18th International Conference on Renewable Energies and Power Quality (ICREPQ'20)
Granada (Spain), 1st to 2nd April 2020
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.18, June 2020

Transient Analysis of Power System with All Inverter Power Sources

Mamoru Kato[1], Hiroki Nakamura[1], Masakazu Kato[1], Junichi Arai[2]

1 Tokyo Denki University, 5, Senju-Asahi-Cho, Adachi-Ku, Tokyo, Japan, 120-8551(Japan)

2 Kogakuin University, 1-24-2, Nishi-Shinjuku, Shinjuku-Ku, Tokyo, Japan, 163-8677(Japan)

Abstract. In relatively small islands, diesel generators are the main power source, but in the near future, a large amount of renewable energy sources which are interconnected via inverter are expected to be introduced in terms of cost. The problem is that power supply via inverter, which is called as 'inverter power sources' in the paper, does not have synchronizimg power and inertia like conventional synchronous generators. So there is no force to restore the system state against disturbances. A system model composed of all inverter power sources has been created. With this model, analyzed is the continuity of operation of the inverter power supply when loads change or system faults occur. The goal of this study is to evaluate feasibility of a system with all inverter power sources.

Key words. Inverter power source, Photovoltaic, Wind power, Battery, Transient analysis

1. Introduction

In small islands, diesel power generators are the main power source. Its generation cost is very expensive because of expensive heavy oil cost for diesel generators, transporting cost, and so on. Therefore, there is a demerit that the unit cost of power generation is high in remote islands. Renewable energy source (RES) including wind power and photovoltaic is rather expensive power generation method compared to the conventional power generation. Even with this disadvantage, it can be said that RES introduction is relatively highly effective for small islands [1]. The introduction of RES to remote island power systems can be expected to reduce generation costs, and it is expected to be the main stream in the future.

The problem is that inverter power sources such as photovoltaic (PV), wind power (WP), and batteries do not have the synchronization power and inertia unlike conventional synchronous generators. There is no power to restore the state of the system against disturbances.

In this study, we have created a power system model with all inverter power sources, assuming a small island system, and analysed its operation continuity when loads change or system faults occur.

Also, in systems where a large amount of RES has been introduced, multiple batteries are often used. Each battery SOC (State of Charge) may vary. When sharing the load among the batteries, it is necessary to distribute each output, depending on its SOC. Cooperative control method to share the load between batteries is proposed and analysed its operation of the inverter power source.

The goal of this study is to evaluate the feasibility of a system with all inverter power sources.

2. Target system

A target system is a small power system for islands. The system model is composed of three types of inverter power sources: WP, PV, and battery. Table 1 summarizes an overview of the system model, and Fig. 1 shows system model (1). In addition, system model (2) composed of two types of inverter power sources: PV and two batteries is also used for simulating output sharing between two batteries (Fig. 2). Inverter of Battery 1 is treated as a master one, and inverter of Battery 2 as a slave one.

2.1. PV model

Normally, the PV system is subjected to MPPT (Maximum Power Point Tracking) control so that the maximum power is output from the power conditioner (inverter). The control system employs active power control and reactive power control. Fig. 3 shows the PV inverter configuration. Fig. 4 shows a PV inverter control block.

2.2. Battery model

Since photovoltaic power generation and wind power generation are power generation methods relying on natural energy, the output basically fluctuates, and there is a possibility that the supply and demand balance will be disrupted. By using a battery, it is possible to compensate for excess or deficiency of the supply power in the system. Therefore, batteries need to be able to charge/ discharge active power and reactive power according to the state of the system. Since the frequency and voltage must always maintain within the permissible range, their control systems are necessary. Inverter of a battery applies frequency control and AC voltage control so as to maintain a constant frequency and constant voltage. Fig. 5 shows the battery inverter configuration. Fig. 6 shows the battery inverter control block.

2.3. WP model

WP has various interconnection methods with power systems, and each has its advantage and disadvantage. Onshore wind power generally employs gear type interconnection because it is inexpensive and has a simple structure. Although gear type interconnection have the disadvantage of being prone to malfunctions near gears, the cost is not very high on land because maintenance staff can easily access the generator. However, in a remote island targeted in this study, as with offshore wind, access to generators is likely to be not easy and labor costs will increase. Gearless type direct drive system, is equipped with no gear that is likely to cause a problem, and maintenance costs can be reduced even in a remote island. This interconnection method is the most likely to be introduced in the future, considering the cost for islands. As described before, the simulation model of the wind power generation system is performed by connecting a synchronous generator, a converter, and an inverter in series. In the model in this study, generating electricity is converted to DC by a converter, and then converted to AC at power frequency by an inverter and connected to the grid. For this reason, it is necessary to use control to keep the DC voltage constant so as not to fluctuate. The control method used is not the active power control and the reactive power control, but the DC voltage control and the reactive power control. Fig. 7 shows the WP inverter configuration. Fig. 8 shows the WP inverter control block.

