Performance Assessment with Different Inductance Model
in the Ultra Scaled-Down Distribution Grid Simulator

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ABSTRACT: In order to connect PV system to the grid, it is necessary to test various functions of a PV inverter. Moreover in view of diffusion of PV systems, it has to be required to test a lot of PV inverters on their mutual interference of islanding detection or voltage arising. These tests require a huge experimental equipment and a facility, which are to be high cost. This paper presents a new experimental equipment for PV inverters. The proposed system is composed of the ultra scaled-down network simulator with electronic circuits. The cost and size can be reduced because the distribution line network is composed of electronic circuits. For the first step, a scaled-down low voltage distribution system of single-phase two-wire type has been improved and tested. This system is a part of scaled-down distribution grid simulator [1]. In this paper, the electronic inductance is improved, which leads to further reduction of cost and size.
Keywords: PV system, Interfaces, Grid-Connected

1. INTRODUCTION

Recently, the number of grid-connected PV systems has been rapidly increasing. In order to connect PV system to a grid, it is necessary to test the functions as a PV inverter, which is islanding protection, grid protection, circuit protection and so on. To test these functions directly, a distribution grid of actual scale or scaled-down network simulator is needed. In the future, it has to be required to test a lot of PV inverters on their mutual interference of islanding detection or voltage arising. In order to test for them, the experimental equipment has to be expanded to connect a lot of PV inverters; therefore it becomes large and expensive. Such as equipment is generally difficult to change its configuration because of the scale, space, and cost.

The purpose of this study is to develop a new scaled-down network simulator which has advantages in size and cost for expanding. In the previous study, 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], is proposed. That model includes resistance, capacitance and inductance composed with electronic circuit. Using the API, it is possible to connect actual PV inverters to electronic circuit directly. However API remains the problem which current can not be controlled. Against the problem, scaled-down PV simulator is connected to the ultra scaled-down network simulator.

In this paper, the authors focus on the inductance with electronic circuit. In our previous study, an ultra scaled-down network simulator used an electronic inductance with Bergeron method [3]. The inductance with Bergeron method was still large because it was composed of a lot of devices. On the other hand, equivalent inductance with Generalized Impedance Converter (GIC) circuit has a simple structure with a few parts. Therefore, by using GIC circuit the cost and size can be reduced.

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 have been tested. As a result the operation of inductance with GIC circuit is confirmed.

2. ULTRA SCALED-DOWN NETWORK SIMULATOR

2.1 Basic design

An ultra scaled-down network simulator is composed of electronic circuits. The advantage is the flexibility in the expanding and the replacement. In addition it makes the space and cost reduced. However, it was impossible to connect the actual PV inverters for grid connection and the electronic circuits. Because there is a serious difference in the power levels between PV inverters and electronic circuits. A solution is inserting API between a PV inverter and an ultra scaled-down network simulator.

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

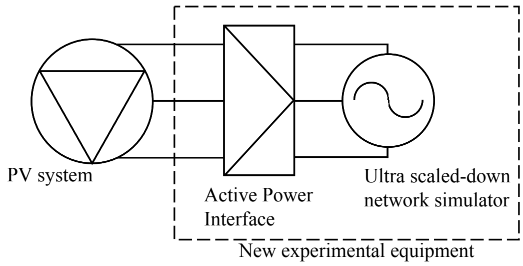


Fig.1.Composition of ultra scaled-down distribution grid simulator

2.2 Composition of the proposed simulator

A scald-down distribution network model simulator is shown in Fig.2 [3]. It is modeled on Japanese standard residential area [4]. High voltage distribution system is composed as 3000kVA-6600V, three-phase, three-wire type, and low voltage distribution system is 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 OPamp circuits. Actual PV inverters are connected through the API. They are supplied from a PV array simulator which performs various characteristics of PV array [5]. There are two ways to connect a PV inverter and the API. First, one PV inverter is connected to one API as shown at the division 7 when a PV inverter output power is the almost as API capacity. Secondly, some PV inverters are connected to one API as shown at the division 6 when PV inverter output power is much smaller than API capacity. Therefore, 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.

