Development of Power Conditioner Using Digital Controls for Generating Solar Power

Tadashi Ryu

Power electronics has been in the limelight in recent years in conjunction with the promotion of energy conservation. Power electronics is a technology for controlling electric power consumption using semiconductors, such as field effect transistors (FETs). A lot of progress has been made particularly to increase efficiency and extend the capacity of inverters to output alternating current. Such efforts have been contributing to energy conservation in the form of various products, ranging from household appliances, such as refrigerators and air conditioners, to hybrid cars.

OKI Information Systems (hereinafter referred to as "OIS") has been involved with the development of power electronics and power conditioners for generating solar power through the application of digital controls, in partnership with OKI Power Tech (hereinafter referred to as "OPT"). Power conditioners are equipments that generate solar power by converting direct current, supplied by solar cell modules, into alternating current. These devices play a very important role in the promotion of higher efficiency (energy conservation) solar power generating systems.

This paper describes the current status of digitally controlled power supplies, the functions of power conditioners for generating solar power and elemental technologies, as well as the status of the developments and future activities.

Current status of digitally controlled power supplies

Power supplies in use at the present time primarily use analog controllers. In recent years, however, research and development has concentrated on digitally controlled power supplies that use microcomputers and digital signal processors (DSPs)[*1]. Digitally controlled power supplies control the overall system that involves voltage control, current control and remote communication controls using microcomputers and DSPs. The efficiency of the whole system can be increased utilizing controls that respond to the current conditions, using information derived from such controls.

OIS, in partnership with OPT, started the commercialization of a DC-DC converter power supply in 2004, as an evaluation board for digitally controlled power supplies that use DSPs manufactured by Texas Instruments. The external appearance of a DC-DC converter power supply is shown in **Photo 1**. Such units were supplied to customers who expressed a desire to conduct trials on digitally controlled power supplies and a favorable outcome resulted.

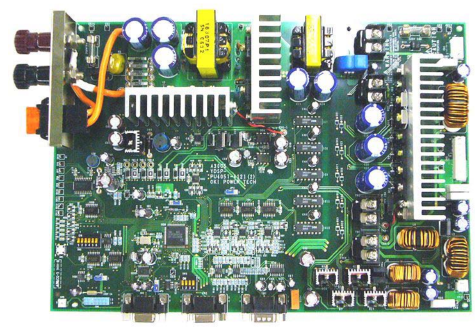

Photo 1 DC-DC converter power supply

Photo 2 DC-AC inverter power supply

Commercialization of a DC-AC inverter power supply for communication base stations was completed in 2007. The external appearance of a DC-AC inverter power supply is shown in **Photo 2**. This product is capable of sustaining high conversion efficiency from light to heavy load conditions, with the use of load-adaptive control. Details pertaining to the load-adaptive control are provided in a later section.

Since 2008 OIS has been developing power conditioners to generate solar power, as products intended for green energy initiatives, in partnership with OPT.

The hardware for these products has been developed by OPT, since OPT possesses a wealth of experience in the development of power supplies and the software has been developed by OIS, since OIS has an abundant experience with digital controls.

*1) DSP is an abbreviation for "digital signal processor".

Power conditioners for generating solar power

Power conditioners for generating solar power (hereinafter referred to as "PV[*2] power conditioners") feature functions for converting direct current electric power, supplied by solar cell modules (hereinafter referred to as "PV modules") that output electric power dependent on irradiance and temperature, into alternating current electric power. Ordinary DC-AC inverter power supplies are controlled to output the amount of electric power required by the load, whereas PV power conditioners require controls to ensure efficient output of electric power supplied by PV modules.

PV power conditioners are configured either as a power grid interconnecting system or a self sustained operation system. A power grid interconnecting system is configured to connect the output of a PV power conditioner to commercial AC mains, which allows for the sale of unconsumed excessive amounts of electric power to the electric power company by supplying it to the power grid. A configuration that does not offer any connection to the power grid is called a self sustained operation system, which features the ability to operate even during a power outage. We are developing a hybrid system that combines the power grid interconnecting system and the self sustained operation system. The configuration of the hybrid system is shown in **Fig. 1**.

