MICROGRID PREDICTIVE CONTROL METHOD THAT SUPPORTS RESILIENCY AND ECONOMIC EFFICIENCY

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ABSTRACT

This paper presents the concept and simulation result of a predictive control method of a microgrid (MG) supply-demand balance that supports resiliency and economic efficiency at the same time. To maintain these, we use an optimization technique and power system analysis. To use the results of power system analysis in an optimization technique, we converted them into an inequality equation of master generator output and demand. In this paper, as a representative stability phenomena, we focused on a MG islanding transition process and converted result.

INTRODUCTION

Microgrid (MG) installations are expanding to improve the resiliency and economic efficiency of regional power systems. The total installed capacity of MGs is expected to be over 15.0GW in 2022 [1].

Numerous studies have been conducted for optimization techniques for generator operation [2-6] or control techniques for voltage/ frequency/ transient stability [7-11].

However, there are few studies that satisfy economic efficiency and stability at the same time. Prior studies focus on minimizing MG operation costs by maintaining voltage stability [12]. However, in addition to voltage stability, an MG has frequency stability and islanding transition stability.

Therefore, we are developing a predictive control method with an analysis-based power system optimization technique called SEDEC (SElf-DEfense Control), to effectively allocate power supply of all generator in MG via economic load dispatch (ELD) which will satisfy all stability factors.

To use the results of a power system analysis in an optimization technique, we converted them into an inequality equation that we can use as a constraint condition.

In this paper, as a representative stability phenomena, we focused on an MG islanding transition process. We show an inequality equation that was converted from simulation result. The inequality equation has two variables, master generator output and demand.

We present the SEDEC concept in Section 2, simulation conditions in Section 3, simulation results and evaluations in Section 4, and conclusion in Section 5.proceedings.

SEDEC CONCEPT

SEDEC optimizes MG ELD, which satisfies an MG's stability, using grid simulation. Figure 1 shows two MG representative compositions, distributed and centralized. In distributed composition, devices operate on the basis of local measurement data to maintain stability. On the other hand, in centralized composition, an MG AEMS (Area Energy Management System) develops operation plans for all controllable devices to improve economic efficiency.

In this research, our target MG composition is a hybrid of distributed and centralized compositions to satisfy MG resiliency and economic efficiency. To realize this concept, we are developing an ELD technique that solves the optimization problem of MG generator operations with the constraint of MG stability.

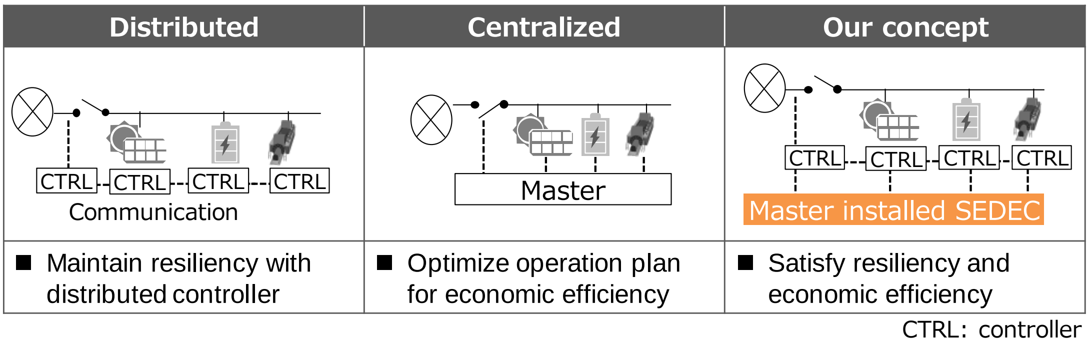

Figure 1 General MG composition and our concept

ELD plans that satisfy stability requirements requires an optimization algorithm that operates under all stability restrictions. An MG has voltage, frequency, and islanding transition stabilities. Therefore, SEDEC must solve optimization algorithm under these stability restrictions.

To develop an optimization algorithm with stability restrictions, SEDEC must have inequality equations that show the boundary condition between stability and instability for all MG conditions. To solve the optimization of a non-linear programming problem, like MG ELD, particle research is generally used. Every time particles move, it is necessary to use grid simulation for judging whether they satisfy all constraint. Hence, the amount of computer calculation becomes enormous. For this reason, it is necessary to reduce the times of grid simulations.

To reduce the amount of computer calculation, we formulated equations to calculate MG stability boundary conditions. The steps are as follow:

1. Calculate the stabilities under multiple conditions with a grid simulation and judge whether the condition is stable or not.
2. Formulate an equation that shows stability boundary conditions with classification techniques, including the least squares method and machine learning approaches, such as support vector machines.

