Priority Subjects — **Development of a Supply/Demand Infrastructure for Next-Generation Electric Power**

Assessment of System Security with High Penetration of Photovoltaics

Background and Objective

It is important to ensure power system stability (rotor angle stability, frequency stability, voltage stability, etc.) under the conditions created by the widespread use of renewable energy such as photovoltaics (PVs). In this study, we aimed to help stabilize power system operation by assessing its stability assuming the widespread use of PVs. First, we conducted tests using CRIEPI's Power System Simulator, which consists of small analog components that simulate generators, transmission lines and other power system components. We then used the results to develop and improve the models for CPAT*1 simulation analysis of the operation of power conditioning systems (PCS) and other components used with PVs.

Main results

1 Improving a PV model for Y-method simulation to support the analysis of angle stability after a system fault

To improve the accuracy of angle stability analysis performed assuming the massive interconnection of PCS for residential PVs, we improved the PV model for Y-method simulation, which can simulate phase-by-phase the responses of relays in PCS used with PVs, to better represent the characteristics of recovery after the stoppage of PCS, the re-operation of relays after identifying the undervoltage relay, and so on. Moreover, to improve the accuracy in simulating the transient response of the active current from PVs to a power swing caused by a system fault, we improved the model to change the operation of the PCS effective current limiter depending on whether or not the rated current is exceeded. These improvements enabled more accurate analysis of angle stability under various power system conditions such as PV operation status and interconnection points.

2 Assessment of the effects of the frequency feedback function of the PCS for PVs on angle stability

The PCS for residential PVs has an automatic islanding detection relay. The Standard of the Japan Electrical Manufacturer's Association mandates the use of a new islanding detection relay named AICOT (Anti-Islanding Control Technology) as a standard model of such a relay. Therefore, the number of PCS using this technology is expected to increase. With this technology, a feedback proportional to the frequency variation controls the output of the reactive power. In order to assess how the responses made by this feature may affect angle stability, we performed prototype testing using CRIEPI's Power System Simulator (Fig. 1), and the results showed the following. The phase of changes of reactive power from a PCS is determined by how the frequency variation is computed inside the PCS. When the period of the power swing caused by the system fault is longer, the phase of the reactive power fluctuation is more advanced in relation to the reversed phase of the detected frequency variation. The angle stability worsens when the phase advance is small, and vice versa (Fig. 2).

3 Assessment of the effects of various power system conditions on the angle stability of trunk transmission power systems

It is difficult to assess how the angle stability of trunk transmission power systems may be affected by a system fault under the conditions created by the widespread use of renewable energy because it may greatly differ depending on power system conditions such as the operation statuses of generators and renewable-based power supply systems, and also on whether or not any renewable-based power supply system is tripped after the fault, for example. Therefore, using the results of angle stability analyses performed on real power system data, we summarized how various power system conditions may affect the angle stability under the conditions created by the widespread use of renewable energy (Fig. 3). In a real power system, circuits in a voltage class of 66 kV or less are connected to many loads and renewable-based power supply systems. Therefore, models of lower-level power systems were added to those to be used for simple simulation of utility-level power system model*2 interconnected using 500 kV transmission lines and the effects of various power system conditions on the angle stability. Then we defined a scenario for the widespread use of renewable energy (Table 1) in order to perform an analysis using this power system model. We confirmed that this made it easy to identify the impacts on angle stability and their causes even when different power system conditions contribute in a complex manner (Fig. 4) (R14013).

*1 CPAT (CRIEPI's Power System Analysis Tools) was developed by CRIEPI. In this study, a transient stability analysis tool of CPAT was used. CPAT is used by all 10 electric utilities in Japan.
*2 IEEJ (The Institute of Electrical Engineers of Japan) WEST 10-machine system model.

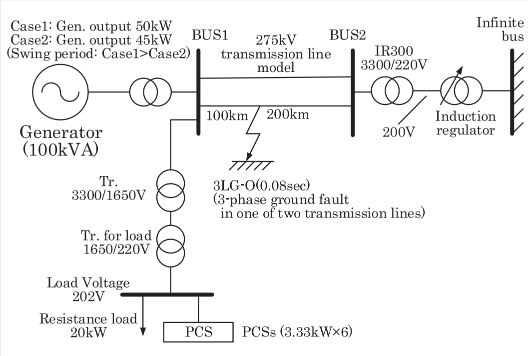

Fig. 1: A power system provided for experiment by CRIEPI's Power System Simulator

For each of two cases with differing swing periods, a generator output of 50 kW in one case and 45 kW in the other, the angle stability with the PCS frequency feedback function turned on was compared to that with the function turned off.

