Development of Large-Capacity Solar Inverter

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In Japan, an increasing number of megawatt-class solar power systems have been established for industrial use since the introduction of the feed-in tariff system, a policy that requires electric power companies to purchase electric power generated by solar power systems at a relatively high price. In line with this, we have added new functions to our 100 kW and 250 kW solar inverters with the aim of preventing voltage fluctuations that are caused by the increased number of solar power systems. This paper describes the specifications and performance of our solar inverters and the new functions added. We also outline the 110 kW solar power system installed in our factory.

Keywords: solar system, feed-in tariff, solar inverter

1. Introduction

Commercializing renewable energy and expanding its utilization is an urgent necessity for societies to continue prospering into the future. Renewable energy will be the key to solving the challenges of the exhaustion of fossil energy, the increase in CO_2 resulting from the consumption of fossil-based energy, global warming, and similar issues.

One solution attracting attention is a solar system that converts solar energy into electrical energy. For over 20 years, we have worked on the development and commercialization of solar inverter (hereinafter, "SOLARPACKs") rated at 10 kW or more mainly for public and industrial facilities, successfully supplying many units of the SOLARPACK. Based on this experience and technology, we have developed new SOLARPACK units for the domestic market with 100 kW and 250 kW ratings. These products are compatible with large-scale solar power plants, called mega-solar power plants. We have also developed a 100 kW-rated SOLARPACK units compatible with overseas, mainly European and Chinese, standards and regulations.

With the aim of making the SOLARPACK products not only compact and highly efficient but also easily matched with solar module characteristics and open to an expanded degree of freedom in system design, the range of input voltage (solar module operating voltage) has been widened. Furthermore, various optional functions friendly to power distribution systems have been added, which include SVC (static var compensator) and LVRT (low voltage ride through) functions that are required for large-scale mega-solar systems. In Japan, the feed-in tariff system that requires electric companies to purchase all generated output has started on a full scale, indicating the rapid expansion of mega-solar power stations.

This paper presents an overview of the SOLARPACK series and describes certifications that the SOLARPACK series have received from Germany's Technical Inspection Association (TUV certification) and the China Compulsory Certificate (CCC standards). This paper also discusses several optional functions that are required for solar inverters in configuring mega-solar systems.

2. Overview of SOLARPACK

2-1 Outline of the specifications

Table 1 shows the major specifications of the 100 kW and 250 kW SOLARPACK units for domestic sale and the 100 kW unit for overseas sale.

The one-circuit input method is applied across general-purpose solar modules connected in series, with the input voltage range set at values between 0 and 600 VDC and the MPPT (maximum power point tracking) operating range, in which a solar system can output the rated power, set between 320 and 600 VDC. For the two-circuit input method, the input voltage range is set from 0 to ±440 VDC (corresponding to 880 VDC) with the aim of increasing the degree of freedom in combination with solar modules; this enables about 1.5 times greater input voltage range and about 1.2 times greater MPPT operating range than in the case where the one-circuit input method is adopted.

For the 250 kW unit, the panel width is limited to 1200 mm, about 1.2 times that of the 100 kW unit, so that the best possible use of the dimensional advantage can be made.

For the 100 kW unit for overseas sale, the DC input is raised to 880 V while the AC output is set at 400 V as the standard, in consideration of interconnections with common low-voltage three-phase distribution systems. In addition, the MPPT range for solar modules is set between 450 and 820 V in response to the change in the upper limit of DC voltage.

In terms of operating efficiency, the 100 kW unit for overseas sale achieves a maximum efficiency of 97% (a euro efficiency of 96%) as a result of raising the DC voltage to higher values and increasing the efficiencies of the reactor and transformer on the AC side.