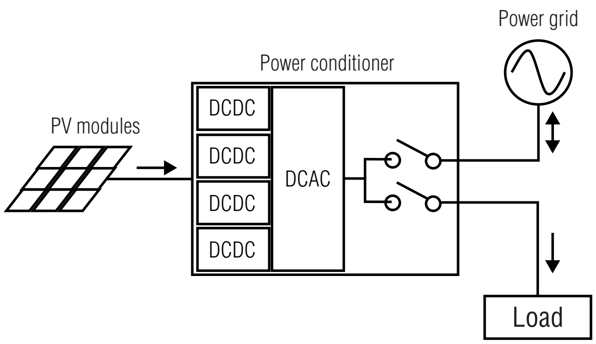

Fig. 1 Configuration of hybrid system

Elemental technologies for PV power conditioner controls

The "Maximum Power Point Tracking", "Power Grid Interconnecting Control" and "Power Grid Interconnecting Protective Function", are the principal technologies required to use the controls of PV power conditioners. Each elemental technology is explained below.

(1) Maximum power point tracking

An electric power output/voltage characteristic for PV modules is shown in **Fig. 2**. PV modules have an optimum operating point at which the maximum amount of electric power can be output under certain environmental conditions. This optimum operating point varies, depending on irradiance and temperature. The constant control to sustain electric power supplied by PV modules to the PV power conditioner at an optimum operating point is called maximum power point tracking (MPPT[*3]).

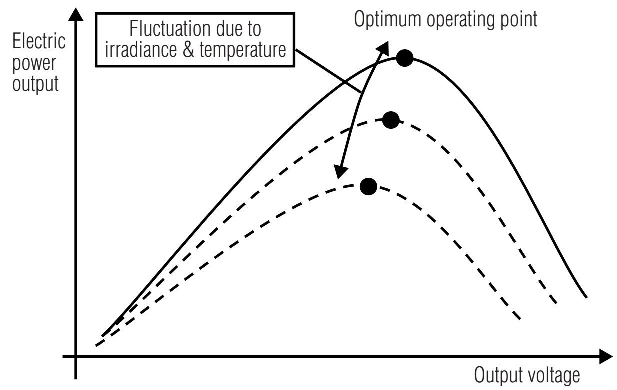

Fig. 2 Electric power output/voltage characteristic for PV modules

Maximum power point tracking plays an extremely important role in a PV system, since the power generating efficiency for the entire system is important, rather than simply the electric power conversion efficiency at the DC-DC converter section or the DC-AC inverter section.

(2) Power grid interconnecting control

Even though the controls of ordinary DC-AC inverter power supplies are for the purpose of supplying output voltage in an alternating current, with the use of PV power conditioners interconnected with a power grid, aside from the controls necessary to match the phase and amplitude of the output voltage with the voltage of the power grid, it is also necessary to use additional controls for the purpose of efficiently supplying electric power provided by PV modules to the power grid. Controls must be executed considering a drop in voltage as well as phase delays due to the reactor in the inverter output section.

(3) Power grid interconnecting protective function

Rapid suspension of operations and protection of the power grid system are obligatory requirements for equipment connected to power grid systems, according to the "Interpretation of Technical Standards on Electric Facilities"[1)], when any abnormality occurs with respect to voltage, current and frequency. This applies to PV power conditioners, which must be equipped with functions to protect the power grid system. The provisions for setting values and setting times vary from one electric power company to another, therefore, discussions with the electric power company are essential prior to connecting a system to a power company's power grid system.

*2) PV is an abbreviation for "photovoltaic".
*3) MPPT is an abbreviation for Maximum Power Point Tracking.

Aside from the protective functions in relation to voltage, current and frequency, as described above, PV power conditioners must be equipped with an islanding detection capability. An islanding involves the output of electric power from PV power conditioners, even when the power grid voltage has been suspended, due to a power outage or the like. Equipment connected to a power grid system is required to have a capability for detecting an islanding, in order to ensure the safety for inspection personnel of power grid systems.

