cigre PARIS 2022

Kansai Transmission and Distribution

Study Committee C6

Active Distribution Systems and Distributed Energy Resources

Paper ID_10594

Economical and Technical Evaluation of Transformation from Existing Distribution System to Off-grid

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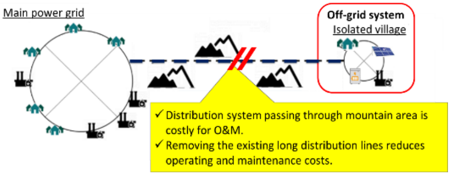
Introduction

- In low-demand areas of Japan, the financial burden will increase because "Wheeling charges < Facility maintenance costs".
- Converting to off-grid could solve the burden by removing the long lines that connect the areas.
- The off-grid requires power quality and reliability equivalent to the existing system.
- In this study, we evaluated the economical and technical feasibility of the off-grid. A mountain village with a contract power of 9.7 kW and a line of 4.9 km was selected for evaluation.



✓ Distribution system passing through mountain area is costly for O&M.
✓ Removing the existing long distribution lines reduces operating and maintenance costs.

Fig. 1 Image of converting off-grid

Economic evaluation

- A supply-demand balance simulation was performed assuming the PV curve, demand curve, and BESS charge/discharge pattern for the area.
- From Fig. 2, the optimal PV capacity of 60 kW and BESS capacity of 28 kWh were the most economical cases for the area.
- The CAPEX and OPEX for the off-grid and the OPEX for the existing system were calculated using DCFM and evaluated in comparison.
- From Fig. 3, the off-grid becomes more economical in the 20th year, when the existing system is undergoing a major upgrade.

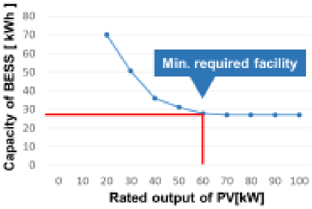


Fig. 2 Optimal installed capacity

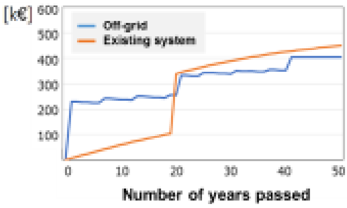


Fig. 3 Economic evaluation

Technical evaluation

- Ground faults, short-circuit faults, and black starts were simulated in the test facility, and system conditions were evaluated.
- In the ground faults, the V_0 was about 5,000V and the I_0 was extremely small. It is desirable to select OVGR for the ground fault protection in small-scale off-grid.
- In the short-circuit faults, the measured current was about 10times higher for about 100ms after the event. It is desirable to select OCR for short-circuit protection because the PCS can supply enough fault current for small-scale off-grid.
- In the black start, the shorter the soft-start time of PCS, the larger the excitation inrush current. PCS capacity was large for the facility size, so black start was possible regardless of the set-up time.

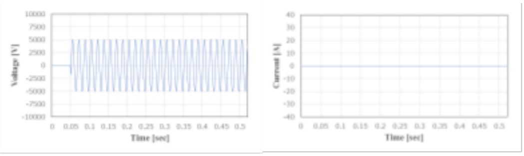


Fig. 4 Ground fault result at Main-Tr (Left: V0, Right: I0)

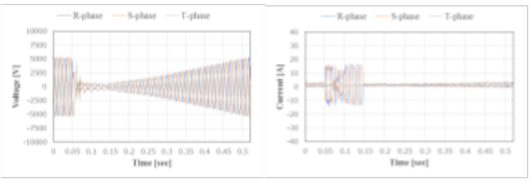


Fig. 5 Short-circuit result at Main-Tr

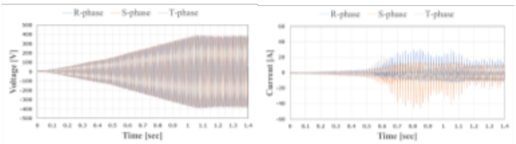


Fig. 6 PCS behavior after black start

Conclusion

- In low-demand areas with long distribution lines, converting to off-grid was found to be economical.
- In a small off-grid system with only PCS, OVGR for ground-fault protection and OCR for short-circuit protection were found to be necessary. For the grid with large PCS capacity, black start was found to be possible regardless of the soft start time of the PCS.