As an insulating transformer is built in all SOLARPACK products, they can be interconnected directly to a power distribution system regardless of the type of system (voltage, grounding method, etc.). This prevents abnormal contact between DC and AC as well as noise outflow to the power distribution system, thus improving the safety and reliability of the entire system consisting of solar modules, a SOLARPACK unit, and a power distribution system. Inverters, each of which has a separately installed insulating transformer with a low voltage primary side and a high voltage secondary side instead of a step-up transformer, are oper-

Table 1. Major specifications of SOLARPACK series

Unit capacity		For domestic sale			For overseas sale
		100 kW		250 kW	100 kW
Input method		One-circuit input	Two-circuit input	One-circuit input	One-circuit input
DC input	Rated voltage	400 VDC	±300 VDC	400 VDC	—
	Input range	0 – 600 VDC	0 - ±440 VDC	0 – 600 VDC	0 – 880 VDC
	MPPT range	320 – 600 VDC	±210 - ±350 VDC	320 – 600 VDC	450 – 820 VDC
Efficiency (at rated output)		94.5% (JISC8961)	95% (JISC8961)	95% (JISC8961)	97%(Max.) 96%(Euro)
Main circuit type		Self-commutated voltage type			
Switching type		High-frequency PWM type			
Output control type		Output current control type			
Insulation type		Utility frequency link type			
AC output	No. of phases	3-phase, 3-wire			
	Rated voltage & frequency	202V, 50/60 Hz		420 or 440 V, 50/60 Hz	400V, 50/60 Hz
	Power factor	0.95 or more (0.99 or more at rated output)			0.99 or more
	Current distortion factor	Overall: 5% max; each harmonic distortion: 3% max			Overall: 3% max
	Utility interactive operating range	Voltage: rated value ±10% or less; frequency: rated value ±1% or less			Voltage: −15% +12.5%; frequency: 47 – 61.5 Hz
Linkage protection		Overvoltage (OVR) undervoltage (UVR); overfrequency (OFR) underfrequency (UFR); isolated operation (passive or active)			
Communications system		RS-485			
Dimensions		W1000 × D900 × H1950mm		W1200 × D1200 × H1950 mm	W1000 × D900 × H1950 mm
Mass		1100 kg (incl. insulating transformer)		2000 kg (incl. insulating transformer)	1100 kg (incl. insulating transformer)
Elevation		Up to 1000 m			Up to 2000 m
Installed location		Indoors			

ated in parallel to interconnect with a high-voltage power system. This setup improves the power generation efficiency of the entire system as described above.

2-2 System configuration of the SOLARPACK unit

Figure 1 shows the system configuration of a SOLARPACK unit. **Figures 2** and **Photo 1** are an example of a mega-solar configuration (with 10 units) and an image of a mega-solar system installation, respectively.

The SOLARPACK unit converts DC power provided by an individual solar module array into AC power and supplies the power to the power distribution system. Factories, stores and buildings can use generated output on a priority

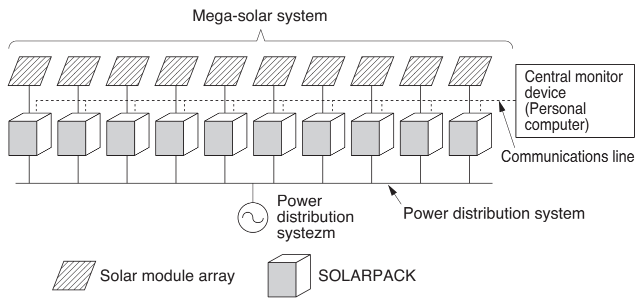

Fig. 2. Example of a mega-solar system

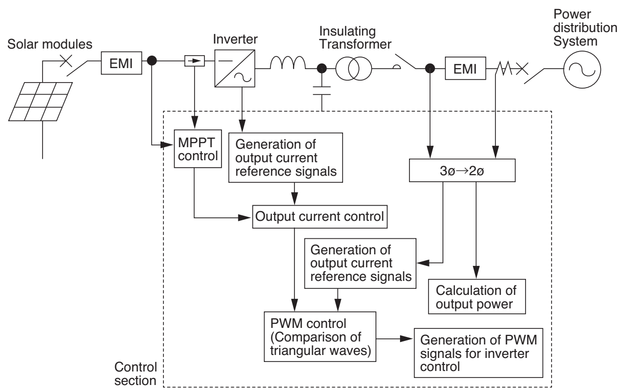

Fig. 1. Schematic diagram of a SOLARPACK system

Photo 1. Image of a mega-solar system installation

basis, while they can also sell the total volume of generated output to the electric company at a fixed price.

