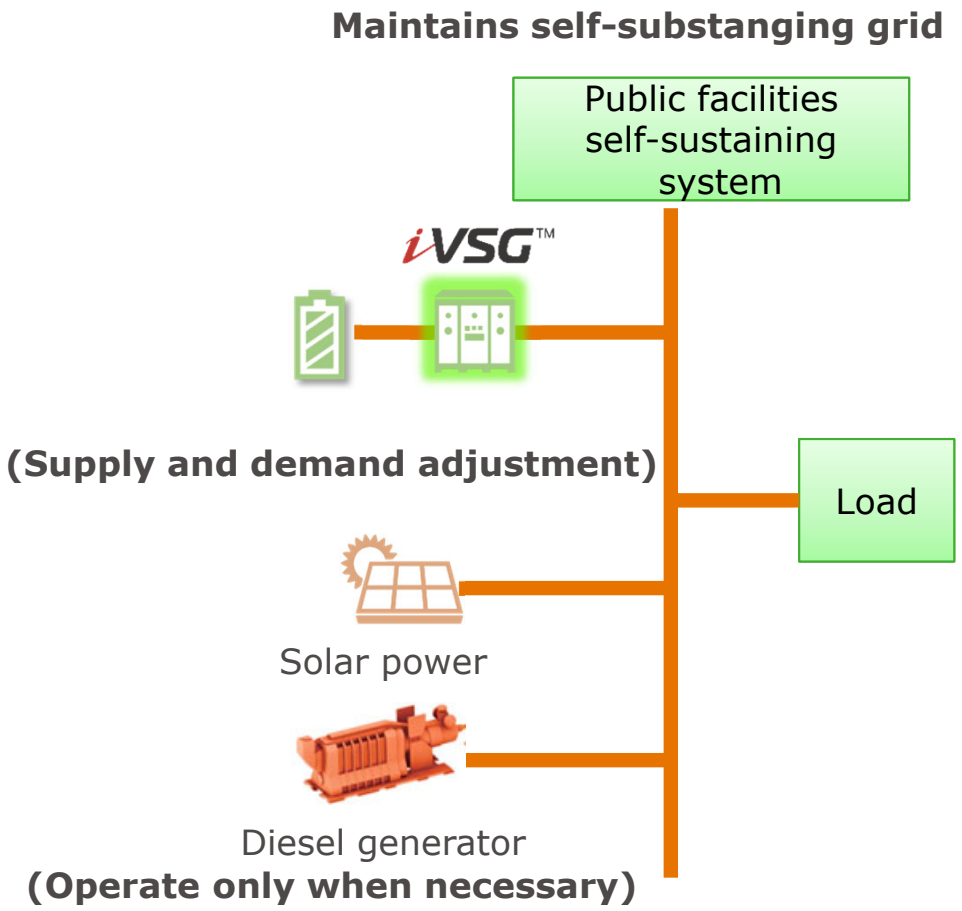


Grid stabilization
Implovement of efficiency

- In remote islands and other areas, fuel costs are expensive. There is a high need to introduce solar, wind and other renewable power.
- On the other hand, the weak grid limits the amount of renewable power that can be introduced.
- iVSG™ provides the inertia, synchronization, and supply-and-demand adjustment capabilities lacking in a small, self-supporting system.
- iVSG™ can increase the installed amount of renewable power, while reducing the number of operating thermal power plant. It enables more efficient system operation.

