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Conceptual considerations on PV systems composed of AC modules

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Abstract

AC module technology has become popular and a number of AC module types are commercially available. Although their specifications are clear, it seems that their technological meaning has not yet been well developed. Therefore, the authors tried to create the total concepts of PV systems composed of AC modules. They are abbreviated AC module-composed PV system or ACM-PV. In the paper, the possible structural configurations of simple AC modules and battery integrated ones are classified in principle. System categories are also classified to show their total concept. Necessary electrical terminals and interfaces, voltage matching method between inverter and PV part, and AC module testing methods are also discussed.

Keywords: Photovoltaic system; PV module; AC module; Power conditioner; Inverter

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1. Introduction

AC module technology has become popular and a number of AC module types are commercially available [1–7]. Although their specifications are clear, it seems that their technological meaning has not yet been well developed. Therefore, the authors tried to create the total concepts of PV systems composed of AC modules. They are abbreviated AC module-composed PV systems or ACM-PV hereafter. It is considered that AC modules were originally developed for very small-scale application rather

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than large-scale systems. It is, however, thought to be very useful for larger applications. From this view point, detailed conceptual construction has been investigated.

An AC module is defined as an assembly of a PV module and an inverter having capacity similar to the module capacity. Wiring among those modules is realized by AC circuitry. It is characterized as follows:

- cost reduction to be attained by inverter mass-production on the same level to module production volume,
- standard voltage/frequency obtainable by a single module including islanding protection,
- array mismatch losses to be minimized by individual Pmax control,
- easy array wiring because of AC circuit and safe wiring works by stopping inverter operation,
- the larger system application to be feasible when the larger cost-down will be brought.

The capability of the first point seems to be very important for AC module future. Almost all the feasible configurations are classified and technical problems for possible applications are examined in this article. The feasibility of the large systems has also become clear recently [5].

2. Classification of AC module configurations and total systems

2.1. AC module configurations

Although the present technology comes out from one-board inverter only, the possibility of one-tip inverter can be suggested. Including this, the possible configurations are classified to 4 categories as shown in Fig. 1. In addition, battery integrated type is also proposed as a future option as illustrated in Fig. 2. One-tip model may be preferable for aiming at larger cost reduction although larger production volume is required.

2.2. AC module-composed PV systems

Figs. 3–6 are classifying the total system concepts of ACM-PV which can be realized by the utilization of AC modules. Fig. 3 shows single module systems, plural module systems in Figs. 4 and 5, an example of a large system having higher hierarchy controller in Fig. 6. These are studied for utility connected mode, off-grid mode and battery provision. In the case of the utility-connected application, problems are rather simple. However, if the off-grid mode is required, there exist many control problems, e.g. master/slave control, the selection strategy of master module, control interface standardization, etc.

Table 1 summarizes possible total system concepts, their appropriate operational/control mode and some of the technical problems that have arisen.

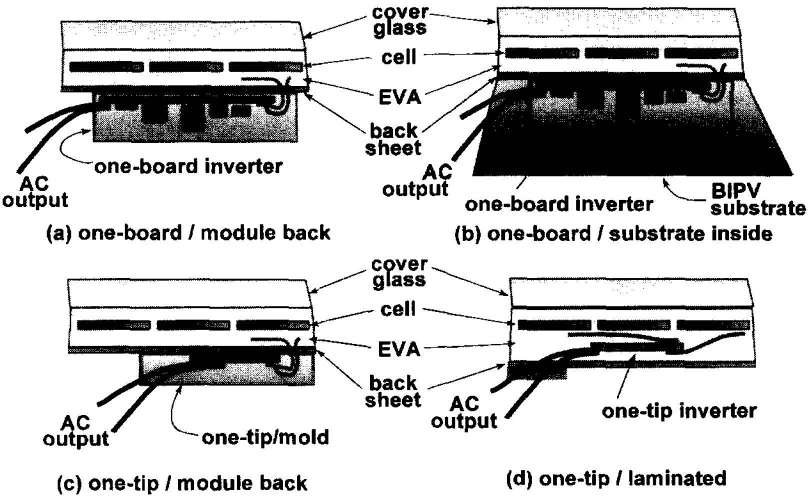

Fig. 1. Encapsulation of inverter for AC module.

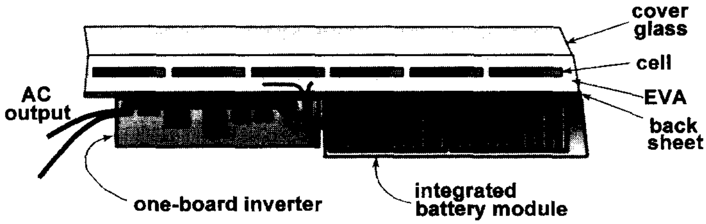

Fig. 2. Battery integrated AC module.

