Development of Inverters for Energy Storage System with Virtual Synchronous Generator Functions (VSG-PCS)

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Abstract

According to the Japanese Government's latest energy mix policy, Japan is expected to expand the introduction of renewable energy and reduce thermal power generation, using Synchronous Generators (SGs), toward the goal of achieving a carbon neutrality. As a result, the inertia of the power grid system is significantly reduced, and there are problems such as reduced system stability when disturbances occur due to sudden changes in the power generated by renewable energy resources and the demand load power.

Therefore, we created a product evaluation model and verified its operation in order to realize inverters for energy storage system with a Virtual Synchronous Generator function (VSG-PCS), in which the inverter for energy storage system has an inertial force function.

The product evaluation model is a parallel system of two VSG-PCS units with a rated output of 6 kVA, which is 1/100 scaled down from the current rating of the product. In this model, performance evaluations were conducted with a circuit configuration that combined VSG-PCS, SG, and Photovoltaic PCS (PV-PCS), and favorable results were obtained.

1 Preface

In recent years, the introduction and expansion of renewable energies such as photovoltaic power and wind power have progressed rapidly in response to global environmental challenges. In the future, the number of operating Synchronous Generators (SGs) in power systems will decrease as distributed power sources using inverters are introduced in large amounts in power distribution systems. A new issue is how to deal with the fact that the inertia of the whole power system decreases due to the reduction of SGs, and that the stability of the system decreases when disturbances occur.

As a countermeasure, Virtual Synchronous Generator (VSG) control, which provides pseudo-inertia to grid-connected inverters, has been proposed, but has not yet been put into practical use.

TEPCO Power Grid, Incorporated and Meidensha Corporation, thereby, jointly developed an energy storage battery inverter with a VSG function (VSG-PCS). This is to realize inverters for energy storage system with a VSG function. We conducted its evaluation using a product evaluation model. This paper introduces VSG control, the specifications and functions of the product, the configuration of the product evaluation model, and the evaluation results.

2 VSG Control

Fig. 1 shows a block diagram of VSG control. Given the induced voltage is E_f and the synchronous impedance Z_s is defined as $Z_s = r + jx$, the SG is modeled simply. The output voltage V_{ac} of this simplified model is given by Expression (1) below.

$$\dot{V}_{ac} = \dot{E}_f - \dot{Z}_s \, \dot{I}_{ac} \quad \cdots (1)$$

When voltage control is carried out on the assumption that the output voltage is voltage command value V_{ac}*, an output is generated while synchronous impedance of the SG is simulated.

For a VSG model, the phase angle θ is calculated based on the swing equation of the SG and a

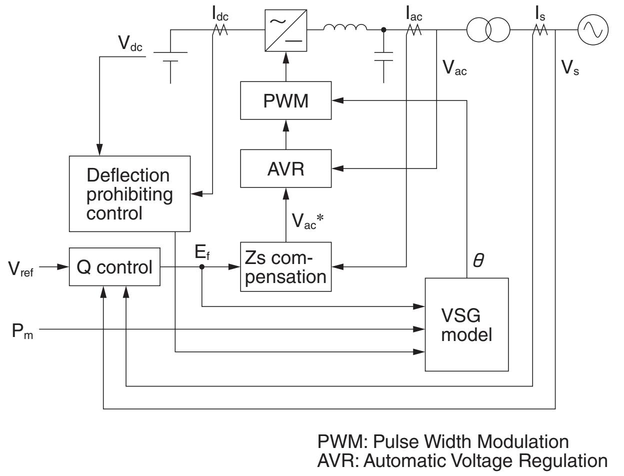


Fig. 1 Block Diagram of VSG Control

An outlined block diagram of VSG Control is shown.

Table 1 Specifications of Target Product

The target product to be developed is a VSG-PCS unit with the rated voltage of 6600 V and the rated capacity of 600 kVA.

Items		Specifications
Rated power		600 kVA
Rated AC output		600 kW
Power-frequency insulated transformer		Provided
DC block	Maximum voltage	750 V
	Voltage deviation range	432～745 V
AC block	Rated output voltage	6600 V (3300 V also available)
	Rated output current	52.5 A
	Rated frequency	50/60 Hz
	No. of phases	3-phase 3-wire system

Table 2 A List of Target Product Functions

Typical functions of the target product VSG-PCS are shown.