(1) Remote Islands / Resilience

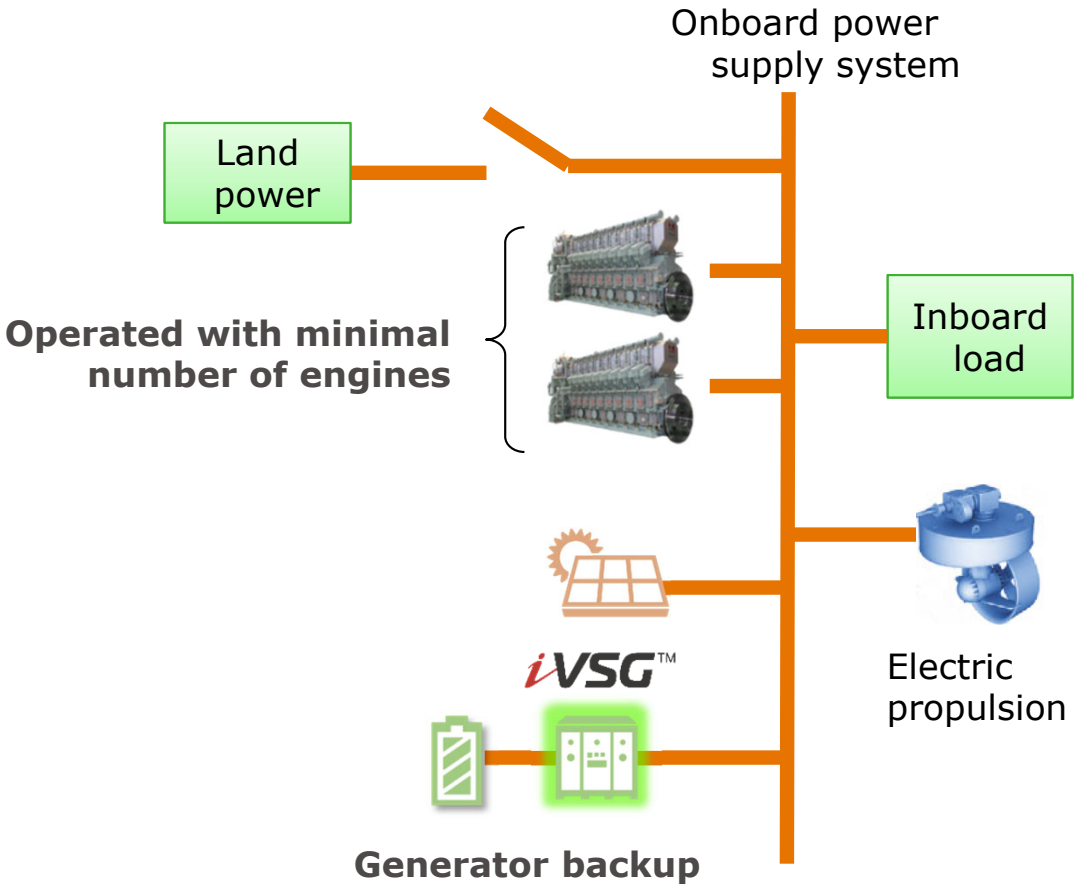
Application	• Emergency power supply in case of a major power outage by public facilities used as shelters, such as gymnasiums and community halls
Benefits	• Use of solar power during power outages • Reduction of fuel consumption by keeping the generator operation to the minimum necessary



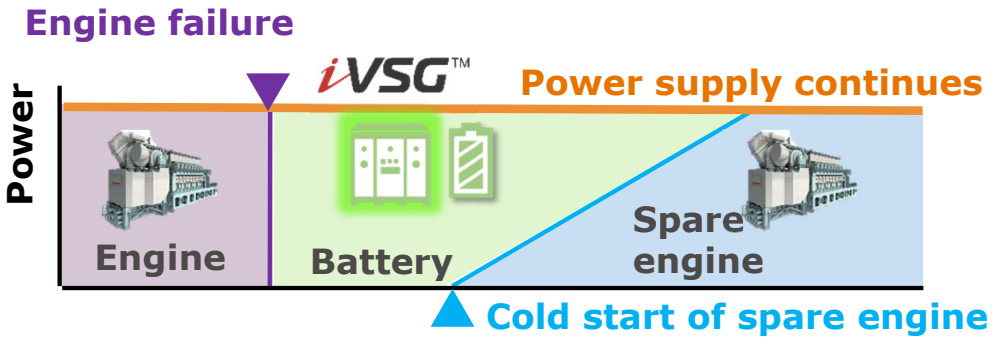
- Solar power generation can only work in a grid-connected operation and can not used in the event of a commercial grid power outage. So, the solor power is not available at the power outage.
- Storage batteries are becoming more popular in households. But there are restrictions such as temporary power outages when switching between grid connection mode and self-substaining operation mode.
- iVSG™ has the ability to maintain an isolated grid to operate seamlessly according to the state of grid.

(2) Marine

Application	• Hyblid propulsion system for vessel
Benefits	• Switching operation without blackout • Minimizing the number of operating engines