3. Basic technical requirements of AC modules

3.1. Necessary electrical terminals

According to considerations in the previous section, the electrical terminals required for individual AC modules are not only AC output but also DC intermediate terminal and control interfaces optionally as shown in Table 2. The DC terminal becomes necessary for monitoring PV performance, as input terminal for inverter separate test, or for connecting battery. The control interfaces is required for inverter operation block, control mode selection, operational mode monitoring, master inverter selection, master/slave control output, slave input, synchronization clock, etc.

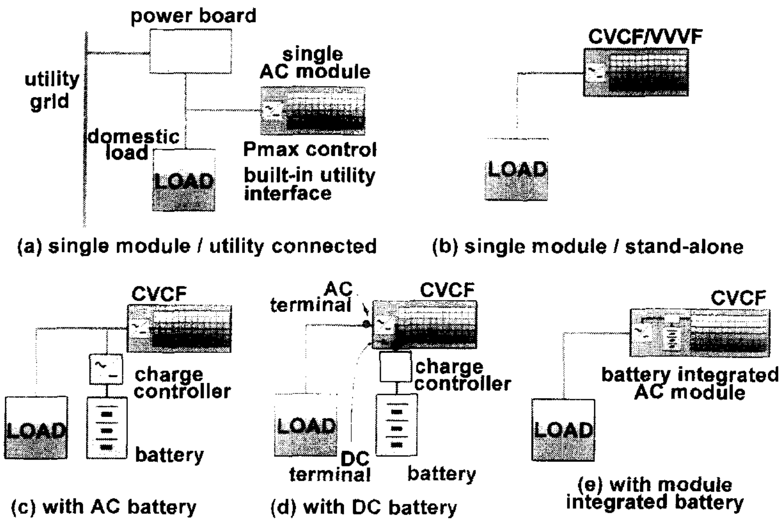

Fig. 3. System configuration composed of single AC module.

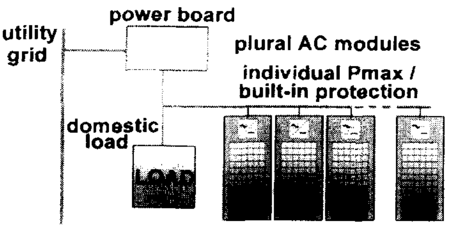

Fig. 4. System configuration composed of plural AC module (utility-connected).

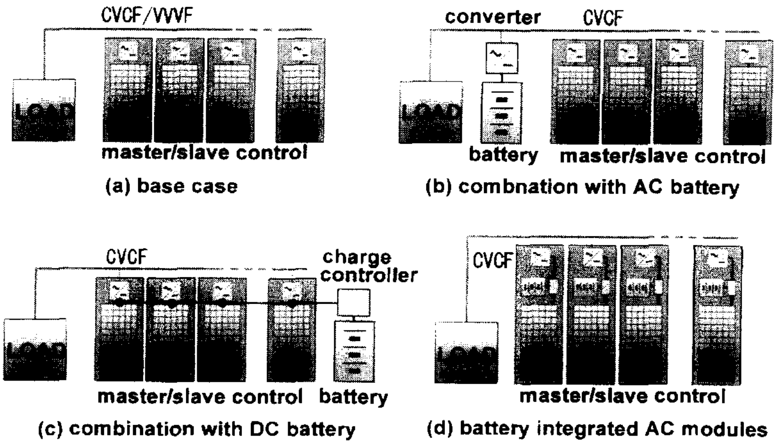

Fig. 5. System configuration composed of plural AC module (Off-grid operation).

Table 1
Classification of total system concepts composed of AC modules

System category	Operation	Option	Basic Control Mode	Problems
Single-Module system	Utility-connected		Overload limiter, Pmax control, constant power factor control, built-in islanding protection	
	Off-grid mode	Without battery	Overload limiter, CVCF/VVVF control	
		With DC battery	Overload limiter, CVCF/VVVF control	
		With AC battery	Overload limiter, CVCF/VVVF control, Pmax control	
Plural-module system (small/medium size)	Utility-connected		Individual overload limiter, individual Pmax control, individual islanding protection	
	Off-grid mode	Without battery	Individual overload limiter, master/slave control/CVCF/VVVF	● Selection method of master module in case of non-Pmax control(for partly shaded array) ● Control interface standardization
		With DC battery	Individual overload limiter, master/slave control/CVCF/VVVF (or loop current suppress control$^{1)}$)	
		With AC battery	Individual overload limiter, VVVF by AC battery with individual Pmax controls	
Master-controlled, plural-module system (medium/large size with high-voltage PV electricity collection)	Utility-connected		Individual overload limiter, individual Pmax control, islanding protection by master control	● Matching between master control and individual control ● Influence of partly shaded array for non-Pmax control ● Control interface standardization
	Autonomous	Without battery	CVCF control by master controller, individual overload limiter, module operation by slave control	
		With DC battery	CVCF control by master controller, individual overload limiter, module operation by slave control	
		With AC battery	Control mode signal from master controller, individual overload limiter, CVCF by AC battery, module operation by Pmax control with power suppression in case of overcharge	

AC battery consists of an ordinary battery bank and an AC/DC converter for charge control.

