Special edition paper

Voltage Control of Power Distribution System to Effectively Use Photovoltaic Electric Power



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When a large number of photovoltaic (PV) panels are installed, reverse power flow has to be appropriately dealt with. To control voltage rise in distribution lines, we proposed cooperative reactive power control among distributed power conditioners of PV systems. With an aim of confirming the effect of cooperative reactive power control of distributed power conditioners, we carried out some experimental tests. The test results show the effectiveness of cooperative reactive power control among distributed power conditioners in controlling voltage rise in distribution lines.

●Keywords: Solar panel, Reverse power flow, Power conditioner, Cooperative reactive power control

1 Introduction

With the tight balance of supply and demand for electric power after the 2011 Great East Japan Earthquake, photovoltaic (PV) facilities are increasingly being set up due to the relative ease of their installation. If the electric power generated by PV facilities exceeds load consumption, such excess electric power flows back into the power distribution system and the voltage in distribution lines is raised. Too much voltage rise in distribution lines may lead to adverse effects on equipment connected to those lines, and that voltage thus needs to be controlled so as not to exceed the limit voltage in distribution lines. If that voltage cannot be controlled to the limit voltage, however, power generation of PV facilities has to be throttled, thus inhibiting effective use of the generated electric power.

Particularly in areas along railway lines where large-scale PV facilities are installed, there are often no significant loads. In order to effectively use electric power generated by such PV facilities, it is necessary to send the excess electric power to distant loads while controlling voltage rise. However, the results of past studies proved that, taking into account the estimated amount of reverse power flow, investing much money to send reverse excess electric power to distant loads is not reasonable.

We therefore studied a measure to simply control voltage rise caused by excess electric power, aiming to effectively use electric power generated in excess by PV facilities.

2 Voltage Control in Distribution Lines

2.1 Method of Voltage Control in Distribution Lines

Use of voltage control devices has been pointed out as a method of controlling voltage rise in distribution lines. Such devices include load ratio transformers (LRT) attached to the distributing substations as well as step voltage regulators (SVR) and static var compensators (SVC) attached to the distribution lines. However, those made the facilities much larger, incurring large costs.

2.2 Reactive Power Control Using PCS

We thus focused on reactive power control using power conditioner systems (PCS) of PV facilities, and we investigated a method of simple voltage control for distribution lines as a whole. By controlling the power factor of the PCS units and adjusting reactive power output, voltage at interconnection points and finally voltage in distribution lines can be controlled. Power factor of PCS units is stipulated in the "Grid-interconnection Technical Requirement Guidelines on Quality of Electricity" to be 85% or more. If the electric power generated by PV facilities (effective power) is equal to the PCS rated capacity, no reactive power is outputted. However, in actuality, PV panels generate power of just around 80% of their individual rated capacities, and they thus have a margin to those rated capacities that enables reactive power control. Fig. 1 shows an image of reactive power control using PCS.

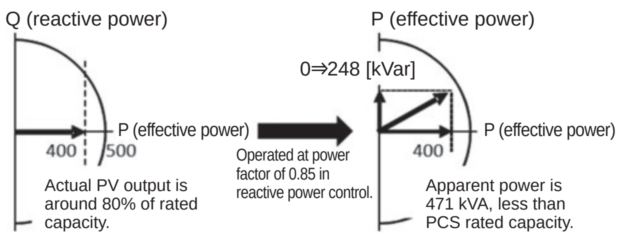

Fig. 1 Amount of Reactive Power Control Using PCS (PCS rated power 500 kVA)

2.2.1 Reactive Power Control Using PCS

Reactive power control using PCS can control voltage at interconnection points to some extent. However, a single PCS unit can only output limited reactive power; so, in some cases, it cannot control voltage in distribution lines to the appropriate value. In such cases, PV output itself—the amount of power generation of the PV facilities—is limited and voltage rise in distribution lines is controlled. On the other hand, even if another PCS unit is incorporated in the same distribution lines, that PCS unit does not control reactive power if the voltage at the interconnection point of that PCS unit is less than the upper limit voltage value. Fig. 2 shows an image of reactive power control using only one PCS unit.