In addition, a parallel connection of two or more units increases the system capacity, enabling the system to work with mega-solar systems with a capacity of 1 MW or more. Operation data under such conditions are sent to a monitoring device by the RS485 communication function installed on individual SOLARPACK units for central control.

Table 2 shows an overview of typical communication data elements.

Table 2. Overview of typical communication data elements

Communication data elements	
DC voltage	V
DC current	A
DC power	kW
AC voltage	V
AC current	A
AC power	kW
Frequency	Hz
Integrated electric energy	kWh
Solar irradiance	kW/m^2
Air temperature	°C
Device condition	Running, standby, stopped
Minor failure	—
Major failure	—

2-3 Operating characteristics of the SOLARPACK unit

(1) Efficiency enhancement

Figure 3 shows the efficiency curve of the 250 kW unit used mainly for mega-solar power plants.

The measuring method is in accordance with JISC 8961. Although a SOLARPACK unit contains an insulating transformer, the optimization of both the main circuit equipment and the switching characteristics of the inverter makes it possible to attain an efficiency of 96% or more under a load factor of 60% (an efficiency of 95% or more under a load factor of 30% or more).

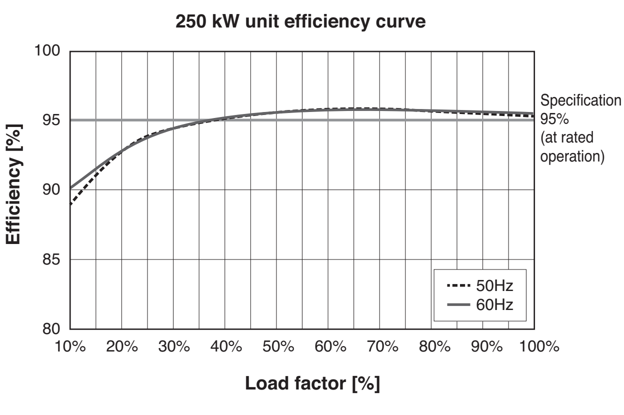

Fig. 3. Efficiency curve for the 250 kW unit

(2) Optimization of the structure

To maintain the temperatures of devices installed in the panel below the specified values and obtain an electrically and functionally optimal device arrangement, simulation was conducted using thermal fluid analysis and the results were incorporated into the structural design. **Figure 4** shows the examples of the analyses.

Adopting a cooling structure that minimizes the temperature rise of individual main circuit devices not only extends the service life of devices but also increases the efficiency of the entire system through the simplification of the cooling system.

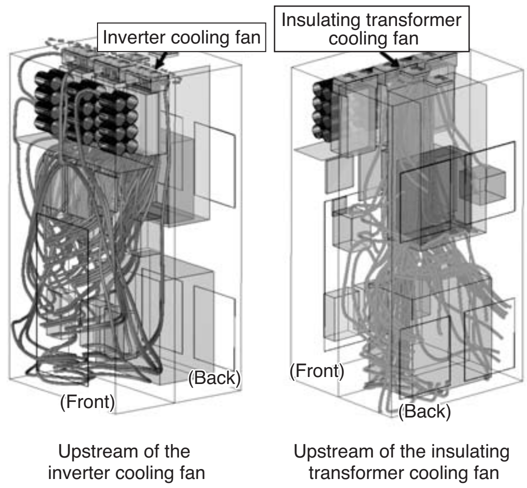

Fig. 4. Airflows inside the panel

(3) Protection of the grid interconnection

For interconnection with a power distribution system, protection of the grid interconnection is required by the Grid Interconnection Code (JEAC 9701-2006). When two or more solar inverters are installed as in a mega-solar power plants, it is necessary to detect a state of isolated operation upon service interruption (a state in which power generation is perfectly balanced with power consumption, and therefore, the electric voltage does not fluctuate even when electric service is interrupted; and which, for this reason, an ordinary interconnection protection detecting element cannot detect) to stop all the units within a specified time period. To meet this requirement, we verified whether the state of isolated operation is detected with certainty by using multiple SOLARPACK units (five units for this time).