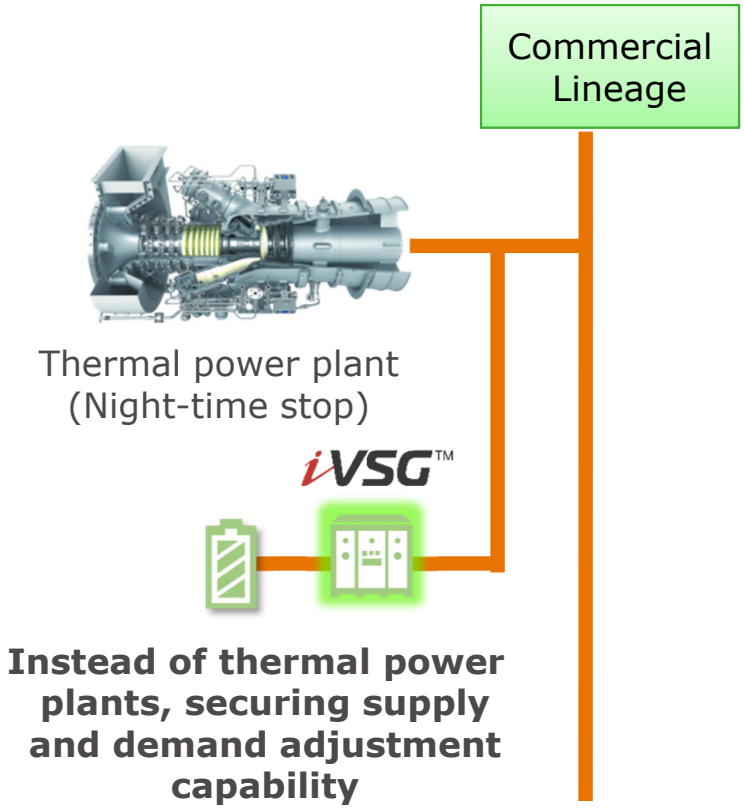


- Hybrid propulsion systems are becoming popular, which combine multiple power supply facilities with different characteristics and switch equipment configurations depending on the situation.
- iVSG™ has the same characteristics as generators, so adding iVSG™ to a hybrid system provides a more flexible and efficient power configuration.
- Also, iVSG™ backs up power supply at engine failure. Even at single generator operation, both efficiency and redundancy can be improved.



(3) Fast Supply/Demand Adjustment

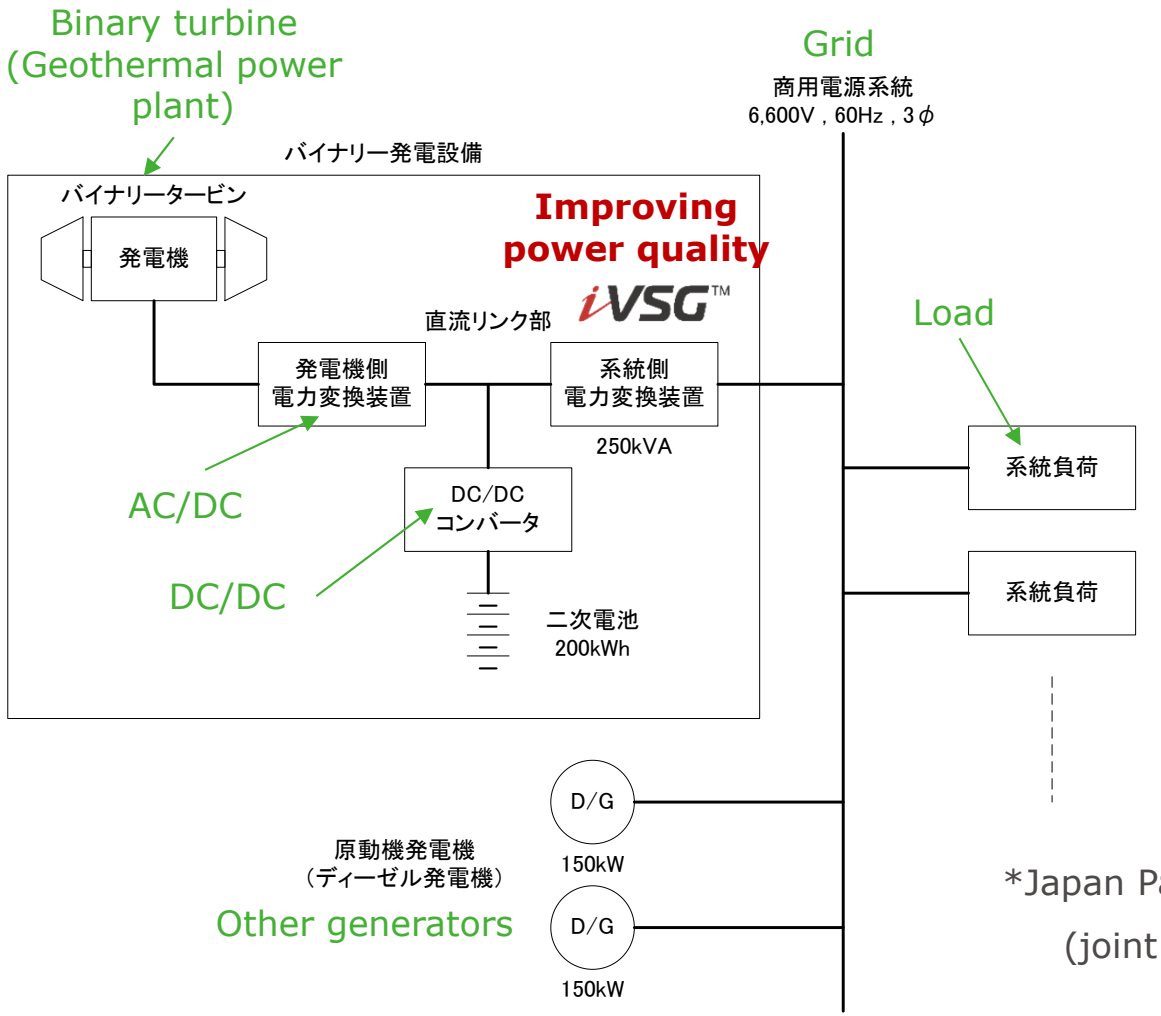
Application	• Power supply and demand adjustment
Benefits	• Improvement of grid stability (Even if thermal power plants are shut down at night) • Use as an alternative to pumped storage power plants



