Development of ultra scaled-down network simulator for testing PV inverters

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ABSTRACT

This paper describes a new experiment equipment for PV inverters. It is composed of the ultra small scaled-down network simulator with electronic circuits and an active power interface (API). For the first step, a scaled-down low voltage distribution system of a single-phase two-wire type has been developed and tested. As results of experiments, fundamental operations of the proposed equipment have been verified.

Keyword

PV inverter, scaled-down network simulator, interconnection

1. Introduction

Recently, the number of grid-connected PV systems has been rapidly increasing. In order to connect PV systems to a gird, it is necessary to test the functions as a PV inverter, which are islanding protection, gird protection, circuit protection and so on. To test their functions directly, a distribution grid of actual scale or scaled-down network simulator such as the experimental equipments developed at our laboratory [1] which is composed of inductance, capacitance and resistance is needed. In the future, in addition to them, it has to be required to test such a system including a lot of PV inverters on their mutual interference of islanding detection or voltage arising. In order to test for them, the experimental equipments have to be expanded to connect many PV inverters. However, it is generally difficult to use them except some confined institutions because of the space and setup cost and to change the components following installation.

The purpose of this study is to develop a new scaled-down network simulator which has advantages in size and cost to be expanded. The authors have been developed a new equipment for testing PV inverters which is composed of ultra scaled-down network simulator with electronic circuits and an Active Power Interface (API) [2]. Using a special developed API, it is possible to connect actual PV inverters to electronic circuits directly.

This paper describes the scaled down distribution model in the proposed equipment. For the first step, the scaled-down low voltage distribution system of single-phase two-wire type has been developed and the fundamental operations has been tested.

2. Ultra scaled-down network simulator

2.1 Basic design

An ultra scaled-down network simulator composed of electronic circuits could be smaller, which would make it easy to expand one and to change the components. However, it was impossible to connect the PV inverters for grid connection and the electronic circuits because the output power level of the PV inverters is much different from the operating power level of the electronic circuits. It is possible to connect the PV inverters and the electronic circuits directly inserting an API, which is developed specially, between them.

A basic design of the proposed simulator is shown in Fig. 1. It consists of ultra scaled-down network simulator and an API. The most significant component in this proposal is the API, which makes it possible to be connected with actual size power sources such as PV inverters.

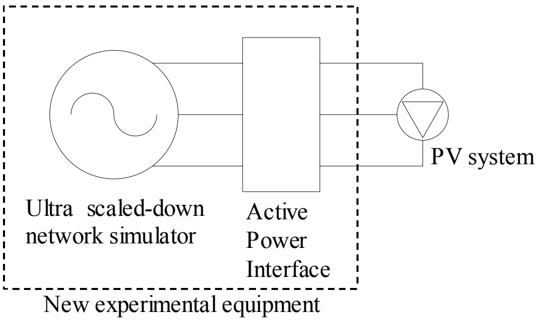


Fig. 1 Basic design of new type experimental equipment.

2.2 Composition of the proposed simulator

A scaled-down distribution network model of the proposed simulator is shown in Fig. 2. It is modeled on Japanese standard residential area [3]. High voltage distribution system is composed of 3,000kVA - 6,600V, three-phase three-wire type, and low voltage distribution systems are composed of 100/200V, single-phase, three-wire type. Low voltage distribution systems are connected into high-voltage distribution system through pole transformers of 20kVA. Imitated distribution system consists of the distribution transformer, the line impedance of high and low voltage distribution systems, a high voltage load, domestic loads in the low-voltage distribution system, and the pole transformers. Power capacitors to improve the phase factor are applied for adjustment of reactive power. Their components, especially inductances, consist of electronic circuits such as OP amp circuits. Actual PV inverters are connected through the API. They are supplied from a PV array simulator which imitates the characteristics of PV array [4]. There are to ways to connect a PV inverter and the API. Firstly, one PV inverter is connected to one API as shown at the division 7 when a PV inverter output power is the almost same as API capacity. Secondly, some PV inverters are connected to one API as shown at the division 6 when a PV inverter output power is much smaller than API capacity. Thus, how to connect PV inverter to API is decided by capacity of the API. It is difficult to connect a lot of PV inverters because of the space and cost for the purchase.