We use the equation as a restriction of the ELD calculation.

In this report, we formulated an inequality equation that shows the boundary conditions of islanding transition stability in one MG.

SIMULATION DESIGN AND CONDITIONS

The MG used in the simulation has three synchronous generators and one load. We formulated an inequality equation with load and master generator output as variables. Figure 2 shows the design of this simulation. We developed this simulation model with reference to [13]. Table 1 shows simulation conditions.

In this simulation, we used GEN3 as the master generator. The master generator switches its control method between two modes: connected and islanded. In connected mode, the master generator uses droop control and automatic power factor regulation (APFR). In islanded mode, the master generator uses isochronous control and an automatic voltage regulation (AVR). The master generator switches its control methods when the MG frequency drops under 57.0 Hz. The other generators use droop control and APFR in all modes. We used the IEEE standard model for the generator governor and exciter.

When the bulk grid frequency drops from 60.0 to 59.3Hz, the power common coupling (PCC) separates the MG from the bulk grid. When the MG frequency drops to 54.0Hz or the MG voltage increases to 10.925kV, the MG fails islanding. In connected mode, the MG load consumes reactive power, which is the same as the total generator reactive power outputs.

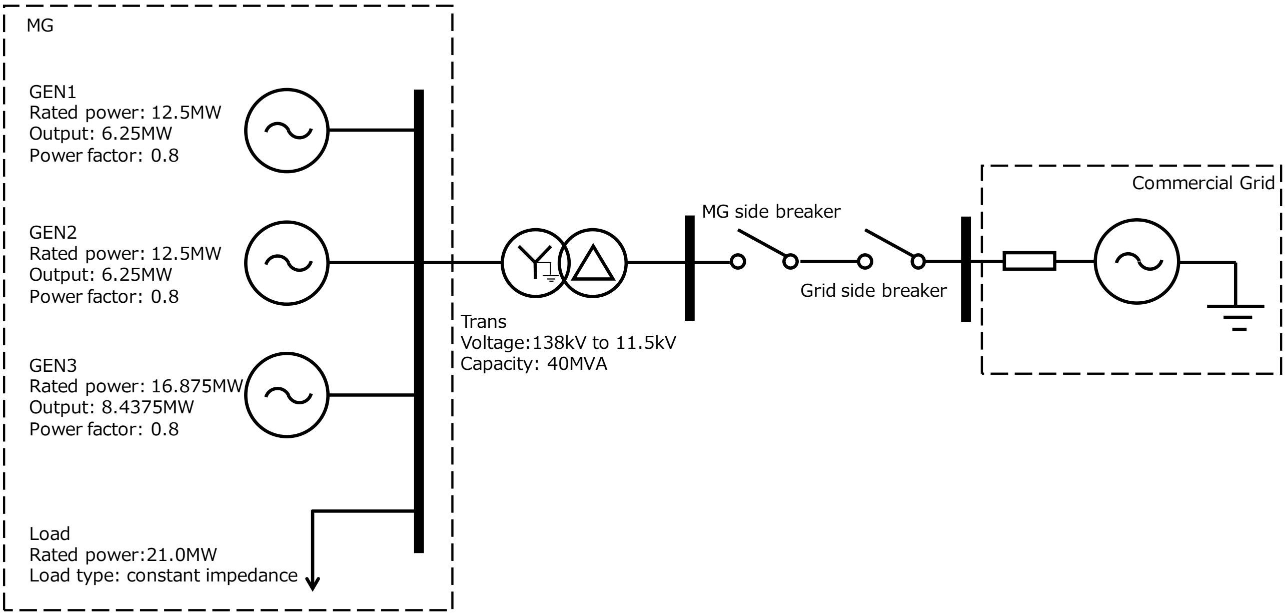

Figure 2 Simulation design

Table 1 Simulation conditions

GEN1 active power	MW	6.25
GEN2 active power	MW	6.25
Power factor (In APFR)	-	0.8
GEN1 rating power	MVA	12.5
GEN2 rating power	MVA	12.5
GEN3 rating power	MVA	16.375
Load reactive power	MVA	Equal to total generator Q
Frequency which GEN3 change control mode	Hz	57.0
Frequency which MG fails islanding	Hz	54.0
Voltage which MG fails islanding	kV	10.925
Bulk grid frequency when PCC opens	Hz	59.3