- Only thermal power plants have the capacity to adjust supply and demand, so when the number of operating thermal power plants decreases, the capacity to adjust load-decreases.
- To maintain a certain level of supply and demand adjustment capacity even at night when electricity demand decreases, a certain amount of thermal power plants need to be operated.
- If a thermal power plant is accompanied by iVSG™, grid stability is maintained even if the thermal power plant is shut down at night because iVSG™ wil adjust supply and demand. iVSG™ improves efficiency to reduse surplus operation of thermal power plants at night.
- The supply and demand adjustment capacity of thermal power plants is a few percent of the rated capacity. For example, the supply and demand capacity of a 100MW thermal power plant is thought to be only a few megawatts, which can be sufficiently achieved by iVSG™ storage facilities.
- Additionally, it also provides an allowance for lowering power, making it a substitude for pumped storage power plants.

(4) Improving Power Quality

Application	• System with power generation facilities that alone are difficult to improve power quality
Benefits	• Stabilizing power quality



- This is an example of the use of iVSG™ in response to a request to install binary turbines of geothermal power plant on remote islands with heat sources.
- We planned to add power storage with a DC/DC converter to a binary turbine and use iVSG™ as the power converter on the grid side.
- Even if the binary turbine itself does not have sufficient stability, iVSG™ can form a stable grid.
- The system simultaneously realizes the demand on grid side, control of the rotation speed of the binary turbine, and control of the charge and discharge of the storage battery.

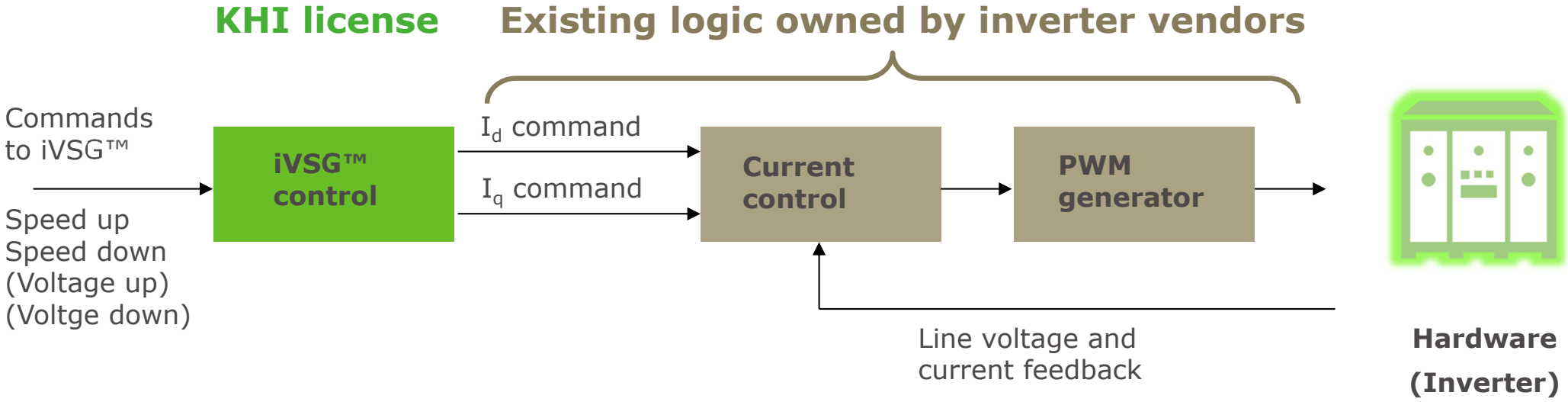
*Japan Patent 6371603

(joint application with Kyushu Electric Power Co., Inc.)

