Priority Subjects with Limited Terms — **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 and voltage stability) following transmission system faults with high penetration of renewable energies primary of photovoltaics (PV).
However, how transmission system faults, which occur when there is high PV penetration, impact on power systems has not yet been fully investigated. Therefore, it is important to clarify the influence and develop countermeasures relating to future power system stability.

The purposes of this project are:
(1) Evaluation of the influence of power system faults on the transmission system
(2) Experimental tests for extracting the characteristics of a Power Conditioning System (PCS) which consists of inverter of the PV with anti-islanding protection
(3) Establishment of numerical PV models for time-domain simulation.
(4) Development of countermeasures against power system stability for the future power system.

Main results

1 Experimental Verification of the Fundamental Influences of Transmission System Faults on Power Systems with High Penetration of PVs

In order to evaluate the fundamental influences of transmission system faults on power systems with high penetration of PVs, rotating synchronous generators G1 (100kVA) and G2 (90kVA), 275kV and 66kV transmission line models, DC power resources which can emulate PV solar panels, and residential-use PCS for PV (Latest PCS*1) were installed in CRIEPI's Power System Simulator. Figure 1 shows a testing system in the simulator. It is assumed that the synchronous generator G2 could be replaced with the PCSs for PV due to the high penetration of PV. The power transfer limit of G1 was used as evaluation criterion for the testing systems which consist of "G1+G2" or "G1+PCSs".
As a result, the power transfer limit of "G1 + PCSs" was around 35% lower than "G1+G2". Figure 2 shows an example of testing results of the rotor angle oscillation of G1. In the case of the "G1+G2" system, the rotor angle of G1 was well-damped after opening three-phase transmission lines (3LO) between BUS2 and BUS3. On the other hand, in the case of the "G1+PCSs" system, the rotor angle of G1 was not damped following the same disturbance (3LO).
Moreover, the experimental tests revealed that the PCSs of PV could be stopped for a short period depending on system configurations such as the length of 275kV or 66kV equivalent transmission line model, the number of the connected PCSs of PV, and the various types of transmission system faults.

2 Dynamic Behavior of Photovoltaic Inverters Responding to High-Voltage Transmission System Faults

Several functions such as (1) the automatic anti-islanding detection relay (IDR), (2) DC control system, (3) protective relay, (4) PV inverter control, and (5) the voltage rise control function were additionally implemented in the numerical model of the PCSs of PV for CPAT*2. The newly installed elements shown in Table 1 are necessary to represent dynamic behavior of the PCSs of PV following system faults.
The performance of the IDR of PV for detecting the condition of the islanding high-voltage transmission system with and without a synchronous generator were examined using CPAT (See Fig. 3) (R12015) (R12016). The IDR always detected the islanding condition for the isolated system without synchronous generators, while the IDR did not always detect the islanding condition for the isolated system with synchronous generators. According to the CPAT simulation results, the IDR could detect the islanding condition less than 170ms after three-phase short-circuit (3LS) faults.
It was also showed that the IDR or high-speed under voltage relay could operate following a single line to ground fault (1LG). It was found that the stoppage time of the PCSs of PV could vary depending on the PV penetration ratio or the mismatch between the total active power generations and loads at PCC before islanding.

*1 Latest PCS model that has a new islanding detection relay named AICOT (Anti-Islanding COntrol Technology).
*2 The CPAT (CRIEPI's Power system Analysis Tools) is developed by CRIEPI. In this study, a transient stability analysis tool of the CPAT is used. The CPAT is used by all 10 electric utilities in Japan.