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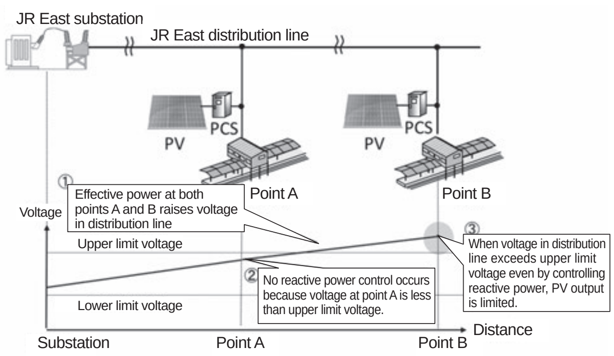


Fig. 2 Reactive Power Control Using a Single PCS Unit

2.2.2 Cooperative PCS Reactive Power Control

In conventional reactive power control using a single PCS unit, PV output itself is limited when the voltage at the PCS installation point exceeds the upper limit so as to control voltage rise. On the other hand, that PCS unit does not control reactive power if the voltage at the installation point of that PCS unit is less than the upper limit voltage value, even if another PCS unit is installed in the same distribution lines.

We therefore decided to develop a reactive power control method where reactive power is controlled at multiple PCS installation points in a cooperative manner to lower the voltage over the set upper limit. In this method, if reactive power control using only a single PCS unit cannot alleviate overvoltage, that PCS unit requests other PCS unit with a margin of control capacity to conduct cooperative PCS reactive power control. That will reduce the limiting of output of PV facility power generation, allowing utilization of more power generated. Fig. 3 shows an image of cooperative reactive power control using multiple PCS units.

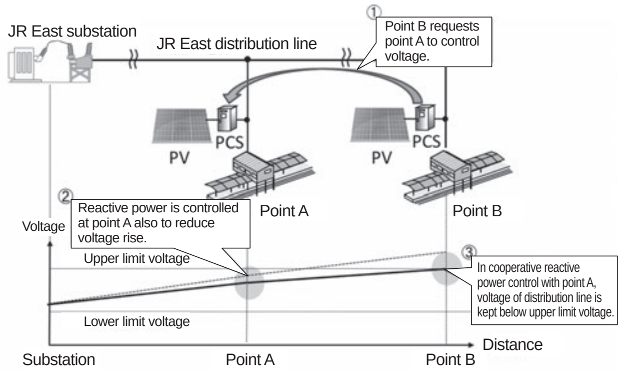


Fig. 3 Cooperative Reactive Power Control Using Multiple PCS Units

3 Proving Tests in Factory

3.1 Overview of In-factory Proving Tests

In order to actually confirm the effectiveness of reactive power control using multiple PCS units, we carried out tests using proving equipment in a factory as shown in Fig. 4. Table 1 summarizes the control methods tested in that. We carried out the tests with an aim of identifying what level of control of voltage in distribution lines can be achieved by controlling reactive power alone without limiting PV output (throttling effective power).

Taking into account conditions of the facilities where such control will actually be introduced, we set the maximum reactive power output of PCS at around 100 kVar.The definitions are as follows, and we controlled voltage at interconnection points not to exceed Vm.

Vss: Transmission voltage

Vm: Upper operation limit of voltage (here set at 6,600 V)

V_PCS_1: Voltage at interconnection point of PCS_1

V_PCS_2: Voltage at interconnection point of PCS_2

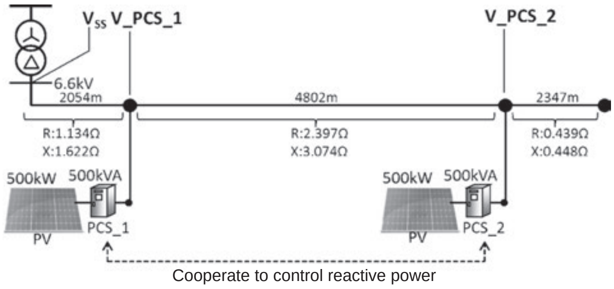


Fig. 4 Distribution System in In-Factory Proving Tests

Table 1 Voltage Control Method in In-Factory Proving Tests

Pattern No.	Reactive power control	Cooperation between PCS units
1 (no control)	×	×
2 (independent control)	○	×
3 (cooperative control)	○	○

3.2 In-factory Proving Test Results

Fig. 5 shows the results of the in-factory proving tests. The tests were carried out under the conditions that no load was connected to the PCS unit and all that PV output is returned to the upstream distribution system (became reverse power flow). From the results shown in Fig. 5 (c), the effective power was around 270 kW for PCS_1 and around 300 kW for PCS_2 in the tests.

