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Robust Control Technique for Grid-connected Power Conditioner

Hikaru Meguro
Kazuya Tsutsumi
Masaya Ichinose
Tomomichi Ito
Akira Kikuchi

OVERVIEW: In response to global environmental problems, mass introduction of variable renewable energy sources such as photovoltaic generation systems and wind turbine generation systems are spreading all over the world. On the other hand, the instability of power systems caused by large-scale integration of variable renewable energy sources (RESs) has come to be recognized. The two problems are, respectively, instability caused by disconnection of large numbers of RESs in response to grid faults, and variations in the grid voltage and frequency due to RESs' intermittent nature caused by weather conditions. For those problems, Hitachi is developing a fault-ride-through function to avoid disconnection from the grid, and unique control techniques to contribute to the stability of grid voltage and frequency.

INTRODUCTION

INTRODUCTION of renewable energy sources to the grid is now strongly expected to become a solution against global warming and reduction of carbon dioxide (CO_2) emission. In particular, the introduction of photovoltaic generation systems (PV systems) and wind power generation systems (WT systems) is increasing throughout the world as the equipment cost declines. The amount of installed capacity is growing dramatically, with PV system capacity reaching 63,610 MW(1) in 2011 and WT systems capacity reaching 282,480 MW(1) in 2012.

However, there are concerns about degradation of power quality from the grid with a high penetration ratio of RES. This degradation can be brought about by a) large numbers of RESs disconnecting from the grid triggered by voltage drop, b) voltage variation, and c) frequency fluctuations(2). The disconnection from the grid in cases of grid fault is due to the technical constraints of power conditioning systems (PCSs). And the voltage variation and the frequency fluctuations are due to the intermittent nature of RESs.

This article describes technical countermeasures for PCSs to deal with the requirements to stay connected to the grid in case of grid fault (fault-ride-through function), and to stabilize grid voltage and frequency.

Parameter		Specification
AC output (grid connection)	Circuit	Three-level inverter
	Rated capacity	690 kVA/660 kW
	Rated voltage	AC 360 V
DC input (battery connection)	Voltage range	DC 520 V–900 V DC 1,000 V (max.)
Reverse conversion efficiency		98.8% (DC 520 V, AC 360 V, power factor: 1.0)
Operating temperature range		0°C–40°C

PV: photovoltaic generation PCS: power conditioning system
AC: alternating current DC: direct current

Fig. 1—Photograph and Main Specifications of PV PCS.
The table lists sample specifications for this 1,000-V DC PCS for PV systems.

CHARACTERISTICS OF PV SYSTEMS AND WIND TURBINE GENERATION SYSTEMS

PV Systems

Fig. 1 shows one of the PCSs for PV systems and its specifications.

This PCS for mega-solar power plants can operate with a direct-current (DC) voltage up to 1,000 V. The inverter has an advanced three-level topology with high efficiency and the maximum system efficiency of 98.8 % (at DC 520 V). The grid stabilization function provided as standard features include optimum power factor control, voltage rise suppression control, and constant power factor and other reactive power control functions. It also has a fault-ride-through (FRT) capability[3].

Wind Turbine Generation Systems

Fig. 2 shows one of the PCSs for wind turbine generation systems and its specifications.

It can withstand very severe conditions (ambient temperature of −20°C, 0.1 s of 130% over voltage, 0.2 s of 50±10 Hz frequency variation), and its standard features include active and reactive power control functions as well as FRT function[3]. It uses serial communications via PROFIBUS*1 and CANopen*2 to interface with the wind turbine system controller.

*1 PROFIBUS is a registered trademark of PROFIBUS Nutzerorganisation e.V.

*2 CANopen is a registered Community Trademark of CAN in Automation e.V.

Parameter	Specification
Generator type	DFG
Rated capacity	2,300 kVA/2,070 kW
Rated voltage	AC 690 V
Over-voltage rating	130% 0.1 s
Rotor voltage	AC 0 V–735 V
Circuit	Two-level inverter
Operating temperature range	−20°C–+50°C