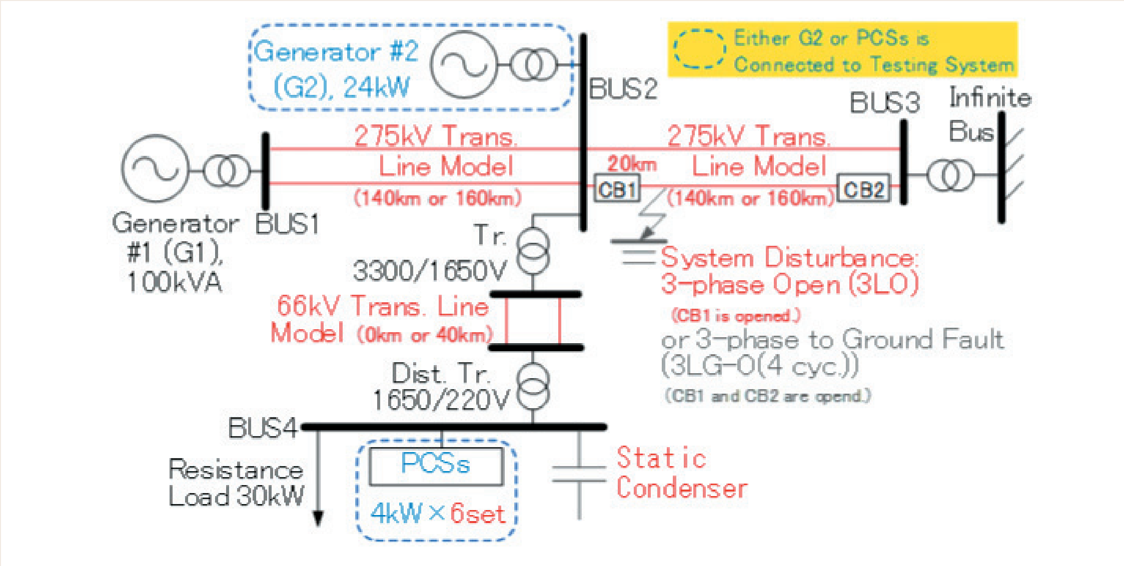

Fig. 1: Testing System in CRIEPI's Power System Simulator

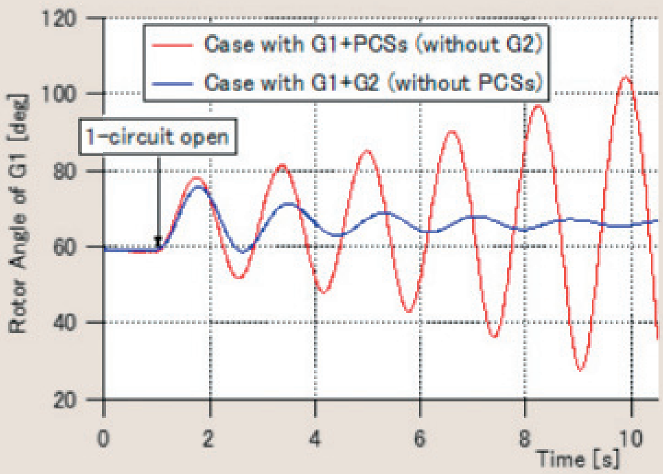

Fig. 2: An example of testing results in CRIEPI's Power System Simulator

Table 1: The Functions of the PCSs Model for PV in the CPAT

Classification	Function
Fault Ride Through	Stoppage Characteristic
	Recover Characteristic
Control Element	(4) Active Power Control
	(4) Reactive Power Control
	(2) DC Control
	(5) Voltage Rise Control
Protective Element (Apparatus & Grid Connected Operation	(3) Overvoltage Relay
	(3) High-speed Overvoltage Relay
	Frequency Relay
Protective Element (Automatic Islanding Detection Relay)	Scheme to detect Jumping Voltage Phase
	Scheme to detect Changing Rate of Frequency
	Variable Reactive Power Scheme
	Frequency Shift Scheme
	(1) AICOT

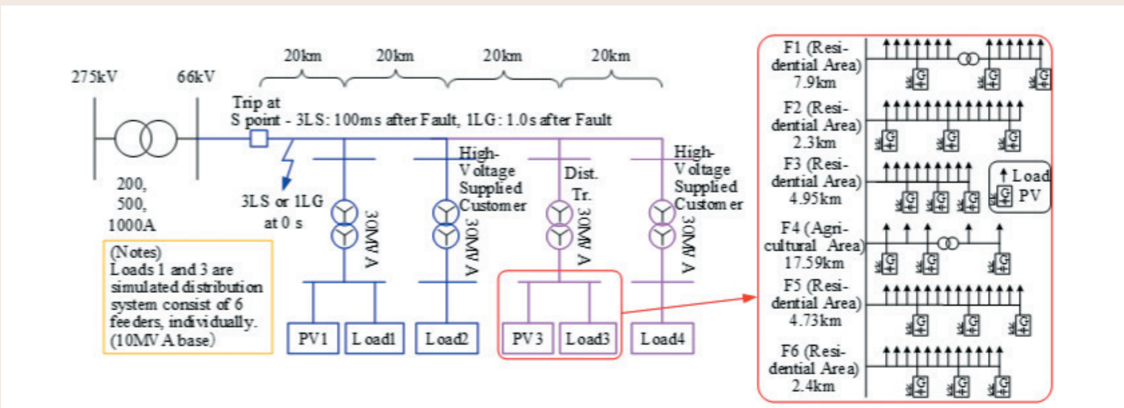

Fig. 3: CPAT Simulation System