Characteristics of PV power conditioners in development

The PV power conditioner currently being developed has the following three features, aside from the improved basic functions for PV power conditioner controls described in previous sections:

- Incorporation of insulation method
- Improvement of power generating efficiency
- Compatibility for networks

(1) Incorporation of insulation method

Equipment connected to power grid systems ordinarily offer protection against current leakage (grounding current) through the use of a ground-fault interrupter or the like. PV modules and the power grid system are not insulated in non-insulated PV systems, indicating a potential for current leakage overlaid with direct current components. Therefore, a need exists to insulate the junction between the grounding detector capability and the section that connects to the power grid system using an alternating current transformer.

An alternating current transformer is required for the insulation method, but this produces the drawback of a larger system volume. A volume equivalent to that of equipment adopting the non-insulated method has been realized with the PV power conditioner currently being developed, through the control of multiple compact transformers. This represents a volume less than two-thirds that of conventional non-insulating-type PV power conditioners.

(2) Improvement of power generating efficiency

The power conversion efficiency of a power supply ordinarily represents the value for the output of rated electric power. The power conversion efficiency during lower electric power output is lower than that of the rated electric power output. The PV power conditioner currently being developed is equipped with multiple DC-DC converter circuits and the number of these DC-DC converter circuits in operation varies, depending on the electric power output conditions. This makes it possible to maintain a high efficiency electric power conversion in conditions ranging from low to high electric power outputs. A conceptual diagram of a load-adaptive control is shown in **Fig. 3**.

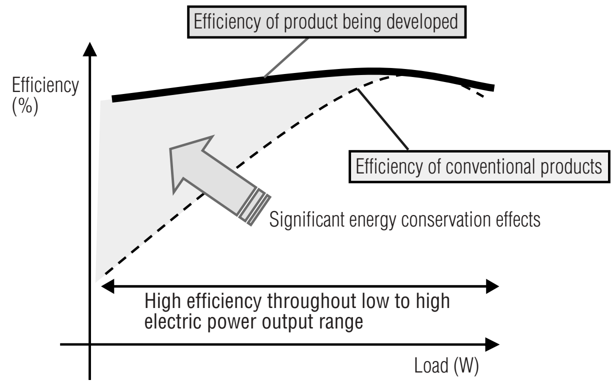

Fig. 3 Concept of load adaptive control

Improvements to the electric power generating efficiency are being made from a structural approach for the housing of the PV power conditioner currently being developed. When the internal temperature of the PV power conditioner rises, a function that restricts output is triggered in order to prevent damage and the deterioration of the device. Although large amounts of electric power can be generated during periods when the level of irradiance is high, the internal temperature rises when the surrounding temperature increases. The function for restricting the electric power output from the PV power conditioner is then triggered, which results in a deterioration of the electric power generating efficiency. The thermal analysis simulation, shown in **Photo 3**, was used in preparation for the housing design, to enable the design of a structure that minimizes a rise in temperature. This allowed us to extend the time period during which the maximum amount of electric power can be supplied, while improving the electric power generating efficiency.

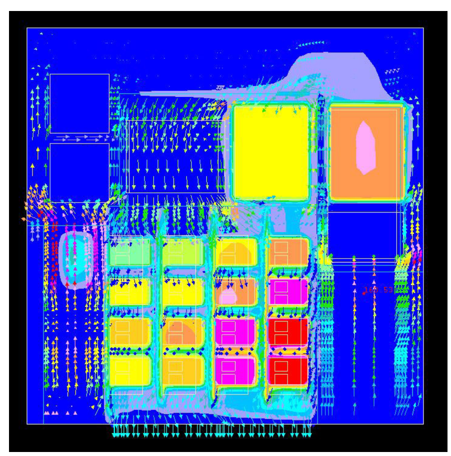

Photo 3 Thermal analysis simulation

(3) Compatibility for networks

PV systems are often installed at unmanned locations and for this reason it is essential for them to be connected to the internet in order for such PV systems to be maintained in an efficient manner. Hence, a piece of equipment, such as a personal computer capable of connecting to the internet, is most commonly used with conventional PV power conditioners.