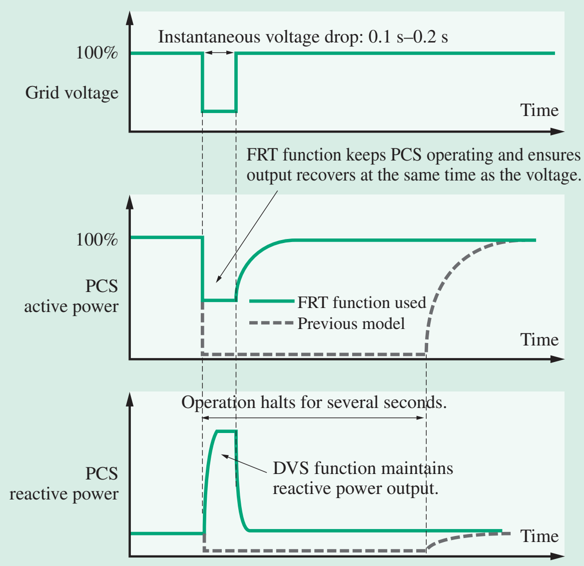
DFG: doubly-fed generator

Fig. 2—Photograph and Main Specifications of Wind Turbine Generation System PCS.
The table lists sample specifications for this DFG wind turbine generation system PCS.

FRT TECHNIQUES (PREVENTING LARGE-SCALE DISCONNECTION)

Instability resulting from the large-scale disconnection of wind turbine generation systems from the large-scale disconnection of wind turbine generation systems during the wide-area blackout in Europe in November 2006 led to revisions to national and regional grid codes and the formalizing of FRT specifications[4].

As indicated by the solid line in Fig. 3, wind turbine generation systems where PCSs are installed are required to be connected to the grid and keep operating in the event of a voltage dip caused by a grid fault, provided the depth and duration of voltage dip are within the stipulated limits. Some



FRT: fault ride-through DVS: dynamic voltage support

Fig. 3—FRT and DVS Operation of PCS during Grid Fault.
The top graph shows the variation of grid voltage with time, including an instantaneous voltage drop. The middle graph shows the active power output of the PCS. The solid line represents the case when the FRT function is used, showing how the PCS continues to operate and output active power through the instantaneous voltage drop. The dotted line shows the case without an FRT function (previous model). In this case, the PCS shuts down and the active power output falls to zero for a time after the instantaneous voltage drop. The bottom graph shows the reactive power output from the PCS. The solid line representing the case when the FRT function is used shows how the DVS function increases reactive power output in response to the instantaneous voltage drop. The dotted line representing the case without an FRT function (previous model) shows how the PCS shuts down in response to the instantaneous voltage drop, as in the active power graph.

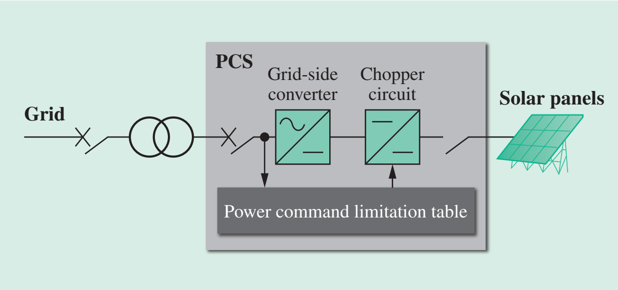


Fig. 4—Block Diagram of PV System.
The Hitachi PCS uses a power command limitation table.

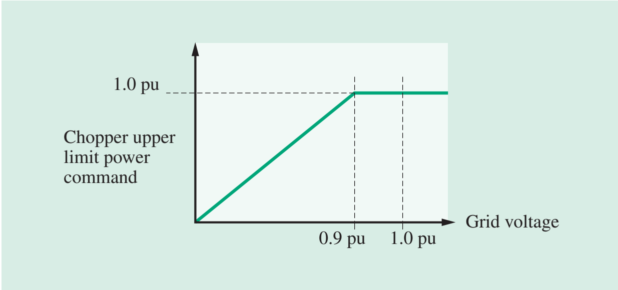


Fig. 5—Power Command Limitation Table[6].
The graph shows the form of the power command limitation table (function).

countries and regions also stipulate dynamic voltage support (DVS)[5] functions, which require wind turbine generation systems to inject reactive power during faults. FRT and DVS functions improve grid stability by preventing large-scale disconnections. The following sections describe specific FRT techniques.

FRT Capabilities of PV PCS

Fig. 4 shows the configuration of a PV system.

The voltage generated by the solar panels is boosted by the chopper circuit and the generated DC power is converted into alternating current (AC) power by the grid-side converter and fed to the grid. In the case of a voltage dip, the output power from the converter is rapidly reduced. So the generated power from the solar panels loses its path and that causes over voltage at the DC-link circuit, which makes the PCS trip to protect the PCS itself.