Thus, a lot of ideal current sources are connected instead of PV inverters. The high voltage load and domestic loads consist of LCR parallel circuits because the impedance of them is able to be changed variously from inductance to capacitance component.

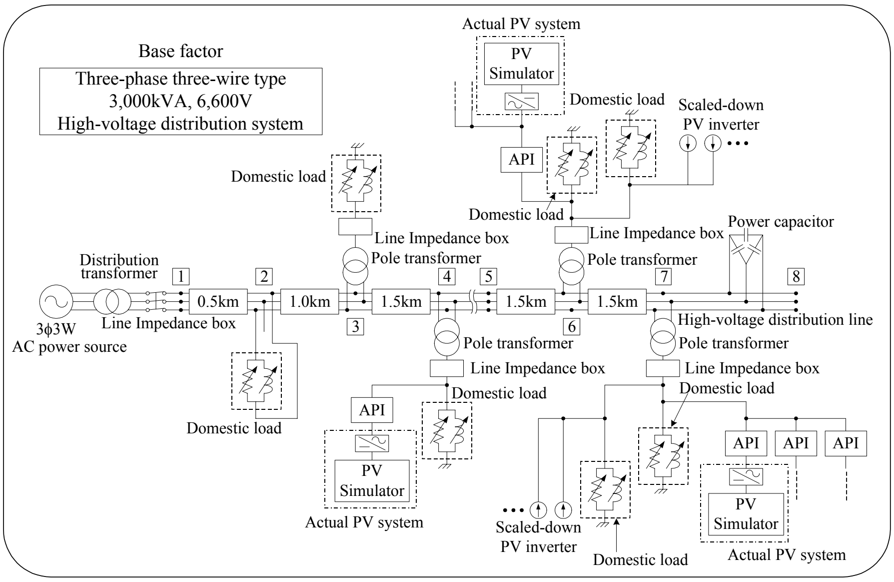


Fig. 2 Composition of the ultra scaled-down network simulator (residential area).

2.3 API

The block diagram of an API is shown in Fig. 3. It consists of two voltage sensors, two current sensors, two OP amps, two resistors, and two comparators composed of the OP amps. Currents, I_1 and I_2, are measured by the voltage drop over the resistances, R_1 and R_2.

A fundamental function of the API is to transfer electrical properties: voltage, V_1 and current, I_1 at a terminal1 are transferred to a teminal2 by multiplying factors of n and m respectively. At the same time, the voltage, V_2 and the current, I_2 at the teminal2 have to be transferred to the terminal1 by multiplying $1 / n$ and $1 / m$, vice versa.

The voltages and currents at both terminals are controlled as follows; the voltages are controlled by feed back loop1 composed of OP amp1 and comparator1. They are always kept as $V_2 / V_1 = n$. The currents are controlled by feed back loop2 composed of OP amp2 and comparator2. They are always kept as $I_2 / I_1 = m$.

2.4 Inductance composed of electronic circuits

It is difficult to make inductances in LCR because their characteristics are very complicated and they need a large space. Against these problems, inductance components are built as electronic circuits by using the Bergeron method [5]. Bergeron method is usually used transient state analysis. In order to clarify the inductance behavior, the elements are shown in Fig. 4. The Relation between V_1, V_2 and I_L is given by

$$V_1(t) - V_2(t) = L\frac{dI_L(t)}{dt} \qquad \cdots (1)$$

By using the integral trapezium formula, inductance current I_L is approximated as

$$I_L(t) = \frac{\Delta t}{2L}\{V_1(t) - V_2(t)\} + i_L(t - \Delta t) \qquad \cdots (2)$$

where Δt is the smallness sampling period and i_L is

$$i_L(t - \Delta t) = I_L(t - \Delta t) + \frac{\Delta t}{2L}\{V_1(t - \Delta t) - V_2(t - \Delta t)\}. \qquad \cdots (3)$$

