

THE DEVELOPMENT OF A SCALED-DOWN SIMULATOR FOR DISTRIBUTION GRIDS AND ITS APPLICATION FOR VERIFYING INTERFERENCE BEHAVIOR AMONG A NUMBER OF MODULE INTEGRATED CONVERTERS (MIC)

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ABSTRACT

Islanding is one of serious problems in an electric power system connected with dispersed power sources. To secure the power system from islanding, it is quite important to verify the ability of islanding detection for the individual power sources in advance. The authors have been developing a scaled-down, simulated distribution network including a distribution substation, 6.6kV distribution line, pole transformers, low-voltage lines, customer loads and a number of PV systems. This paper describes the development of the scaled-down simulator and the experimental results about the interference phenomena among multiple module integrated converters (MIC).

INTRODUCTION

In Japan, the number of grid-connected PV systems has been increasing rapidly. To secure the power system from islanding, it is very important to verify the ability of islanding detection for the individual power sources in advance. Islanding has been tested in the actual scale distribution network simulator up to now, however it is impossible to experiment in a laboratory of a university, because the facility is large-scale, complicated and very expensive. Toward these problems, a scaled-down distribution network simulator has been needed.

DISTRIBUTION NETWORK MODEL

At the first stage of the development, a scaled-down distribution network model was designed based on a Japanese average distribution network in a residential area. The distribution network is modeled on a 3000kVA-6.6kV distribution line. Low-voltage distribution system is composed of 100/200V single-phase three-wire system. PV systems are connected to 6.6kV distribution

lines and low-voltage lines. Table1 shows the basic data about the model of the standard distribution system in residential area.

Table 1 Japanese standard distribution line in residential area^[1].

	Data
Line impedance (6.6kV line)	1.781+j2.382 [Ω]
Maximum demand (6.6kV)	814 [kW]
Maximum demand (100/200V)	1301 [kW]
Minimum demand	703 [kW]
Number of customers (low-voltage)	1850
Capacitance	345 [kVA]

DESIGN OF THE SCALED-DOWN DISTRIBUTION GRIDS

To design a scaled-down model, the capacity and the voltage of the distribution network model are respectively reduced from 3000kVA to 5kVA and from 6.6kV to 0.2kV. Using these scale-factor, line impedance, connected loads and PV output are calculated.

The impedance of the 6.6kV distribution line impedance is scaled down from Japanese standard ($0.313+j0.377\Omega/\text{km}$) with the p.u. method, which is converted to $0.172+j0.208 (\Omega/\text{km})$.

Minimum unit of the load and PV inverter's output power connected to low-voltage line are to 100W in consideration of MIC's output. Therefore low-voltage network is divided into four units. In order to connect the low-voltage units to the 6.6kV distribution line, insulating transformers corresponding to 20 or 30 pole transformers are installed.

The load units consist of resistors, inductors, and capacitors. And an induction motor is connected to 6.6kV distribution line. Active power and reactive power are able to be changed variously by combinations of these elements.