To prevent this, the generated power from the solar panels is regulated by the chopper circuit based on the residual grid voltage to minimize the rise at the DC-link voltage. The FRT capability is achieved by using a power command limitation table based on the grid voltage to limit the rise in DC-link voltage, thereby improving the ability of the PCS to continue operation[6] (see Fig. 5).

FRT Capabilities of Wind Turbine Generation Systems PCS

In wind turbine generation systems that equip doubly-fed generators (DFGs), power flows from the grid-side converter to the rotor-side converter and the excitation current is supplied from the rotor-side converter to the rotor windings in the DFG (see Fig. 6). With this excitation current, output voltage can be induced from the DFG and that realizes power flow from stator windings to the grid. The following describes the FRT technique mounted in the WT system illustrated in Fig. 6.

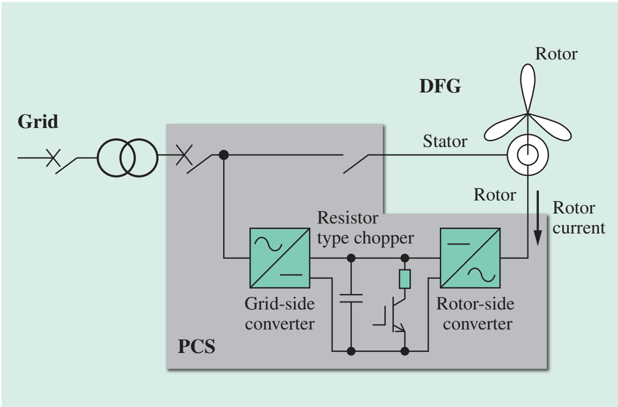


Fig. 6—Block Diagram of DFG Wind Turbine Generation System.
The diagram shows the configuration of Hitachi's PCS for wind turbine generation systems.

Because large current flows in the DFG's stator winding and rotor winding in the case of a voltage dip on the grid side, the PCS has to be able to handle the large current and to output active and reactive power at the same time. The PCS in the wind turbine generation system satisfies this requirement by the following two methods:

(1) Selecting the optimum duty ratio of IGBTs in the rotor-side converter[7]

(2) Stabilizing DC-link voltage using a chopper circuit connected to the discharging resistor

For (1), the large current flow in the rotor that results from the voltage dip on the grid side can be handled by changing the duty ratios of the rotor-side converter's IGBTs, as shown in Fig. 7. This duty ratio selection function allows power to be output from the WT system immediately after the grid voltage dip. For (2), the energy flowing into the PCS during the voltage dip at grid side is absorbed by the resistor and it leads to better FRT capability of WT system. The control method (1) also reduces the load of the discharging resistor, allowing it to be made smaller. Fig. 8 shows

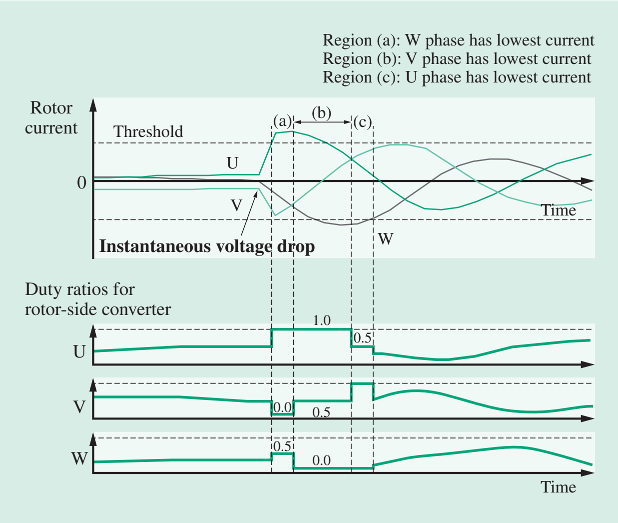


Fig. 7—Duty Ratios for Rotor-side Converter during Instantaneous Voltage Drop[7]*.*
Because a large current flows in the rotor when an instantaneous voltage drop occurs, the duty ratios for the rotor-side converter are set to either 0.0, 0.5, or 1.0 to withstand and limit this excess rotor current.