From (2) and (3), equivalent circuit of the inductance is illustrated in Fig. 4(b). It is composed of a resistance and an ideal current source. The resistance R is

$$R = \frac{2L}{\Delta t}. \qquad \cdots (4)$$

By composing the ideal current source with electronic circuit, the inductance is configured.

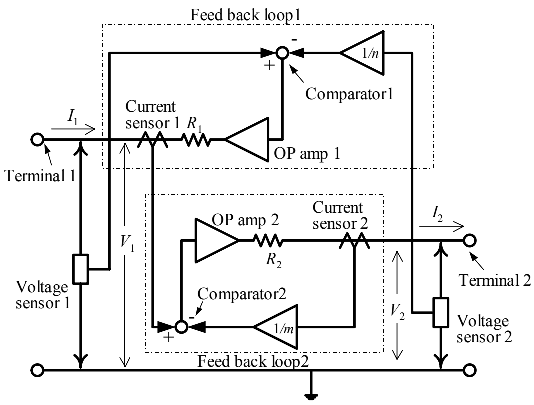


Fig. 3 Block diagram of API.

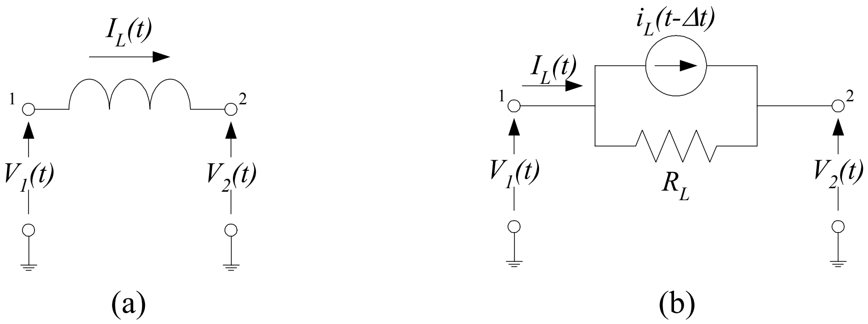


Fig. 4 (a) A inductance element; (b) an equivalent circuit of the inductance.

3. Experimental results to confirm fundamental operations

3.1 Experimental conditions

For the first step, part of low voltage distribution system shown at division 7 in Fig. 2 is developed. This system is composed of single-phase two-wire type as shown in Fig. 5. The capacity of the pole transformer is reduced from 20kVA to 10VA, and the voltage is reduced from 100/200V to 2/4V due to the API capacity and the voltage level of the electronic circuits. By using these scaling factors, the line impedance and the domestic load are transferred. The pole transformer is imitated with sine wave at 50Hz generated by a pulse generator. The line impedance, 0.150 + j0.100 [Ω], includes the pole transformer, the low voltage distribution line (100m), and the drop wire (20m). These components are transferred with the scaling factors using the p.u. method. As a result of calculations, it is converted to 0.13 + j0.08 [Ω]. The domestic load is connected to only resistance load which is about 165W. This component is converted to 82.5mW. The 100W class PV inverter such as MIC [6] which is developed in our laboratory is connected. It is operated by PV array simulator, which outputs 95W. API characteristics are determined as follows; the voltages, V_R and V_S, at both terminals are kept as $V_R / V_S = 50$, and the currents, I_R and I_S, are kept as $I_R / I_S = 40$. API capacity is 100W.

For verification of the API characteristics, the voltages and currents at both API terminals are measured against static state and the instant of power interruption. The phenomena on the ultra scaled-down network simulator with API are compared with that on the conventional scaled-down network simulator without API developed in our laboratory under the same condition.