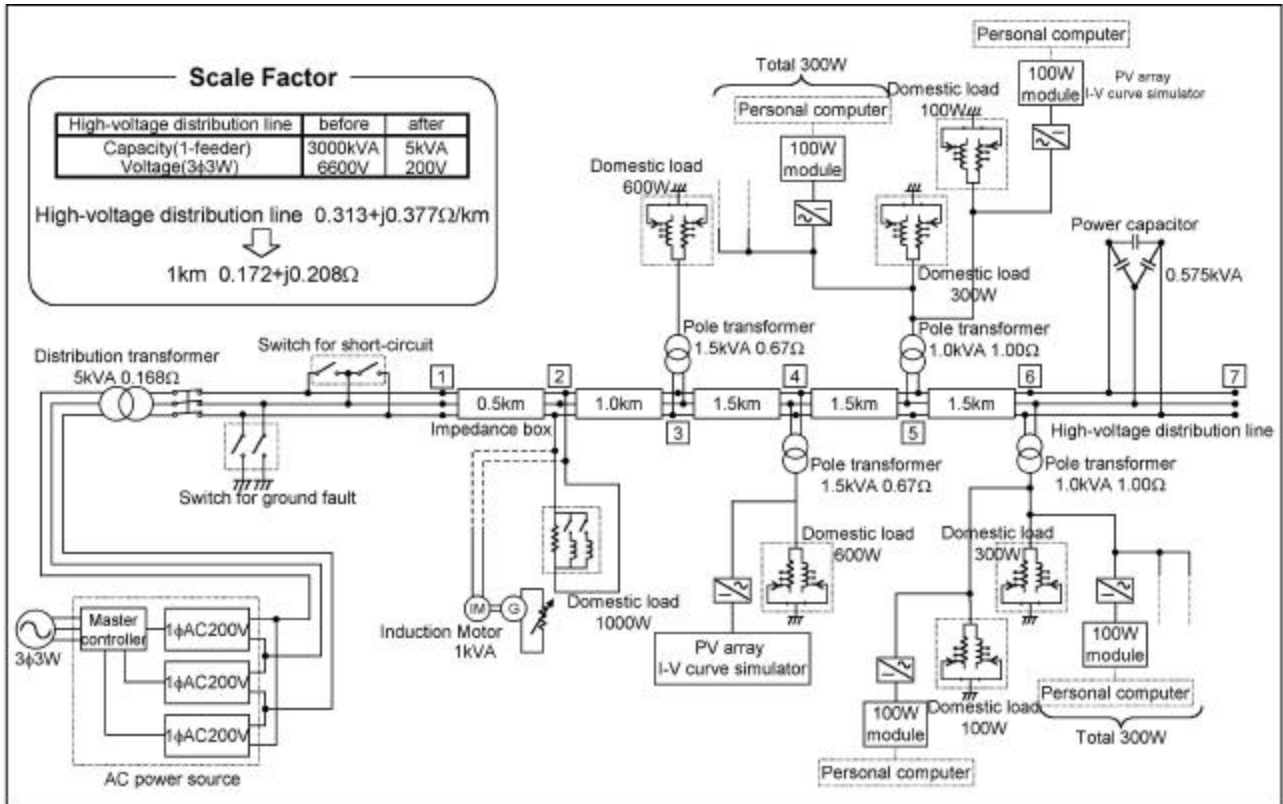


Figure 1 Composition of scaled-down distribution network model (residential area).

The power supplied from PV systems can be over 100% (5kW and over) compared with the capacity of the distribution line. The characteristics of PV array are imitated by PV array I-V curve simulator^[2]. This simulator can perform as a PV modules following given data about solar radiation intensity and the temperature.

Figure 1 shows the composition of the scaled-down distribution network model. Table 2 shows the calculated parameters for distribution line in residential area. And the view of the installed experimental equipment in our lab is shown in Figure 2.

The scaled-down distribution network simulator has the following advantages.

- Smaller installation space compared with the actual scale simulator.
- Whole distribution system can be simulated.
- PV output power and load power can be changed optionally.
- Repeatable condition can be served.

This simulator is also applicable to test the interference phenomena of multiple inverters.

Table 2 Calculated parameters in scaled-down distribution line.

	Data
High-voltage distribution line length	6 [km]
Line impedance (high-voltage)	1.035+j1.246 [Ω]
Maximum demand (high-voltage)	1.357 [kW]
Maximum demand (low-voltage)	2.168 [kW]
Minimum demand	1.172 [kW]
Number of customers (low-voltage)	1850
Capacitance	0.575 [kVA]

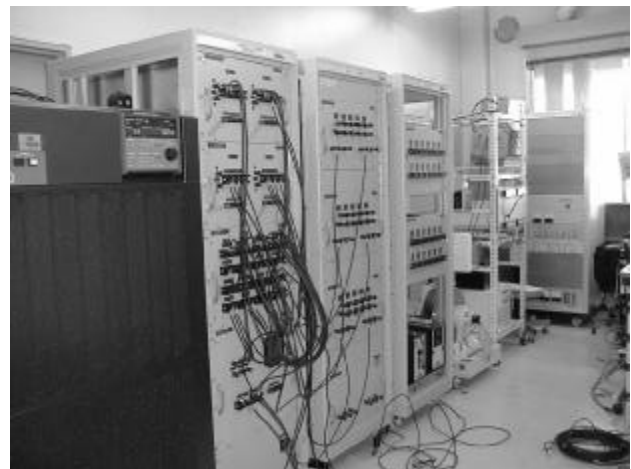


Figure 2 Picture of the installed experimental equipment.