Implementation of Software

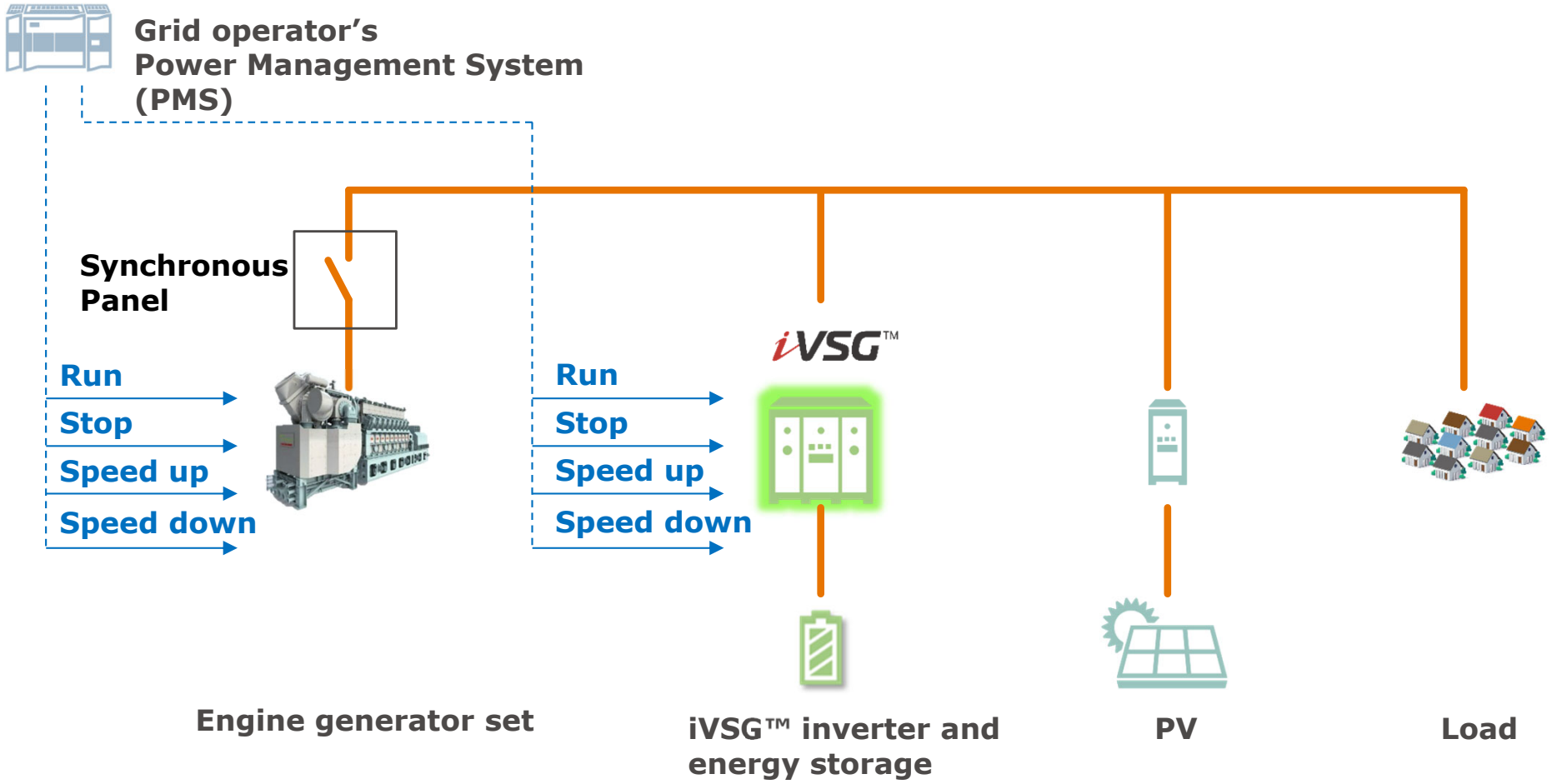
iVSG™

- KHI licenses software design document or source code of iVSG™ logic.
- Inverter vendors can incorporate iVSG™ logic to current control logic.
- Conditions for introducing iVSG™:
  - Control board needs enough performance to run iVSG™ control. Control cycle time of iVSG™ is the same as current control.
  - If an inverter vendor adapts special current control logic, the interface between iVSG™ control and current control may not match.
  - Signal interfaces for commands to iVSG™ is necessary.