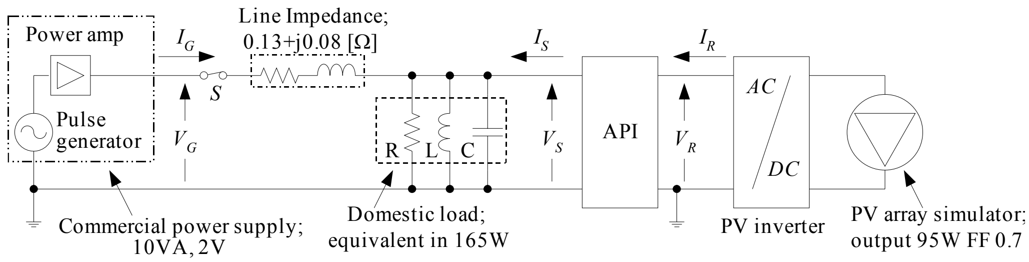


Fig. 5 An ultra scaled-down low voltage distribution system of single-phase two-wire type.

3.2 Experimental results

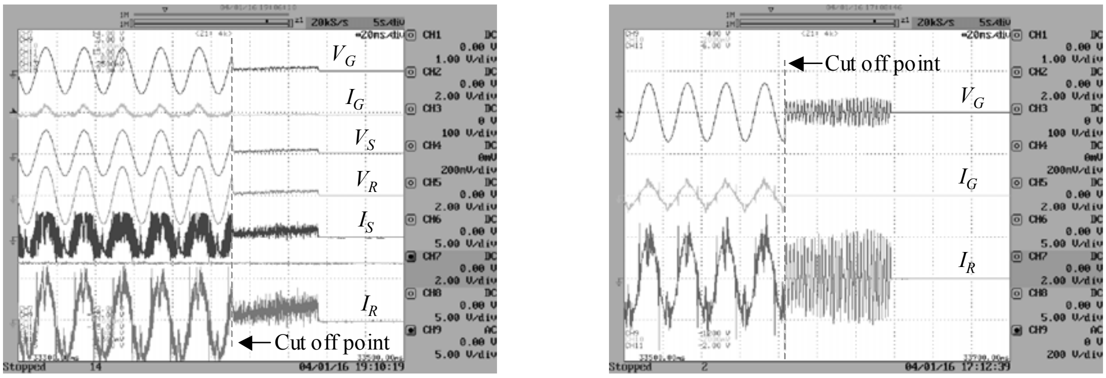
The experimental waveforms are shown in Fig. 6. As shown in Fig. 6 (a), PV inverter for grid connection can operate by using the ultra scaled-down network simulator. The voltages, V_R and V_S, are controlled in set point of the API against static state and the instant of power interruption. However, the currents can not be controlled in the set point of the API although I_S is similar to I_R in waveform. The cause of this result is that feed back loop gain is not large enough to control them because the API oscillates. It is possible to control the currents in set point when feed back loop gain can be larger.

As shown in Fig. 6 (a), (b), PV inverter can stops by the islanding detection within about 60ms in both cases when power interruption is imitated. Fig.6 (a) is similar to (b) in waveform after power interruption. Those results of experiments revealed qualitatively verification of fundamental operations of the proposed equipment.

4. **Conclusion**

This paper described a new experiment equipment for PV inverters. The scaled-down low voltage distribution system of single-phase two-wire type has been developed and tested. As results of the experiment, a PV inverter has been able to be connected to the distribution network simulator with electronic circuits in spite of difference power size each other. A PV inverter has stopped by islanding detection as well as the case without API when power interruption was imitated. By these results, fundamental operations of proposed equipment have been verified qualitatively.

For the future, this equipment is to be evaluated quantitatively.



(a) (b)

Fig. 6 Experimental results; (a) with API; (b) without API

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