Functional Nomenclature
Instant start of the VSG-PCS
Inertial force function
Governor free
Isochronous
Automatic synchronizing
Overcurrent control and fault current supply
Black start
Soft stop
Output voltage constant control
Cross current control
Deviation preventive control for DC voltage/current

resultant output is generated corresponding to the inertial force possessed by the SG.

When a voltage control system is adopted as a control system for the VSG-PCS, stabilized operation can be assured regardless of presence of a power system. For existing products made by the company, however, it is necessary to make a control system changeover between grid connection operation and islanding operation. At the time of this changeover, it is also necessary to shutdown equipment.

If this should happen, it is possible to continue system operation because it is unnecessary to make a control system changeover.

3 Specifications and Functions of Target Product

Table 1 shows specifications of the target product. For the target product, the rated output will be 600 kVA and the DC voltage deviation range will be 432 V to 750 V. For batteries, use of lithium-ion batteries is projected. Table 2 shows a list of target product functions. In addition to the functions required as a VSG-PCS, it will also have a function as inverters for energy storage system and a function assuming use as a power source in a microgrid.

4 Product Evaluation Model and Evaluation Testing Circuit

4.1 Configuration of Product Evaluation Model

Fig. 2 shows a configuration of the product evaluation model, Fig. 3 shows an external appearance of the product evaluation model, and Table 3 shows its specifications. The product evaluation model is a system of 2 VSG-PCS units connected in parallel and the rated output of each unit is 6 kVA, where the rated current of the product machine is scaled down to 1/100.

The product evaluation model consists of a circuit breaker for grid-connection (52PR), two transformers for grid-connection, an inverter, and two DC circuit breakers (72B). In addition, in the actual product, an energy storage battery will be connected to the DC side, but in this model, a DC power source is used to simulate the energy storage battery.

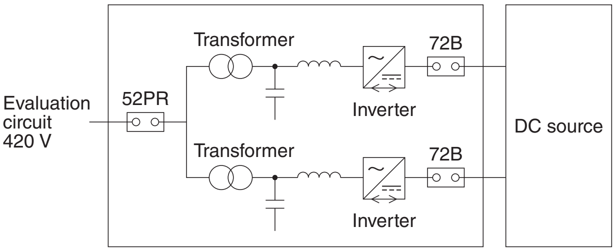


Fig. 2 **Configuration of Product Evaluation Model**

Configuration of the product evaluation model is shown.

Fig. 3 **Product Evaluation Model**

An external appearance of the product evaluation model is shown.

Table 3 **Specifications of Product Evaluation Model**

The product evaluation model has a 1/100 scale-down capacity of the practical product machine.

Items		Specifications
Rated power		6 kVA
Rated AC output		6 kW
Power-frequency insulated transformer		Provided
DC block	Rated DC voltage	666 V
	Rated DC current	9.0 A
	Voltage deviation range	432~745 V
AC block	Rated output voltage	420 V
	Rated output current	8.2 A
	Rated frequency	50 Hz
	No. of phases	3-phase 3-wire system

4.2 Evaluation Testing Circuit

Fig. 4 shows the evaluation testing circuit used for the product evaluation model. The evaluation testing circuit is composed of a system voltage simulator (for the simulation of the system voltage), SG, PV, PCS, and a dummy load.

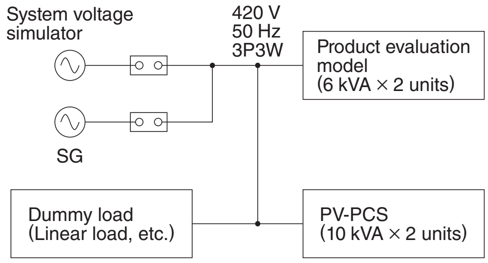


Fig. 4 **Evaluation Testing Circuit**

A configuration of the evaluation testing circuit is shown.

4.2.1 SG

The SG is rated power of 50 kVA. It is used under the condition that the output voltage is adjusted to 420 V and the output frequency to 50 Hz.

4.2.2 PV-PCS

Two mini-models of 10 kVA PV-PCS are used.

4.2.3 Dummy Load

The dummy load is composed of a linear load, nonlinear load, unbalanced load, and a short-circuit testing tool. The linear load consists of a resistance load, a lagging load, and a leading load. The load power factor is adjusted by regulating the load value.