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Selection of area for off-grid

- The installation costs of off-grid and the maintenance costs of distribution lines were roughly evaluated for 10 candidate sites.
- The line to judge whether it is economical or not (orange) was derived from the cost per demand size [kW] and the cost per distribution line[m].
- We selected a mountain village with demand size of 9.7kW and distribution line of 4.9km in Fig. 7,8.

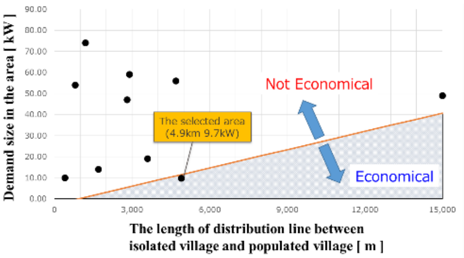


Fig. 7 Simple economic evaluation

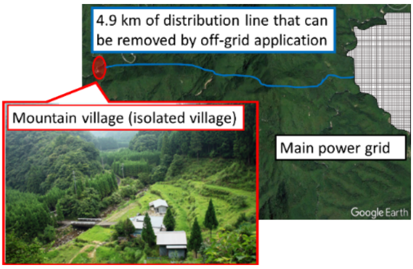
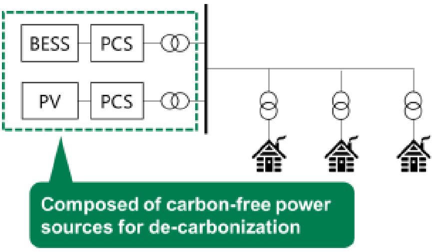


Fig. 8 Selected area

Off-grid model

- In light of de-carbonization, PV and BESS were used as carbon-free power sources, in Fig. 9.
- Other system facilities consisted of AC medium and low voltage lines and transformers.



Composed of carbon-free power sources for de-carbonization

Fig. 9 Off-grid model

Selection of PV and BESS capacity

The PV curve, demand curve, and BESS model for the selected area are below. Based on these conditions, supply-demand balance simulation was performed to calculate the most economical PV and BESS capacities that would not cause supply shortages.

< PV generation curve >

To calculate the PV capacity that would not be under-supplied even in bad weather, conditions were set for five consecutive days of low solar radiation.

< Demand curve >

Basic pattern of the daily demand curve was created from the actual demand in the selected area, and the demand data was repeated every day for one week.

< BESS model >

If there is surplus power in PV output, it is stored in BESS, and if there is a shortage, it is discharged from BESS. When SoC reaches 100%, BESS stops charging and suppresses PV output; when SoC reaches 0%, it is judged as supply shortage.

< Result >

The PV and BESS capacities in Fig. 2 are expressed in terms of cost as shown in Fig. 10, and it can be determined that the PV capacity is most economical when the PV capacity is 60 kW.

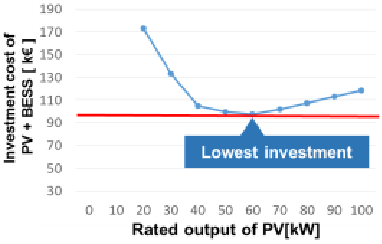


Fig. 10 Optimal installed capacity (Cost)

Economic evaluation (CCM)

- Evaluation results by CCM show that off-grid becomes economical in the 33rd year.