[Pattern 1 (with no control)]

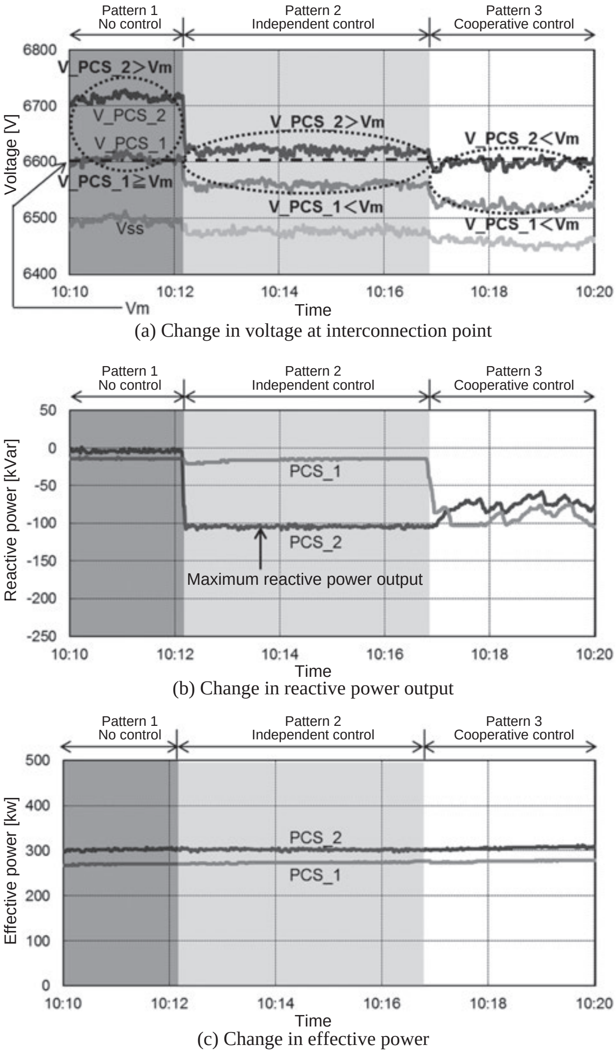
V_PCS_1 and V_PCS_2 both exceeded Vm. Voltage at interconnection points exceeded the upper operation limit of voltage. As reactive power was not controlled in this pattern, voltage in distribution lines needed to be lowered by limiting PV output (limiting effective power). As a result, power generation output of the PV facilities had to be throttled.

[Pattern 2 (control using PCS independently)]

From the status of Pattern 1, we controlled reactive power using PCS_1 and PCS_2 independently to limit voltage at interconnection points to be less than Vm. V_PCS_1 was less than Vm, but V_PCS_2 did could fall below Vm even when PCS_2 controlled reactive power at its maximum output. To control voltage in distribution lines, limiting PV output (controlling effective power) is required in this pattern too.

[Pattern 3 (with cooperative control)]

From the status of Pattern 2, we controlled reactive power by the cooperative PCS reactive power control method. In this method, V_PCS_2 could be kept below Vm by using PCS_1



(a) Change in voltage at interconnection point

(b) Change in reactive power output

(c) Change in effective power

Fig. 5 Results of In-Factory Proving Tests

that had a margin of control capacity for reactive power control in addition to PCS_2. As a result, we are able to reverse flow excess power to distribution lines without throttling PV power generation output.

As described above, cooperative PCS reactive power control enables appropriate control of voltage at interconnection points that could not be made less than the upper operation limit of voltage. We were able to confirm effectiveness of cooperative PCS reactive power control in the proving tests.