An Ethernet[*4)] capability is built into the PV power conditioner currently being developed so that the unit can be connected to the internet on its own. Since multiple Ethernet connections are available on each unit, it is possible to connect PV power conditioners with each other, which makes the implementation of parallel synchronized operations an easy task.

The electric power generating efficiency can potentially be improved even further through the exchange of information and coordination among PV power conditioners. Network configurations are shown in **Fig. 4**.

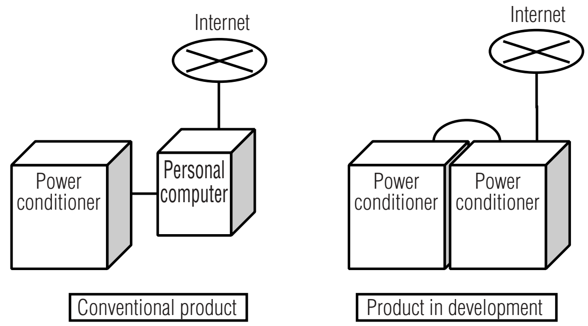

Fig. 4 Network configurations

Future developments

Digitally controlled power supplies are considered more advantageous than analog controlled power supplies, for the purpose of demonstrating the beneficial aspects in the current market, since the enhancement of intelligence for all product systems is being sought. We have been developing DC-AC inverter power supplies and PV power conditioners according to this belief. The green energy market we are about to enter into with our PV power conditioner, is expected to continue growing in the future, which allows us to plan the expansion of our power conditioner product series. A development roadmap is shown in **Fig. 5**.

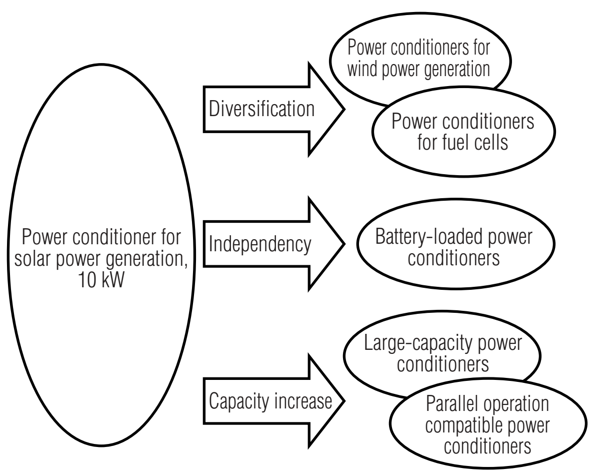

Fig. 5 Development roadmap

*4) Ethernet is a registered trademark of Xerox Corporation of the United States.

A power conditioner with a 10 kW rating for commercial use has been developed. We can conceive of creating units that have a larger capacity with several tens of kW or applications not limited to solar power generation but with other types of electric power generation that use alternative green energy sources, such as wind power or fuel cells. We can also consider applications to fully independent systems by loading batteries onto the PV modules, as shown in **Fig. 6**, in order to provide a stable supply of electric power in the event of a disaster.

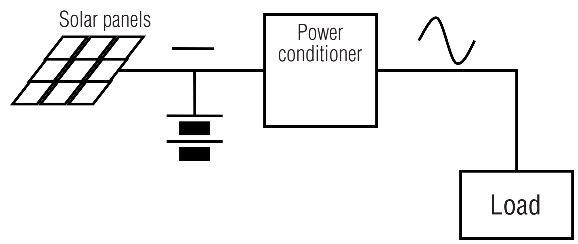

Fig. 6 Fully independent system

In addition we believe that further improvement of the efficiency can be achieved by combining the amorphous powder core, for which OPT is currently making great efforts to develop, with digital control. We believe that this can be applied not only to our PV power conditioners but also to DC-DC converter power supplies, DC-AC inverter power supplies and various other power supplies, in our endeavors to proactively tackle environmental problems.

References

1) Nuclear and Industrial Safety Agency, Ministry of Economy, Trade and Industry (Editing): "Interpretation of Technical Standards on Electric Facilities", 13th edition, Bun-ichi Sogo Shyuppan, published April 2008.

Authors

Tadashi Ryu: OKI Information Systems Co., Ltd., Electronics Manufacturing Development, Dept.-3, Development Team 2.