Using this simulator partially, one or two inverters are able to be tested. This consists of an AC power source, a line impedance system unit, a residential power load unit, a PV array I-V curve simulator, and an inverter. The line impedance $0.15+j0.10\Omega$ which includes the impedance of a pole transformer, low-voltage distribution line (100m) and drop wire (20m). Figure 3 shows the composition of the experimental equipment in this test.

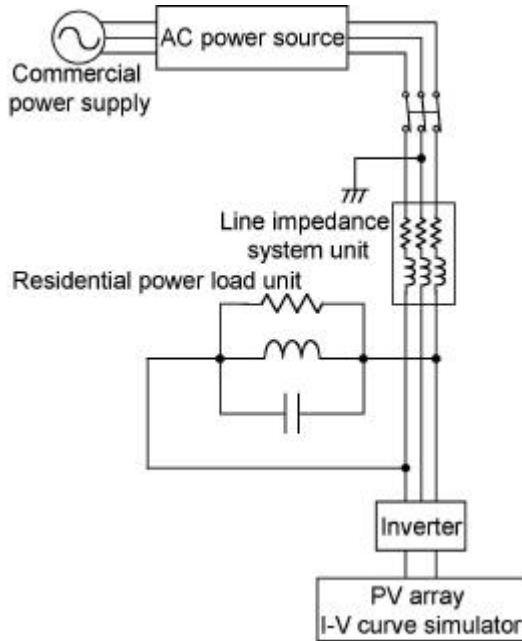


Figure 3 Composition of the experimental equipment for one or two PV inverters' connection.

EXPERIMENTAL RESULTS OF THE ISLANDING DETECTING FUNCTION

Experimental conditions

Using the designed simulator, grid-connected inverters were tested. Islanding detecting functions of commercial AC module inverters were tested under the following conditions.

- The resonant circuit is composed of resistor, inductor and capacitor as domestic power load.
- Domestic power load also includes rotating machine (induction motor).
- Active and reactive power are balanced among inverter output and load consumption.

Experimental results

Before the multiple connecting tests, an inverter was set and tested. In this test, European 230V-50Hz MICs

were tested because the 100W class MICs have not been for sale in Japan. Figure 4 shows the experimental results of islanding detection. After the power interruption, the inverter stopped within 0.2sec in strict condition. During the islanding operation, waveform of the inverter's output current was distorted. And waveform of the load voltage was also distorted. This phenomenon can be also detected by the third harmonic distortion rate of the load voltage. Consequently, it seemed that the inverter stopped since the frequency exceeded the operational frequency range.

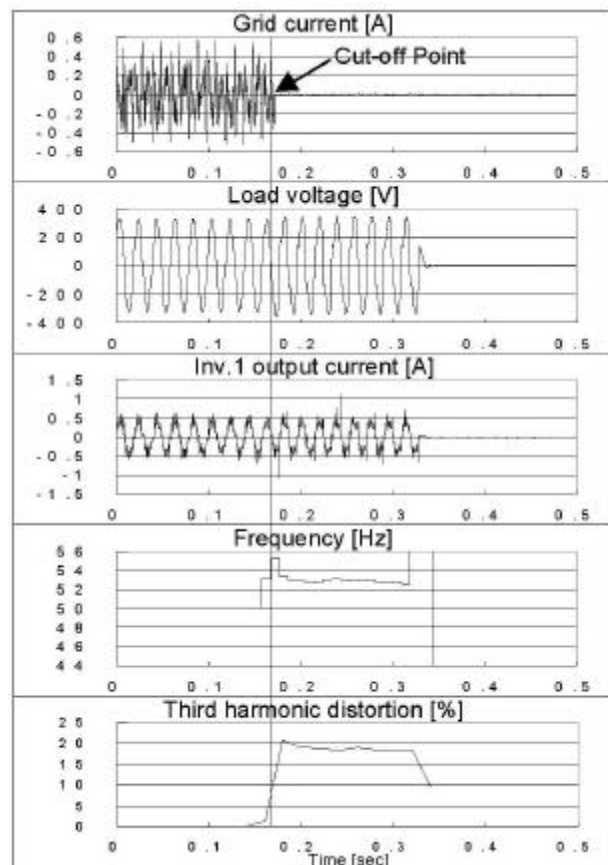


Figure 4 Experimental results of the islanding detecting function (single inverters).