Figure 5 shows the example waves obtained in the isolated operation protection test.

For the detection of isolated operation, there are two types of element detecting methods: passive and active methods. The prescribed detection time is 0.5 seconds or less for the former and 0.5 to 1.0 second for the latter. If, as in the present case, the generated output perfectly balances with the load consumption power, detection based on the passive method (we adopted the voltage phase jump

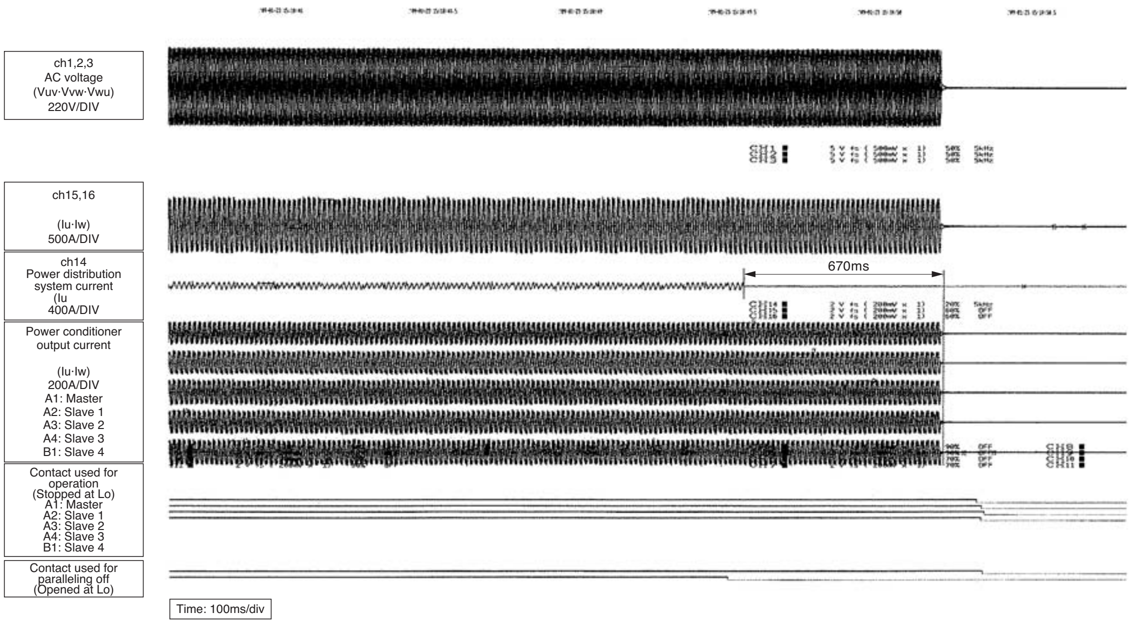

Fig. 5. Results of the isolated operation protection test with 5 SOLARPACK units operating in parallel

method) is theoretically and consequently impossible and we have to rely on the active method (we adopts the reactive power fluctuation method). The test results confirmed that the active method detected isolated operation in 0.67 seconds and all the five units stopped simultaneously.

3. Optional Functions

Due to the feed-in tariff system inaugurated in July 2012, an increasing number of solar systems are expected to be introduced and the trend toward mega-solar power plants with larger capacities will be accelerated. Under these circumstances, solar inverters are required to have new functions which have not been emphasized thus far. Therefore, we have added the following optional functions to the new SOLARPACK units.

(1) LVRT (low voltage ride through) function

When a power distribution system undergoes a short-time voltage drop (hereinafter, "voltage dip") due to an accident or the like, this function works to minimize the effect on the power distribution system by maintaining power generation without interruption if the drop is below a preset voltage value and within a preset time period, and by maintaining the same output current as before the voltage dip. This function is becoming increasingly important because a mega-solar power plant consists of a large number of SOLARPACK units and their simultaneous falling off can cause substantial impact on a solar power plant with a large power generation capacity. **Figure 6** shows the specification of the LVRT function mounted on the SOLARPACK unit, and **Fig. 7** is the results of the test.