2.3 API

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

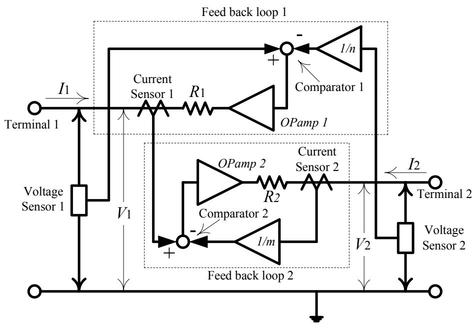


Fig.3 Composition of API

A fundamental function of the API is to transfer electrical properties: voltage, V_1 and current, I_1 at terminal 1 are transferred to a terminal 2 by multiplying factors of n and m respectively. At the same time, the voltage, V_2 and current, I_2 at terminal 2 have to be transferred to the terminal 1 by multiplying factors of $1/n$ and $1/m$, and vice versa.

The voltages and currents at both terminals are controlled as follows; the voltages are controlled by feed back loop 1 composed of OP amp 1 and comparator 1. They are always kept as V_2/V_1=n. The currents are controlled by feed back loop 2 composed of OPamp 2 and comparator 2. They are always kept as I_2/I_1=m.

2.4 Inductance composed of electronic circuit

It is difficult to make inductance in comparison with resistance and capacitance because their characteristics are very complicated. Against this problem, inductance components are built as electronic circuits by using the GIC circuit.

In order to build inductance with GIC circuit into simulator, one side grounding and floating inductance are needed. One side grounding inductance is used in domestic load impedance, floating inductance is used in line impedance.

2.4.1 One side grounding inductance

The circuit diagram of one side grounding inductance is shown in Fig.4. The relation between v and I is given by

$$v = L\frac{di}{dt}. \qquad \cdots (1)$$

Circuit diagram of one side grounding with GIC inductance is shown in Fig.5. Kirchhoff's current low is applied to node point, A and B

$$\frac{v_1 - v_2}{R_2} + \frac{v_1 - v_3}{R_3} = 0. \qquad \cdots (2)$$

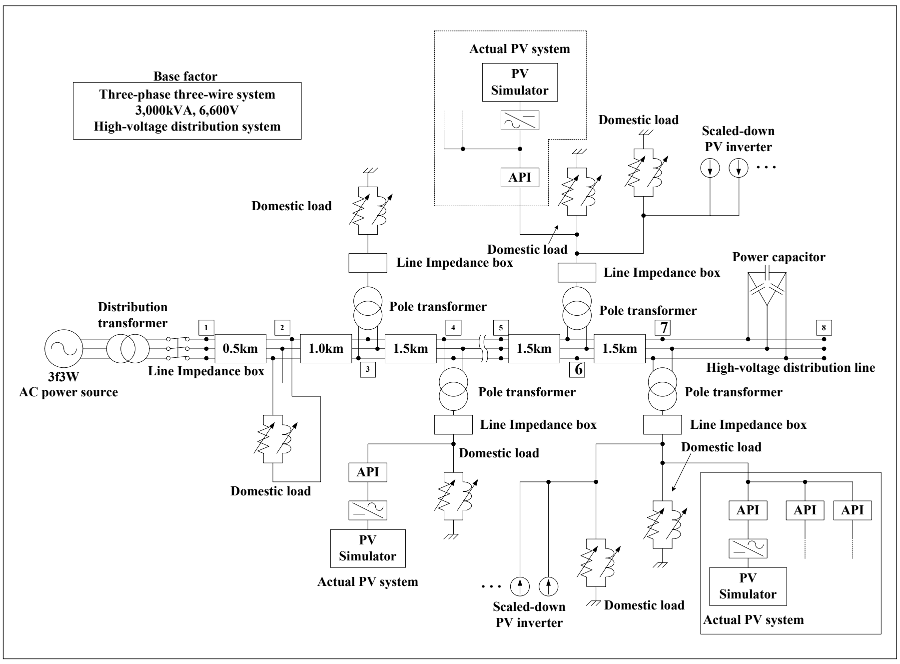


Fig.2 Composition of the ultra scaled-down network simulator

$$\frac{v_1}{R_5} + C_4 \frac{d(v_1 - v_3)}{dt} = 0 \,. \qquad \cdots (3)$$

By equations, (2) and (3)