4 Proving Tests in Keiyo Rolling Stock Center

4.1 Overview of Keiyo Rolling Stock Center Mega Solar

JR East installed its first large-scale PV facilities (Mega Solar) to the Keiyo Rolling Stock Center in February 2014. Fig. 6 gives an overview of the facilities.

The specifications of the facilities are listed in Table 2. Two PCS units (500 kW × 2) are present in the distribution system and connected to existing track high voltage distribution lines. The operation status of the PV facilities can be checked in the office of the Keiyo Rolling Stock Center. Fig. 7 shows photos of the installed PV facilities.

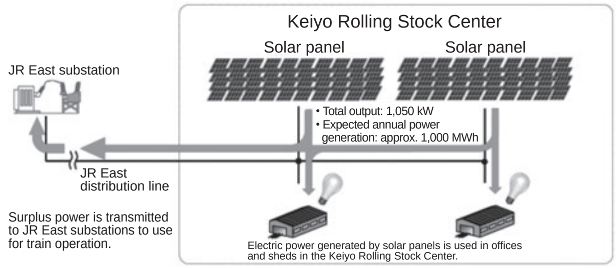


Fig. 6 Overview of Keiyo Rolling Stock Center Mega Solar

Table 2 Specifications of Keiyo Rolling Stock Center Mega Solar

PV electric power generation rated output	Approx. 1,050 kW
Solar panel area	6,600 m^2
Expected annual power generation	Approx. 1,000 MWh
Expected annual CO_2 emissions reduction	Reduction of approx. 500 t *[1]

*[1] Based on CO_2 emissions intensity reported by Tokyo Electric Power Co., Inc.


Fig. 7 PV Facilities Installed at Keiyo Rolling Stock Center

4.2 Demonstration Test of Cooperative Reactive Power Control Using Multiple PCS

Using the large-scale PV facilities installed to the Keiyo Rolling Stock Center, we carried out proving tests of cooperative reactive power control using multiple PCS units. Fig. 8 illustrates the system, and Fig. 9 is the test results. In Fig. 9, we chose data for summer days when the weather was fine all day long, and we compared the results of cooperative reactive power control and of no control under almost equal sunlight. The definitions of V_PCS_1, V_PCS_2, Vss, and Vm are the same as in 3.1; however, Vm was set at 6,534 V and the PV output control (effective power control) start voltage at 6,600 V. Furthermore, the following definitions were added.

P_PCS_1: Effective power output of PCS_1
P_PCS_2: Effective power output of PCS_2
Q_PCS_1: Reactive power output of PCS_1
Q_PCS_2: Reactive power output of PCS_2

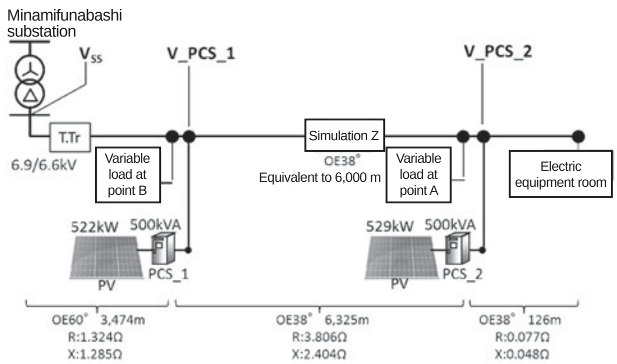


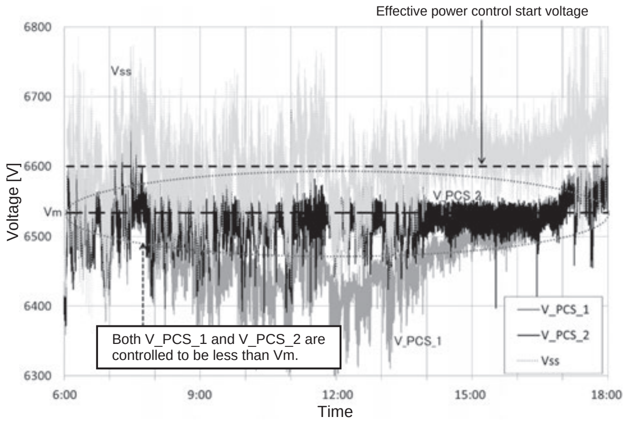
Fig. 8 Proving System at Keiyo Rolling Stock Center