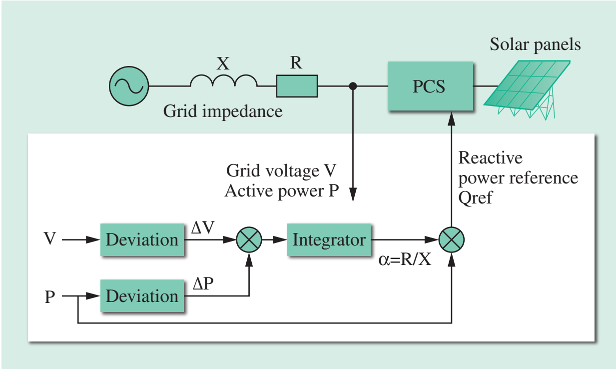


Fig. 9—Block Diagram of Reactive Power Auto-tuning[8]*.*
The optimal reactive power reference (Qref) is calculated from the grid voltage (V) and active power (P). The area inside the white box is the block diagram of reactive power auto-tuning.

measured waveforms during FRT operation using methods (1) and (2). This demonstrates the stable power control of the WT system and continuous operation of the PCS.

GRID VOLTAGE STABILIZATION TECHNIQUES

The following sections describe stabilization techniques for grid voltage and frequency that are incorporated into PV and WT systems' PCSs.

Grid Voltage Stabilization Techniques

Because of grid impedance, when the output power, strictly speaking, the output current from an RES changes, the voltage drop on the grid side also changes. Generated power from an RES changes depending on weather conditions. So the grid voltage changes and the power quality supplied to other consumers deteriorates. Because grid voltage can be controlled by changing injected reactive power from PV system, it is possible to stabilize the grid voltage by injecting optimal reactive power to the grid.

Fig. 9 shows an example of a PV PCS. For a grid impedance with resistance (R) and (X) in Ohm, the PCS automatically estimates α (=R/X) from changes in grid voltage (V) and active power (P), and minimizes the variation in grid voltage by setting

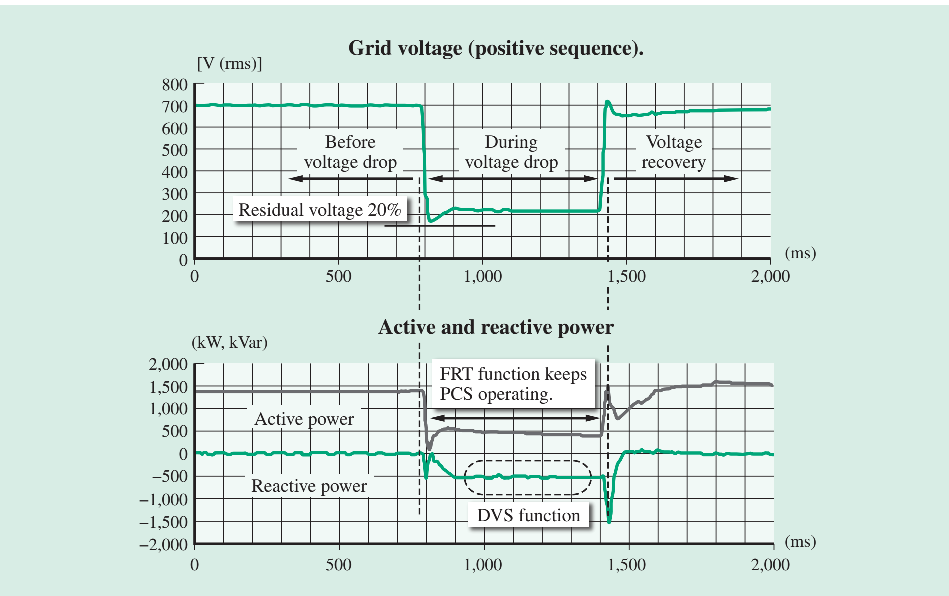


Fig. 8—FRT Waveforms (Three-phase Grounding Fault, 20% Residual Voltage, 1.5-MW Capacity).
The graphs show actual FRT waveforms from a Hitachi wind turbine generation system PCS. The top graph shows how the grid voltage varies with time, including the instantaneous voltage drop. The bottom graph shows the active and reactive power output by the PCS. The FRT function keeps the PCS operating and the DVS function increases the output of reactive power during the instantaneous voltage drop.

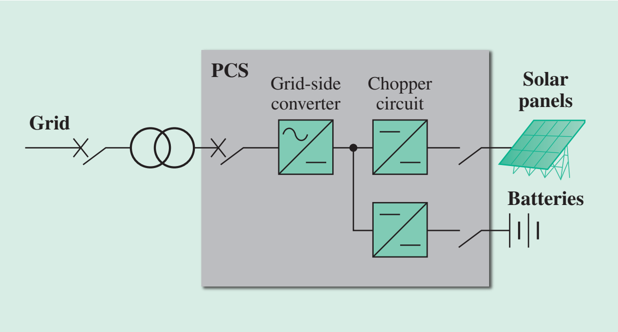


Fig. 10—Hybrid PCS[9].
The figure shows a block diagram of a hybrid PCS that combines solar panels and batteries.

the reference for reactive power output by the PCS (Qref) to P*α. This function is called reactive power auto-tuning[8].