5 Result of Evaluation Test

Evaluations of the product evaluation model were performed under various conditions, and here we introduce typical evaluation results.

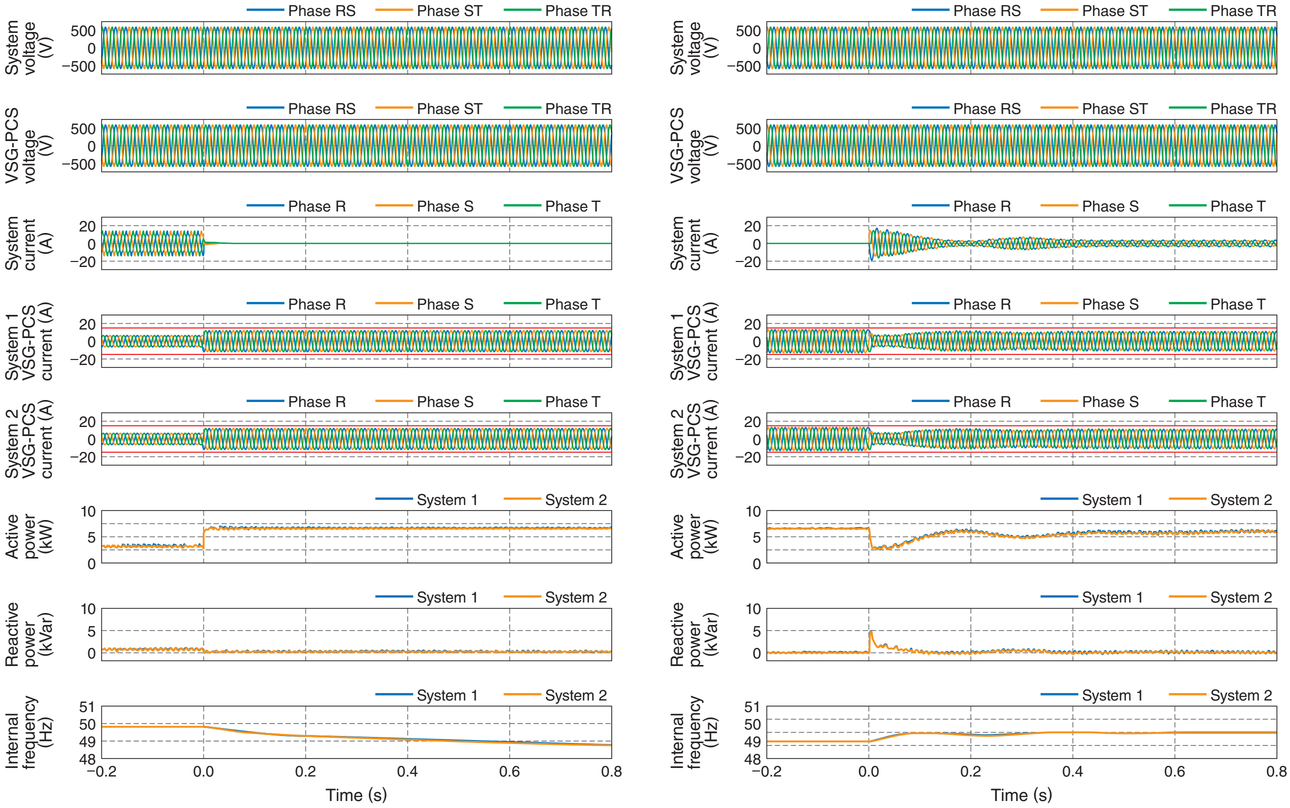
5.1 Combination Test with SG

Fig. 5 shows the test result in combination of the VSG-PCS and the SG. Under the condition that two units of the VSG-PCS and the SG were connected in parallel, a linear load (power factor 1.0, 12 kW) was connected. The SG was removed from the connection and connected again in parallel. Operational performance was confirmed at that time.

Even under parallel operation of two VSG-PCS units, it had almost no effect on the output voltage, and we confirmed that SGs can be parallel-disconnected.