Then, four inverters were connected together and tested under the same condition. Figure 5 shows the experimental results of islanding detections. After the power interruption, no inverters stopped. All the inverters continued operating continuously. The load voltage had been kept on 230V during islanding operation. Although sudden increase in the frequency at the cut-off point, inverters did not stop. After the sudden increase, the frequency fluctuated continuously between 49.8 and 50.2Hz. Third harmonic distortion also increased suddenly, however the distortion rate was lower as compared to that

of single inverter and the frequency did not exceed the operational frequency range.

From the above results, it was cleared that there is a possibility of islanding by interference phenomenon of islanding detecting function.

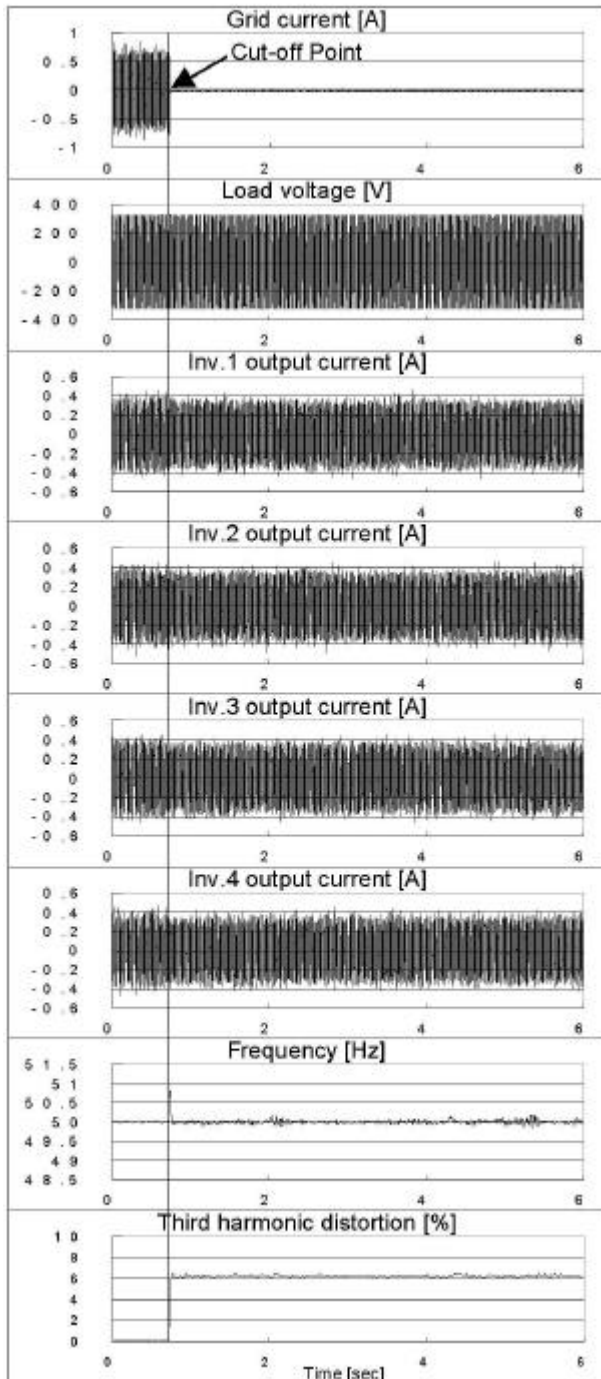


Figure 5 Experimental results of the islanding detecting function (four inverters).

CONCLUSION

This paper has been described the development of the scaled-down distribution network simulator and the experimental results about the interference phenomena among multiple MICs and its influence by their islanding detection.

The proposed simulator has some advantages compared with actual scale simulator. It can be applied for the performance tests with single inverter and interference test with multiple inverters.

European MICs were used for islanding detection tests in this simulator. The experimented results show that there is a possibility of islanding by interference phenomenon of islanding detecting function.

For the future, experiment of the whole distribution system is to be performed, and interference test among multiple inverters is also to be continued. Presently, a new AC module inverter is under development, the simulator is to be used for the test of our new MICs.

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