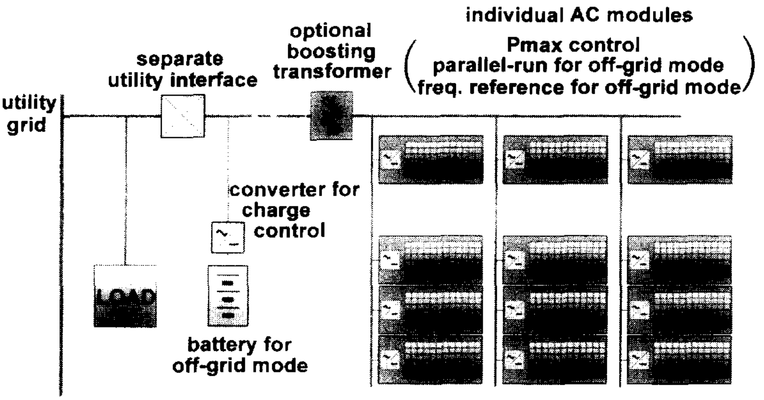

Fig. 6. A system example composed of plural AC module with master controller.

Table 2
Classification of electrical terminals of AC module

Terminals	Remarks
AC output	Screw terminal + terminal box, cable + connector
DC output	(Optional use) monitoring point for PV performance, input terminal for inverter separate test, connection to battery
Control Interface	(Optional use) inverter operation block, control mode selection, operational mode monitoring, master inverter selection, master/slave control output, slave input, synchronization clock (interface standardization required)

3.2. *Considerations on voltage matching*

Generally speaking, power devices prefer higher circuit voltage for improving conversion efficiency and sometimes for their economy. The typical DC voltage of 50–100–200 W modules is supposed to be in the range of 17–34–68 V approx., which is not enough for the direct connection of inverter. The following four options for voltage matching are suggested as shown in Fig. 7:

- standard-frequency transformer,
- high-frequency transformer,
- booster chopper,
- direct matching.

3.3. *Test method of AC modules*

Although conventional modules are normally tested by the pulse-type solar simulator, an inverter integrated in a module cannot follow such a transient state. A stable

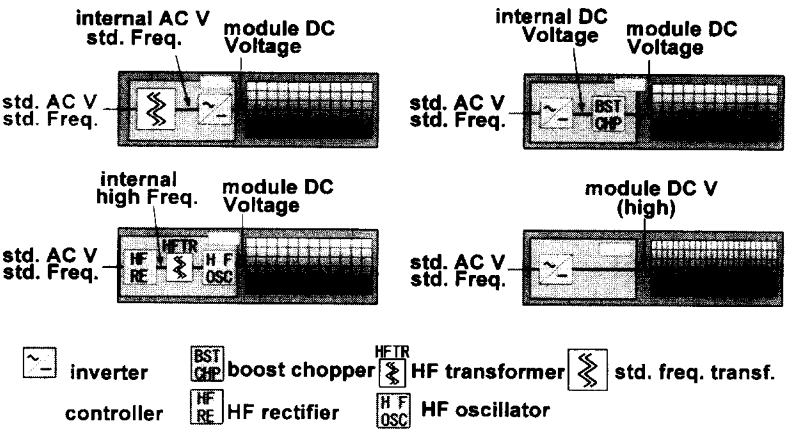

Fig. 7. Voltage matching principle in AC modules.

Table 3
Test methods of AC module

Remarks	Test items		Problems
Objective	Output performance test		– No inverter test equipment/know-how in existing module type approval test facility.
	Electrical stress test		– Possibly different thermal cycle test condition because of inverter temperature rise (considerations on temperature level during inverter operation or stand-by).
	Mechanical stress test		– Comparative weakness on adhesion of inverter container, electrochemical capacitor.
Methods	Overall test	Solar simulator	– Difficult to use conventional pulse solar simulator. – Expensive, large-size, steady state simulator with good uniformity – Possible Pmax tracking disturbance by ripple component of solar simulator output. – Electromagnetic interference against existing module measurement facility which may be caused by inverter operation.
		Outdoor test	– Higher possibility of stable sunlight condition. – Re-consideration on I–V data translation procedures because of inverter efficiency curve and Pmax tracking efficiency.
	Separate test		– Necessity of intermediate terminal between PV part and inverter. – Attainable by indoor test only. – Preparation of formula to evaluate combined performance.

light source is necessary for overall test, or the PV part and the inverter have to be tested separately. For the latter case, the intermediate DC terminal should be provided. The test methods for AC modules are proposed in Table 3 and problems are summarized.

4. Conclusions

The authors have tried to create the total concepts of AC module-composed PV systems. All the possible structures including battery-integrated AC module were proposed. System categories were also classified to show total concepts, capabilities and necessary functions. Electrical terminals, voltage matching and testing were also studied.

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