5.2 Combination Test with PV-PCS

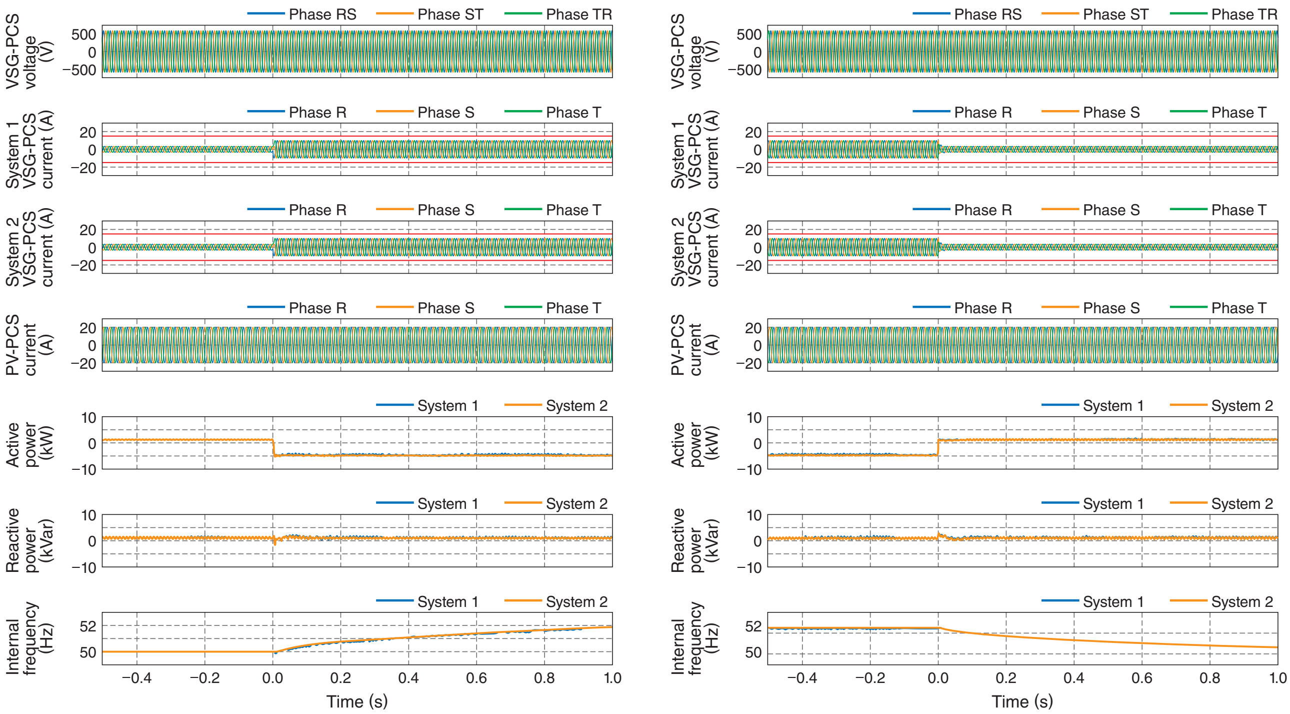
Fig. 6 shows the result of combination testing with the VSG-PCS and the PV-PVS. Under the condition of two VSG-PCS units in parallel connection,



(a) SG in parallel OFF (b) SG in parallel ON

Fig. 5 **Test Result in Combination of VSG-PCS and SG (2 units of SG and 2 units of VSG-PCS in parallel connection)**

Voltage and current waveforms in the case of a sudden load change are shown when the SG and the VSG-PCS were combined.



(a) In parallel OFF (b) In parallel ON

Fig. 6 **Result of Combination Testing with VSG-PCS and PV-PCS (2 units of VSG-PCS and 2 units of PV-PCS in parallel connection)**

Voltage and current waveforms in the case of a sudden load change are shown when the PV-PCS and the VSG-PCS were combined.

two units of the PV-PCS were put into the grid connected operation and a linear load (power factor 1.0, 12 kW) was connected. Under the condition that outputs of the PV-PCS were adjusted to 5 kW respectively, the load was turned on and off to confirm the behavior of operation caused by load variation.

We confirmed that the VSG-PCS was able to keep the output voltage at the rated voltage by charging the PV-PCS output as soon as the load was released.

6 Postscript

We built a parallel system with two 6 kVA product evaluation models and conducted evaluations under various conditions. Favorable results were obtained under various conditions, and representative evaluation results were introduced in this paper.

In the future, we will proceed with further development for commercialization.