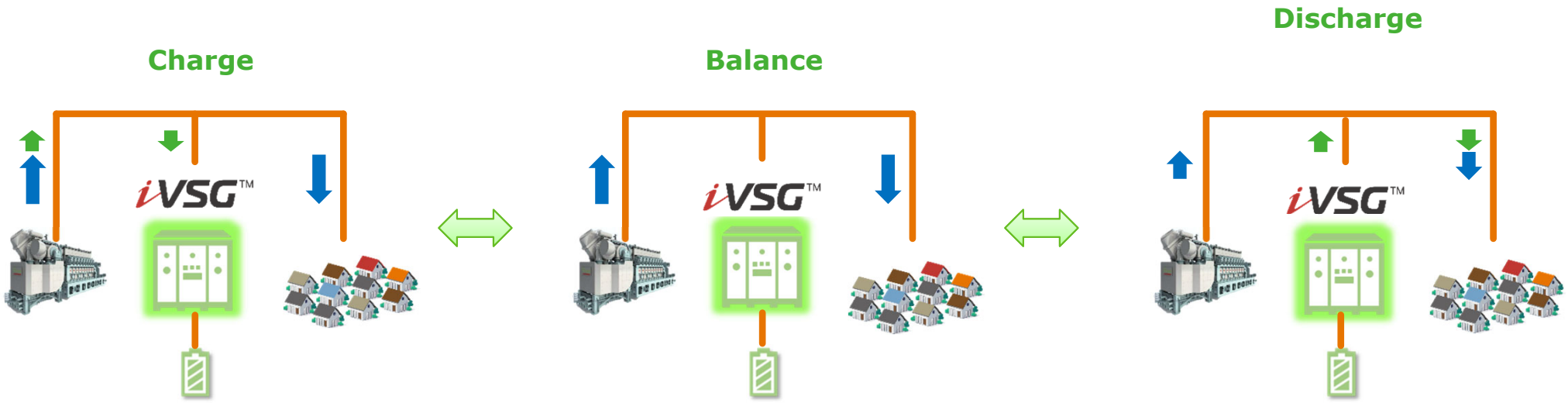
Configuration Example

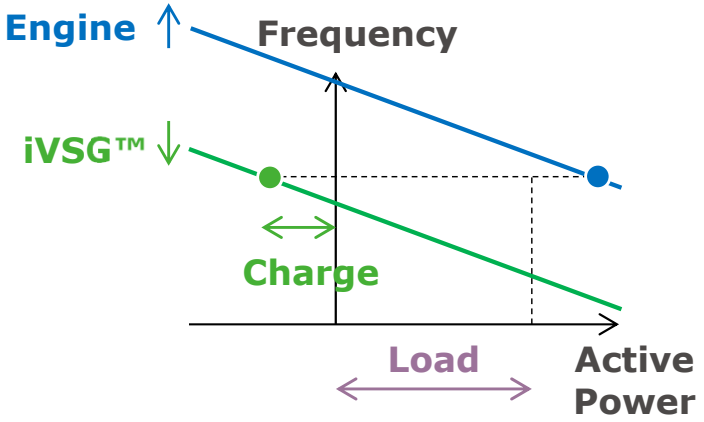
- iVSG™ inverter can be operated like an engine generator.
- Microgrid operator may install a power management system or operate each equipment at machine side.