As shown in Fig. 9, the weather was fine all day on test days for both cooperative reactive control and no control. Therefore, without PV output control, effective power is expected to show a change on a curve with the peak at noon. Compared with this expectation, Fig. 9 (c) (cooperative reactive power control) shows just a temporary drop (PV output suppression) at around 11:00 to 12:00, while Fig. 9 (d) (with no control) shows a remarkable drop of PV output (suppression). Looking at Fig. 9 (a) for cooperative reactive power control, both V_PCS_1 and V_PCS_2 at the system end could keep voltage at interconnection points to less than Vm even with almost no PV output control. In contrast, looking at Fig. 9 (b) for no control, V_PCS_2 in particular exceeded Vm, meaning that voltage in distribution lines was not fully controlled.

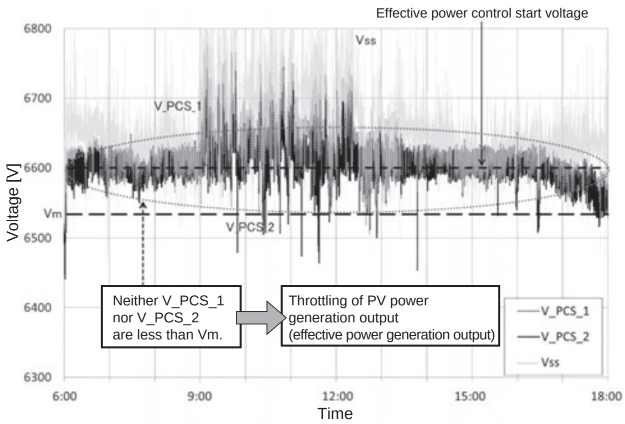
Those results confirm effectiveness of cooperative PCS reactive power control.

5 Conclusion

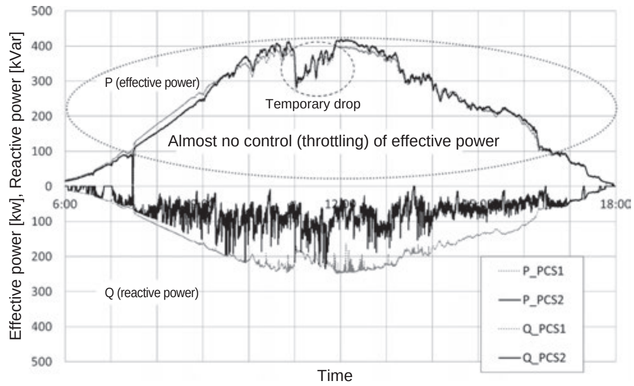
We investigated a simple method of system voltage control in conjunction with installation of large-scale PV facilities, and we successfully confirmed effectiveness of cooperative reactive power control using multiple PCS units. With a view of further installation of such large-scale PV facilities, we will work on items such as investigating the possibility of expanding the applicable range of the method.



(a) Change in voltage at interconnection point (cooperative control, Aug. 15, 2014)



(b) Change in voltage at interconnection point (no control, Aug. 17, 2014)



(c) Change in effective power and reactive power (cooperative control, Aug. 15, 2014)

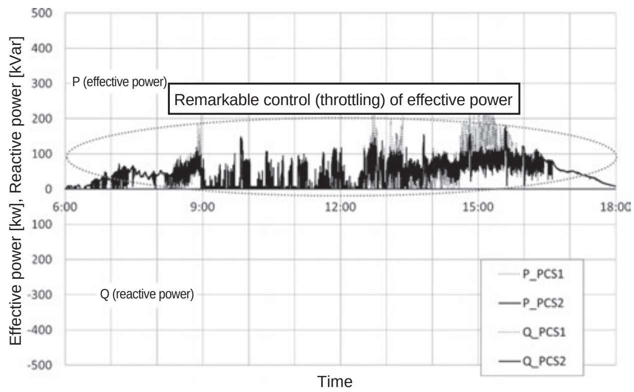


Fig. 9 Results of Proving Tests at Keiyo Rolling Stock Center