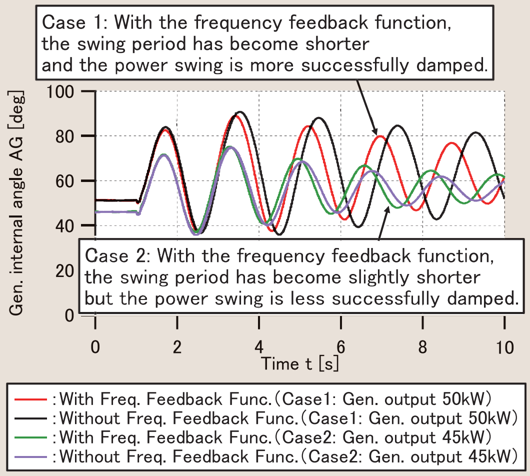

Fig. 2: Results of testing using CRIEPI's Power System Simulator

When the generator output is larger, the swing period caused by a system fault becomes longer and the phase of changes of the reactive power from the PCS for PV is more advanced. A larger phase advance resulted in higher angle stability.

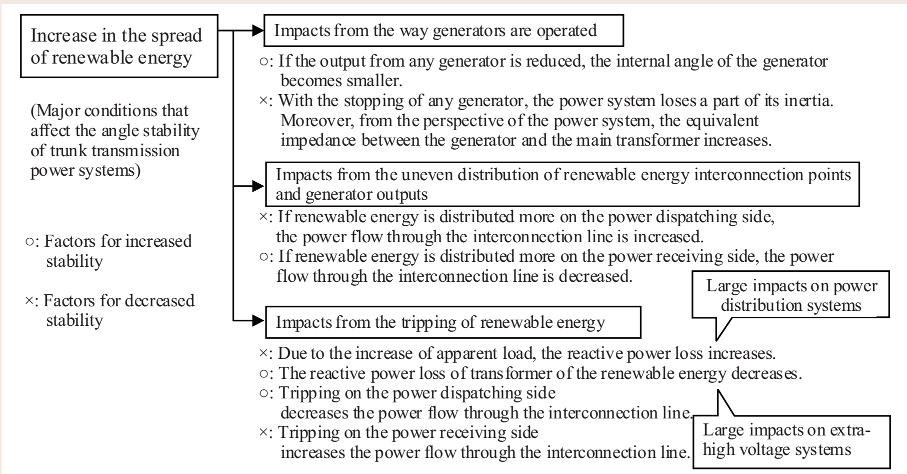

Fig. 3: Effects of various power system conditions on the angle stability of trunk transmission power systems

Table 1: Introduction scenario of renewable energy in a power system model

Base Condition	Off-peak condition of the IEEJ WEST 10-machine system model
Total capacity of generator and renewable energy(RE)	Pre-stage: Total gen. capacity 72GVA PV 0 GW, Wind turbine(WT) 0 GW
	Intermediate-stage: Total gen. capacity 70.83GVA[1)] PV 11.25 GW, WT 2.81 GW
	Last-stage: Total gen. capacity 55.56GVA PV 21.30 GW, WT 5.33 GW
Generator minimum load	40% of generator rated capacity
Upper limit of the gen. capacity to shut it down	50% before renewable energy introduction[2)]
Fault condition (System disturbance)	3-phase ground fault(70ms) in one of two transmission lines in the halfway point of the 'LINE 40' of the 10-machine system model
Tripping of PV and WT	・Nothing ・Tripping 20% of the renewable energy in fault point neighborhood.

1) At the intermediate-stage, almost no generators are stopped.
2) When the total capacity of the interconnected RE exceeded the upper limit of the generator capacity to shut it down, the power flow through the interconnection line was increased to send the surplus power toward generator G10 in the WEST10 machine system.

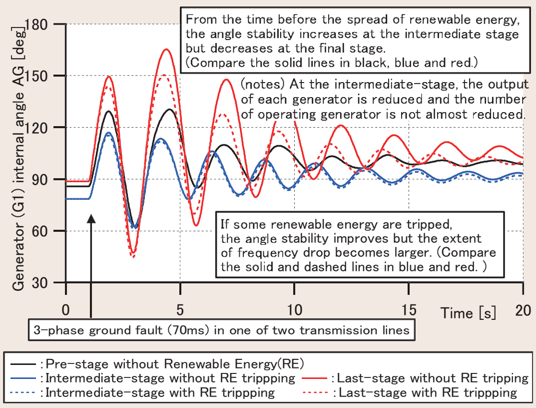

Fig. 4: Example of assessing impacts on angle stability under the conditions created by the widespread use of renewable energy

By evaluating the impacts shown in Figure 3, it is easier to identify how various power system conditions may affect angle stability as well as to determine the causes of such impacts.