Frequency Stabilization Techniques

Because the demand and supply of active power have to be balanced, short-duration excesses or shortfalls are absorbed by the rotational energy of conventional generators and appear as deviations in the grid frequency. Fluctuations in the output power from the PV and WT systems due to their intermittent nature degrade power quality by causing variations in the grid frequency.

Fig. 10 shows a hybrid PCS for PV systems that combines both solar panels and batteries. The hybrid PCS can contribute to grid frequency stabilization by charging or discharging the batteries to smoothen output power from the PCS.

CONCLUSIONS

This article has described how the impact on grid stability from renewable energy sources such as PV and WT systems is now recognized because of the mass introduction of renewables. And Hitachi is developing technical countermeasures such as the FRT function, reactive power auto-tuning control, and hybrid PCS, to solve the problem.

As the higher penetration rate of RES systems creates a bigger impact on grid stability, it will become difficult to maintain grid stability by relying only on the standalone control function of PCSs. What will be required in the future will be total control involving interoperation between the grid and PCSs, and between battery systems and PCSs, and also the utilization of "electric power accommodation" (power sharing arrangements).

To ensure the reliable supply of electric power, Hitachi continues delivering highly flexible power solutions that fuse technologies from power systems, batteries, and power electronics.

REFERENCES

(1) Agency for Natural Resources and Energy, "FY2012 Annual Report on Energy (Energy White Paper 2013)," http://www.enecho.meti.go.jp/about/whitepaper/2013html/ (Jun. 2013) in Japanese.
(2) New Energy and Industrial Technology Development Organization (NEDO), "Renewable Energy Technology Whitepaper," http://www.nedo.go.jp/library/ne_hakusyo_index.html (Dec. 2013) in Japanese.
(3) Japan Electrotechnical Standards and Codes Committee, JEAC9701-2012 Grid Inter-connection Code (Mar. 2013) in Japanese.
(4) "Mapping of Grid Faults and Grid Codes," Risø-R-Report, Risø National Laboratory, Denmark, http://www.risoe.dk/rispubl/reports/ris-r-1617.pdf (July 2007).
(5) N. Kanao, "Research into FRT•DVS for Wind Power Generation," Hokuriku Electric Power Company Annual R&D Report, No. 45 (Feb. 2011) in Japanese.
(6) T. Aihara et al., "Power Converter and Generation Converter System," Hitachi, Ltd., Patent 5260092 in Japanese.
(7) A. Bando et al., "Doubly-fed Generator and Doubly-fed Variable-speed Motor-Generator," Hitachi, Ltd., Patent 5401213 in Japanese.
(8) S. Ohara et al., "Distributed Power Supply System and Grid Stabilization Method," Hitachi, Ltd., Patent 4575272 in Japanese.
(9) Hitachi Battery Solutions, Product Catalog (Oct. 2012) in Japanese.

ABOUT THE AUTHORS

Hikaru Meguro

Power Electronics Design Department, Infrastructure Systems Company, Hitachi, Ltd. He is currently engaged in the development and design of PCSs for wind power turbine generation systems. Mr. Meguro is a member of The Institute of Electrical Engineers of Japan (IEEJ).

Kazuya Tsutsumi

Power Electronics Design Department, Infrastructure Systems Company, Hitachi, Ltd. He is currently engaged in the development and design of PCSs for wind power turbine generation systems. Mr. Tsutsumi is a member of the IEEJ, the Institute of Electrical Installation Engineers of Japan (IEIEJ), and the Japan Wind Energy Association (JWEA).

Masaya Ichinose

Power Electronics Design Department, Infrastructure Systems Company, Hitachi, Ltd. He is currently engaged in the development of a large-scale power converter. Mr. Ichinose is a member of the IEEJ.

Tomomichi Ito

Power Electronics Design Department, Infrastructure Systems Company, Hitachi, Ltd. He is currently engaged in the development and design of a power conditioning system for photovoltaic power generation. Mr. Ito is a member of the IEEE and IEEJ.

Akira Kikuchi

Department of Transmission & Distribution Systems Research, Hitachi Research Laboratory, Hitachi, Ltd. He is currently engaged in the research and development of a power conditioning system for photovoltaic power generation. Mr. Kikuchi is a member of the IEEJ.