$$v_1 = \frac{C_4 R_3 R_5}{R_2} \frac{d}{dt}(v_1 - v_2)$$

$$= \frac{C_4 R_1 R_3 R_5}{R_2} \frac{di}{dt} \,. \qquad \cdots (4)$$

To compare Equation, (4) to (1), Fig4 is an equivalent circuit with Fig.5. Therefore equivalent inductance with GIC circuit is give as

$$L = \frac{C_4 R_1 R_3 R_5}{R_2} \,. \qquad \cdots (5)$$

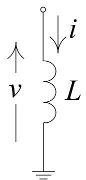


Fig.4 One side grounding inductance:

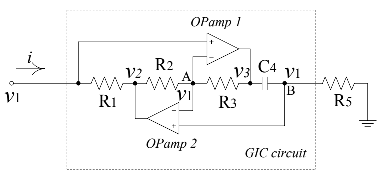


Fig.5 Circuit diagram

2.4.2. Floating inductance

At the floating inductance, each terminal voltage is optional and either terminal voltage is not connected to ground. The diagram of floating inductance is shown in Fig.6. The terminal 1 and 2 are floating, and the terminal 1' and 2' are connected to an earth ground. To imitate this circuit, it has to be satisfied following conditions, which are clarified Fig.7.

(1) In the case of short terminal 2-2', it consists $Z_{11'} = L$ ··· (6)

(2) In the case of short terminal 1-1', it consists $Z_{22'} = L$ ··· (7)

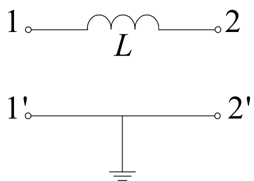


Fig.6 Floating inductance

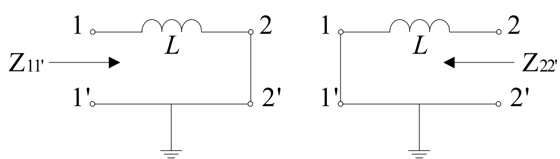


Fig.7 The impedance conditions

A circuit which is satisfied these parameter is shown in Fig.8, Fig.9. Conceptual diagram is shown in Fig.8, the circuit diagram is shown in Fig.9.

First, the input impedance which is shown in Fig.10, Fig.11 is confirmed. Conceptual diagram is shown in Fig.10. Terminal 1 is connected to terminal 2 actually because the potential difference of OPamp of input terminals equals to zero. Therefore, input impedance Z_{in} which is shown in Fig11 equals to zero. Then, the diagram shown in Fig.8 is confirmed. In the case of short terminal 2-2', it equals to short terminal 4-4'. This is the one side ground inductance. Input impedance $Z_{11'}$ is impedance of inductance, and it is satisfied condition (6). The same can be applied to the case of terminal 1-1' short, which satisfies condition (7). Therefore the Fig.9 equals to Fig.6.