Operation is not interrupted when a 3LS (3-phase short-circuit) occurs, the voltage drop in the power distri-

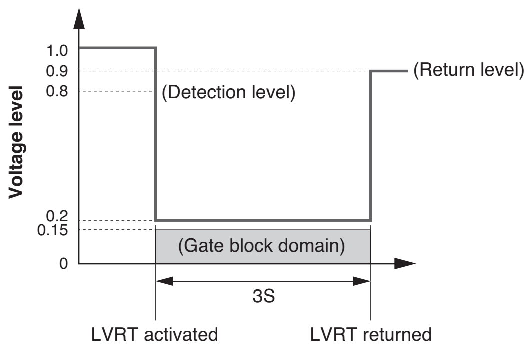

Fig. 6. LVRT specification

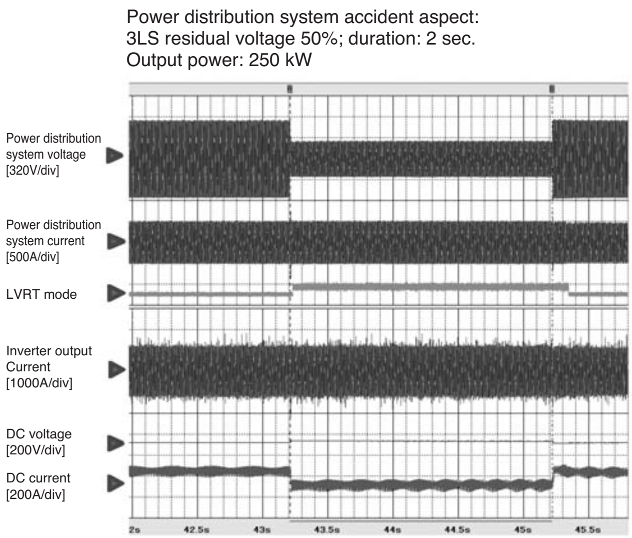

Fig. 7. Results of LVRT functional test

bution system is less than 80% of the rated voltage (20% or more residual voltage), and the period of the voltage drop is less than 3 seconds. A voltage drop is detected when the rated voltage is dropped by 20% or more, while voltage recovery is detected when 90% or more of the rated voltage is attained. To simulate a voltage drop caused by an accident in a power distribution system, tests were conducted using a large-capacity short-circuit generator at our test site. As observed in **Fig. 7**, the test results are satisfactory with little output fluctuations observed at the moment of the voltage drop, during the drop, and at the moment of recovery.

(2) SVC function

This function suppresses a rise in the voltage of a power distribution system by generating lagging reactive power at a preset rate depending on the generated output. This function prevents the voltage of the power distribution system from exceeding a specified value as a result of fluctuations in power output by a large-scale power supply system such as a mega-solar power plant. For this reason, the reactive power from the SOLARPACK unit is controlled by the proven method described below:

$Q\ (kVar) = \alpha \times P\ (kW)$

(α: a constant determined by the impedance on the power distribution system)

4. Establishment of a Field Demonstration Test Facility

We have established a 110 kW solar system on the premises of our plant to conduct a long-term verification test and examine the above mentioned functions.

Photo 2 shows the facility for the verification test. This facility enables us to conduct a long-term verification test for new functions or components used in combination with solar modules in addition to conventional factory tests. This facility can also test solar modules in different combinations and confirm changes in solar module characteristics, enabling us to accumulate various data as a system integrator and manufacturer.

5. Conclusion

This paper has outlined the specifications, basic performance, and optional functions of the 100 kW and 250 kW solar inverters to be operated together with mega-solar power plants.

We will concentrate our R&D efforts on the improvement of the monitoring and communication functions of the SOLARPACK systems so as to contribute to the improvement of power generation efficiency and establishment of stabilized power distribution systems with less voltage fluctuations.

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Photo 2. A 100 kW + 10 kW solar power plant installed on the premises of Nissin Electric

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