SIMULATION RESULT AND EVALUATION

We used multi-grid simulation and stability judgements to determine stable and unstable areas. Figure 3 shows the results. The vertical axis denotes power demand and the horizon axis denotes master generator output. The area under the dashed red line is a non-operation area. If the master generator and demand operate in that area, the MG produces a reverse power flow to the bulk grid. Blue plots show operation conditions that are unstable. Green plots show operation conditions that are stable. The green line shows the boundary condition. The MG is stable inside the green area and unstable outside it. Eq.1 shows the boundary condition inequality equation we formulated, which uses the least squares method because the boundary between the stable and unstable areas was almost straight. In this case, the cause of the MG islanding fails was frequency. Frequency depends on the supply-demand balance in the MG. For this reason, we can draw boundary condition as a straight line.

$$(\mathit{Power\ Demand}) \\ \leq 1.078(\mathit{Master\ generator\ Output}) \\ + 13.28 \qquad \text{Eq.1}$$

To evaluate this inequality equation, we compared the simulation results inside and outside the boundary. The voltage and frequency results of conditions A and B shown in Figure 3 are shown in Figure 4 and Figure 5, respectively.

First, we consider the reason for the frequency drops. Condition B's frequency drops under 57.0Hz and the MG becomes unstable. The reason for this frequency drop is that the supply-demand gap of condition B is larger than that of A. In addition, the voltage of condition B increased more than that of condition A, so the power consumption of constant load became larger. As a result, the MG supply-demand gap is much larger than A, and the frequency dropped dramatically.

Next, we considered the reason for the voltage increase. In both cases, the voltage increased after islanding. It took 4.0 to 5.0 seconds to switch control methods, so GEN3 uses droop control and APFR after islanding. When islanding, the frequency drops, so GEN3 increases the active power output by droop control. Then, GEN3 also increases the reactive power output by APFR control. Therefore, the voltage becomes higher than usual. The voltage of B increases more than that of A. The frequency of B drops to lower than that of A, so GEN3 in condition B produces a larger reactive power than that in A by droop control and APFR.

From the above, we formulated the boundary condition equation. The condition inside the boundary is stable and the condition outside the boundary is unstable. We simulated the islanding transition in condition A, which is inside the boundary, and the result was stable. We also simulated the islanding transition in condition B, which is outside the boundary, and the result was unstable. So, this boundary equation is acceptable.

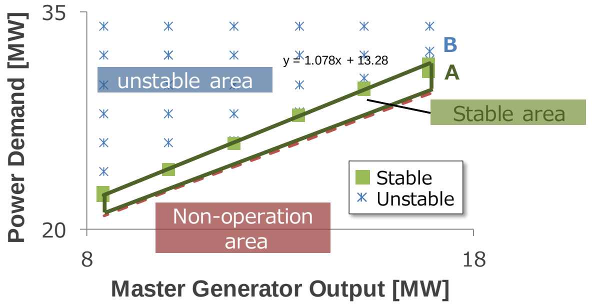

Figure 3 Stable and unstable areas

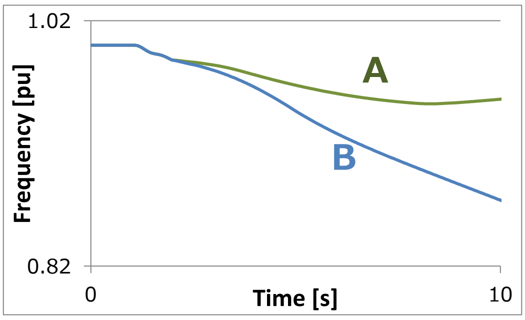

Figure 4 Frequency of conditions A and B

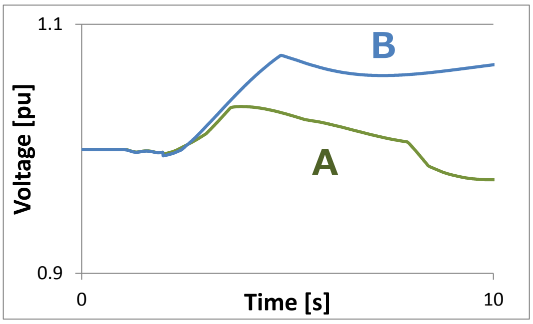

Figure 5 Voltage of conditions A and B

CONCLUSION

We are developing a predictive control method called SEDEC that satisfies stability and economic efficiency at the same time.

The main feature of SEDEC is the development of a boundary condition equation from many grid simulation results. We use this boundary condition for the constraint condition of ELD planning.

In this report, as a representative phenomenon, we formulated the inequality equation that shows the MG stability of islanding transition.

As a result, SEDEC can determine stable and unstable conditions.

In the future, we are going to develop a classification technique that can determine stability. We are also going to apply SEDEC to an optimization technique and validate it.

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