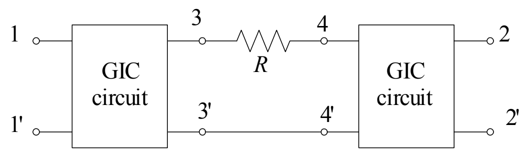


Fig.8 Conceptual diagram

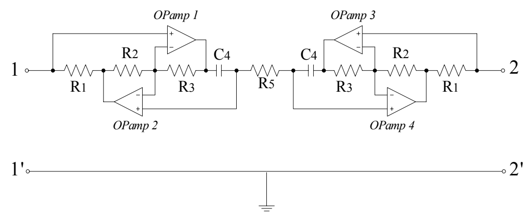


Fig.9 Circuit diagram

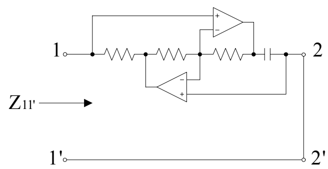


Fig.10 Conceptual diagram

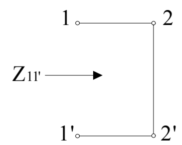


Fig.11 equivalent circuit

3. EXPERIMENT RESULTS TO CONFIRM FUNDAMENTAL OPRATIONS

3.1 Experimental condition

For the first step, part of the low voltage distribution system shown at division 7 in Fig.2 was developed. This system is composed of single-phase two-wire type as shown in Fig.12. The capacity of pole transformer is reduced from 20kVA to 20VA, and voltage is reduced from 100/200V to 5/10V due to the voltage level of the electronic circuit. 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 0.372+j0.228[Ω]. The domestic load is connected to a resistance which is equivalent to 380W, and an inductance is connected in parallel, which is 432mH. The inductance is decided on the phase factor 0.9. The resistance of domestic load converted to 380mW, the inductance converted to 184 mbar. It is connected to an inverter which is 0.3W as a scaled-down inverter.

For verification of the inductance with GIC circuit, currents flowing the line impedance i_L and domestic load i_d are measured. These currents are compared to simulation results with MATLAB/Simulink.

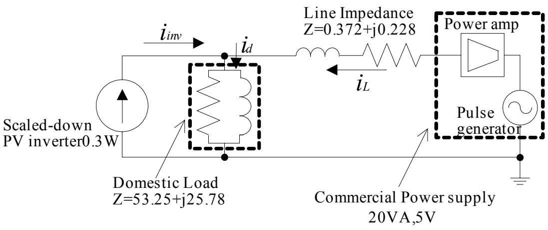
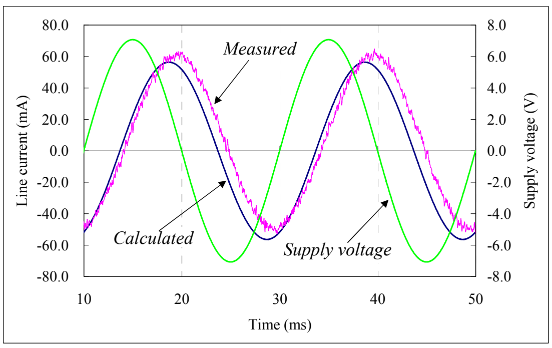


Fig.12 An ultra scaled-down low voltage distribution system of single-phase two-wire type

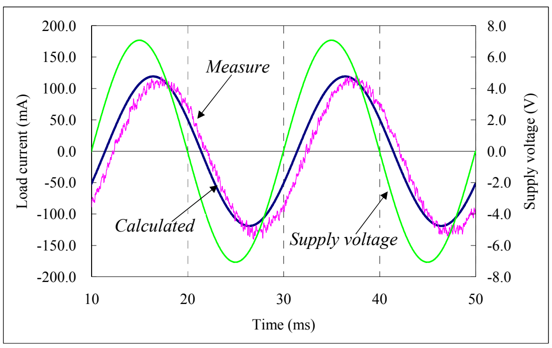
3.2 Experimental results

The experimental waveforms which are compared to simulation results are shown in Fig.13. The current flowing line impedance i_L is shown in Fig.13 (a) and the current flowing domestic load i_d is shown in Fig.13 (b). The current flowing line impedance i_L is lager phase about 1 msec than calculated. However the amplitude is agreed in calculated. On the other hand, the current flowing domestic load i_d is lager phase about 0.7msec than calculated. And the amplitude is agreed with the calculated.

As shown in Fig.13 (a), (b), the waveforms of measured tend to be lager than calculated in the phase. The lagging-phase is caused by error of inductance value. However the amplitude agrees in the calculated. The offset which observed in measured waves forms are measurement error.



(a)



(b)

Fig.13 Observed and calculated wave forms; (a) i_L; (b) i_d

4. Conclusion

A new experiment equipment for PV inverters has been introduced. The low voltage distribution system of single-phase two-wire type has been improved and tested. The inductance model of line impedance and domestic load impedance are improved. As the result of the tests, the inductance with GIC circuit is performs as an inductance. Fundamental operations of proposed equipment which is composed of inductance with GIC circuit have been evaluated quantitatively. By changing inductance models the proposed equipment can be reduced in cost and size compared to the previous one.

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