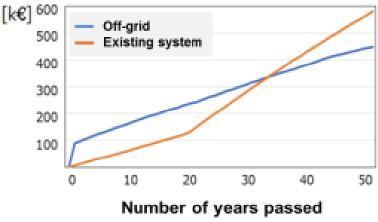


Fig. 11 Economic evaluation (CCM)

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continued

Technical evaluation

- System configuration

The test facility was constructed as shown in Fig. 12. Main/Sub PCS with different specs were installed for the power supply. AC/DC converters were installed on the DC side of these PCSs to convert commercial power (AC 210V) to DC. Main-PCS (rated output: 125kW) has soft-start function and was installed on 480V grid. Sub-PCS (rated output: 16.5 kW) simulates distributed generation and was installed on 210V grid. Transformers (Tr) were installed as Main-Tr (6600V/480V, Δ-Y connection), Sub-Tr (6600V/210V, Δ-Δ connection), and Tr for low voltage interconnection (480V/210V). Measuring instruments (M in the Fig.) were installed on both the medium and low voltage sides of the Main/Sub Tr. GPTs and ZCTs were installed on the medium-voltage side of the Main-PCS, so that V_0 and I_0 could also be measured at the time of the fault. A ground fault/short-circuit simulator (Artificial fault in Fig.) was installed on the medium-voltage side of Main-Tr

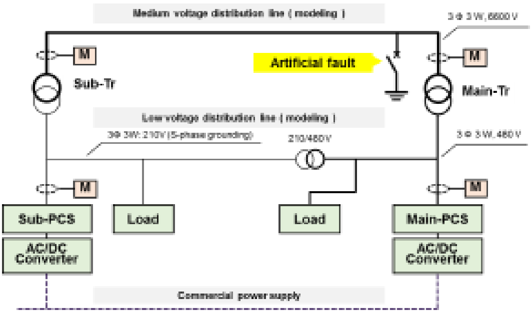

Fig. 12 System configuration

- Ground fault simulation

Ground fault (700ms) was simulated to monitor the grid condition. Fig. 13 shows that the voltage of Main/Sub PCS remained unchanged except for the faulty phase, but the current of Main-PCS increased by about 10% for the three phases.

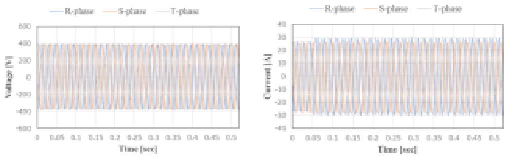

Fig. 13 Ground fault result at Main-PCS

- Short circuit simulation

Short-circuit fault (100ms) was simulated to monitor the grid conditions. From Figs. 14 and 15, the maximum current values of Main-PCS and Sub-PCS were about 7 and 4 times the original values, respectively, during the first 100 ms after the fault, confirming that both PCSs were supplying the fault current.

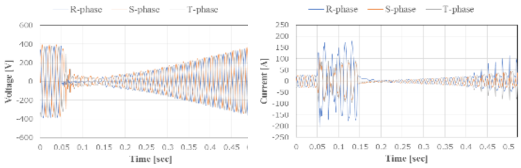

Fig. 14 Short-circuit result at Main-PCS

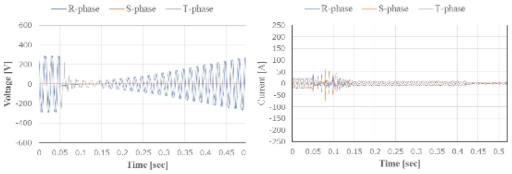

Fig. 15 Short-circuit result at Sub-PCS

- Black start simulation

The soft-start time of the Main-PCS was varied from 8sec, 4sec and 1sec, and the voltage and current of the low-voltage side were measured during the black start. From Figs. 16 and 17, the excitation inrush current was about 25A when its setting time was 8 and 4sec. When the setting time was 1sec (Fig. 6), the peak value was 46A.

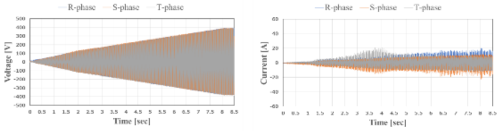

Fig. 16 PCS behavior after black start (Soft-start: 8s)

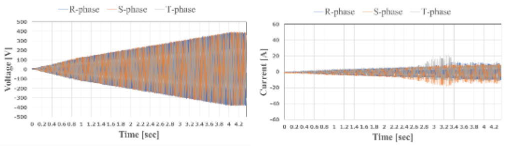

Fig. 17 PCS behavior after black start (Soft-start: 4s)