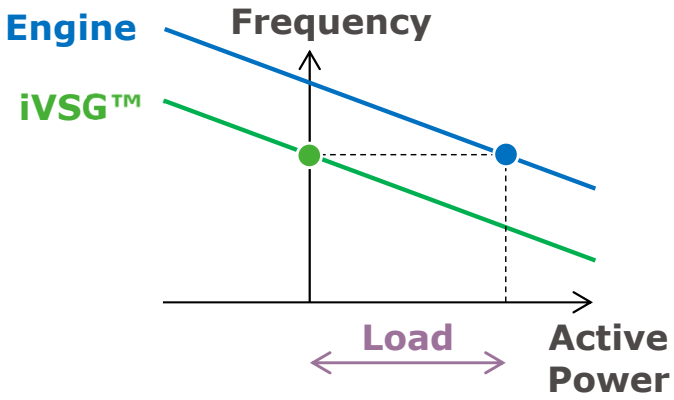


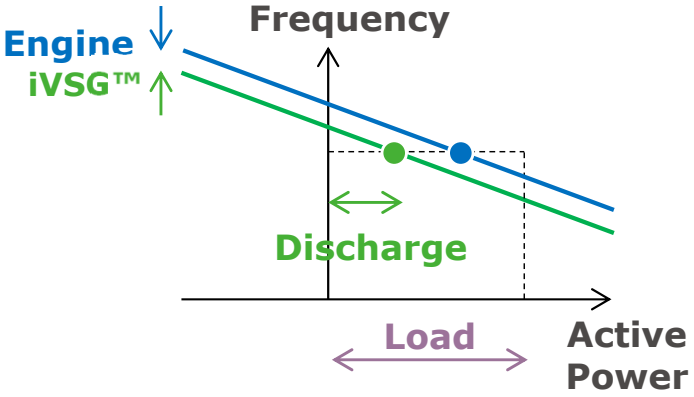
Autonomous Load Sharing

- Load is shared between engine and iVSG™ autonomously.
- Charge and discharge power can be adjusted by moving droop characteristics.









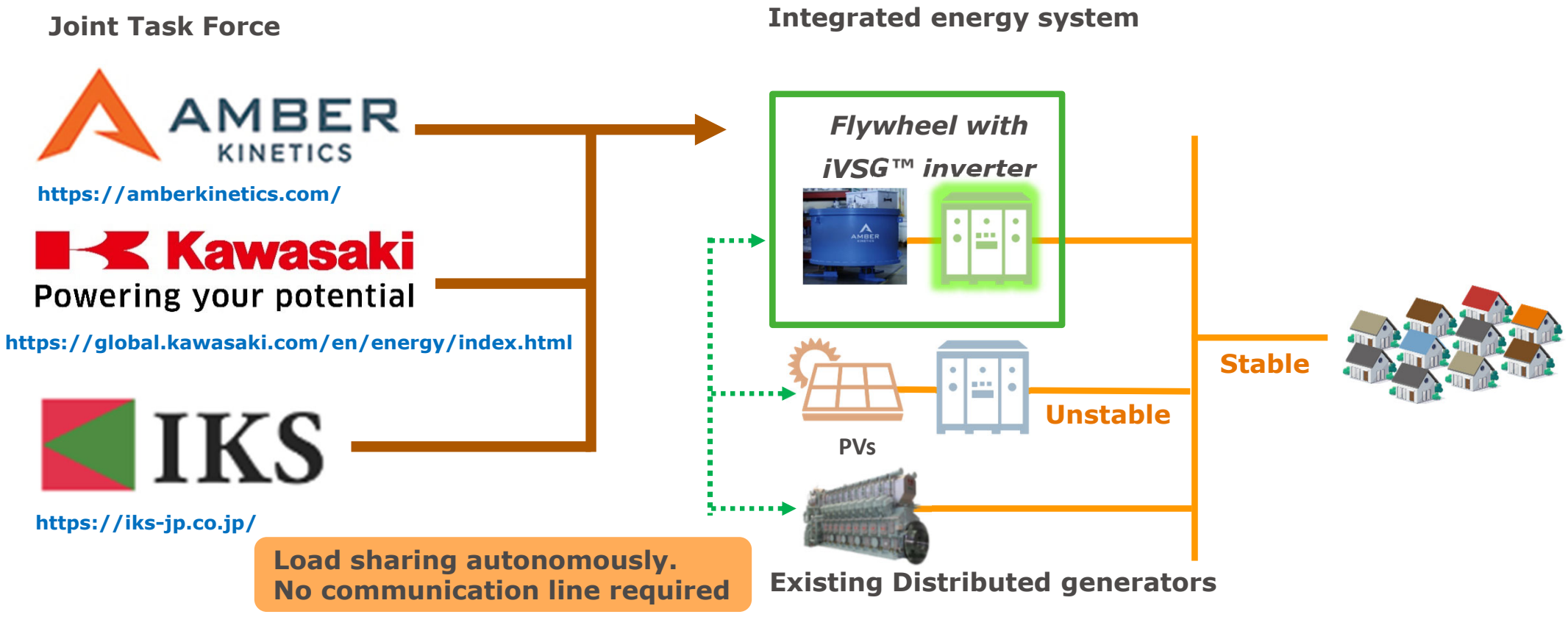
Partnership Scheme to Introduce VSG Technology (1)

- KHI has developed “iVSG™”, a software applicable to inverters, which makes it possible for the inverter type power sources to possess inertia by simulating a characteristic of the synchronous generator.
- KHI is working on a project to introduce a decarbonization-promoting energy system with iVSG™ to ASEAN and island countries through a partnership scheme with local companies.

Partnership Scheme to Introduce VSG Technology (2)

iVSG™

- KHI is launching a cooperative partnership which will aim to evaluate and advance the development of FESS(flywheel energy storage system) by Amber kinetics and iVSG™ inverter by IKS with iVSG™(Virtual synchronous generator) solutions for transition to more renewable energy in the Philippines.



The latest example of joint activity with local companies (the Philippines case,2023)

Summary

- iVSG™ is control software for inverter with energy storage, simulating the characteristics of an engine generator. The outstanding features of iVSG™ are as follows.
  (1) Grid forming
  (2) Droop control
  (3) Simulated inertia
  (4) Charge and discharge

- iVSG™ enables flexible and economical operation of microgrid with energy storage and engine generators while maximizing the use of renewable energy.

- iVSG™ is the key technology to integrate renewable energy and engine generators into microgrid.

Journal / Conference Paper (1)

- Y.Hirase, K.Abe, K.Sugimoto, Y.Shindo "A grid - connected inverter with virtual synchronous generator model of algebraic type" Electrical Engineering in Japan vol.184 no.4 pp.10-21 (2013)
- Y.Hirase, O.Noro, E.Yoshimura, H.Nakagawa, K.Sakimoto, Y.Shindo "Virtual Synchronous Generator control with Double Decoupled Synchronous Reference Frame for single-phase inverter" 2014 International Power Electronics Conference (IPEC-Hiroshima 2014 - ECCE ASIA) pp. 1552-1559 (2014)
- Y.Hirase, O.Noro, E.Yoshimura, H.Nakagawa, K.Sakimoto, Y.Shindo "Virtual synchronous generator control with double decoupled synchronous reference frame for single-phase inverter" IEEJ Journal of Industry Applications vol.4 no.3 pp.143-151 (2015)
- Y.Hirase, O.Noro, K.Sugimoto, K.Sakimoto, Y.Shindo, T.Ise "Effects of suppressing frequency fluctuations by parallel operation of virtual synchronous generator in microgrids" 2015 IEEE Energy Conversion Congress and Exposition (ECCE) pp. 3694-3701 (2015)
- Y.Hirase, O.Noro, K.Sugimoto, K.Sakimoto, T.Ise "Effects and analysis of suppressing frequency fluctuations in microgrids using virtual synchronous generator control" IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society pp. 43-49 (2015)

Journal / Conference Paper (2)

- Y.Hirase, K.Abe, O.Noro, K.Sugimoto, K.Sakimoto "Stabilization effect of virtual synchronous generators in microgrids with highly penetrated renewable energies" 2016 IEEE 17th Workshop on Control and Modeling for Power Electronics (COMPEL) pp. 1-8 (2016)

- Y.Hirase, K.Sugimoto, K.Sakimoto, T.Ise "Analysis of Resonance in Microgrids and Effects of System Frequency Stabilization using a Virtual Synchronous Generator" IEEE Journal of Emerging and Selected Topics in Power Electronics vol. 4, no. 4, pp. 1287-1298 (2016)

- Y.Hirase, Kensho Abe, K.Sugimoto, K.Sakimoto, H.Bevrani, T.Ise "A novel control approach for virtual synchronous generators to suppress frequency and voltage fluctuations in microgrids" Applied Energy Vol.210, pp.699-710 (2018)

- Y.Hirase, H.Nakagawa, E.Yoshimura, S.Katsura, K.Abe, O.Noro, K.Sugimoto, K.Sakimoto "Stable Power Supply Method for Household Appliances via Virtual Synchronous Generator in Single-Phase Three-Wire Microgrid" 2018 International Power Electronics Conference (IPEC-Niigata 2018 -ECCE Asia) pp. 767-774 (2018)

- K.Sakimoto Y.Hirase, O.Noro, H.Nakagawa, E.Yoshimura, S.Katsura, K.Abe, K.Sugimoto "Decentralised and interlink-less power interchange among residences in microgrids using virtual synchronous generator control" Applied Energy Vol.228, pp.2437-2477 (2018)

Kawasaki, working as one for the good of the planet

“Global Kawasaki”

Kawasaki

Powering your potential