2.4. Overcurrent suppression control

Each inverter has an overcurrent suppression control that suppresses the inverter voltage when an overcurrent is detected. After the overcurrent clears, that is to say, after the fault clears, the output of the inverter is returned to its original state. If a start-up performes instantaneously, there is a possibility that saturation current of a transformer will flow. The inverter voltage increases linearly to 1 pu in T_0 ms after the fault clears. Fig. 9 shows an overcurrent suppression signal control model. Fig. 10 shows its control block.

Table 1 System model 1 overview

System frequency	60 Hz
PV output	50 kW(const.)
WP output	50 kW(const.)

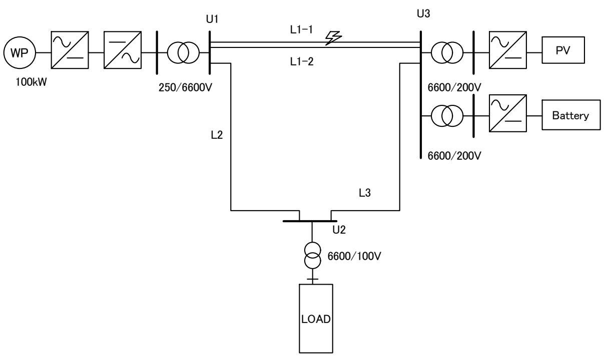

Fig. 1 System model (1)

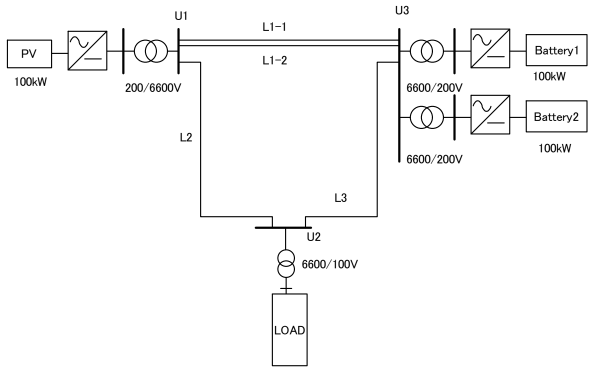

Fig. 2 System model (2)

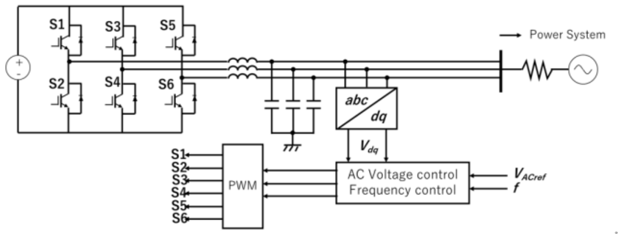

Fig. 3 PV inverter configuration

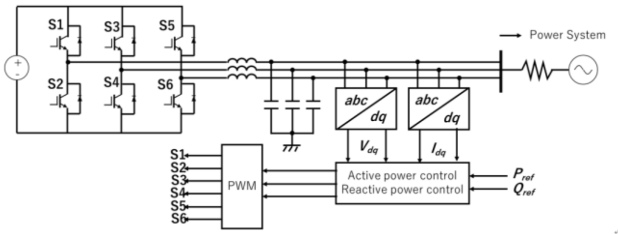

Fig. 5 Battery inverter configuration

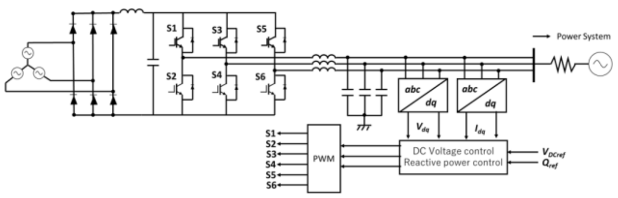

Fig. 7 WP inverter configuration

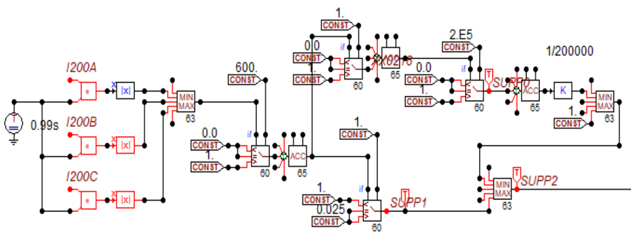

Fig. 9 Overcurrent suppression control model

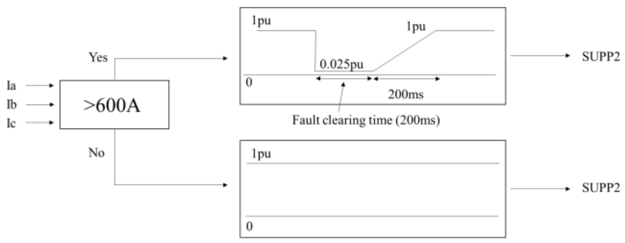

Fig. 10 Overcurrent suppression control block

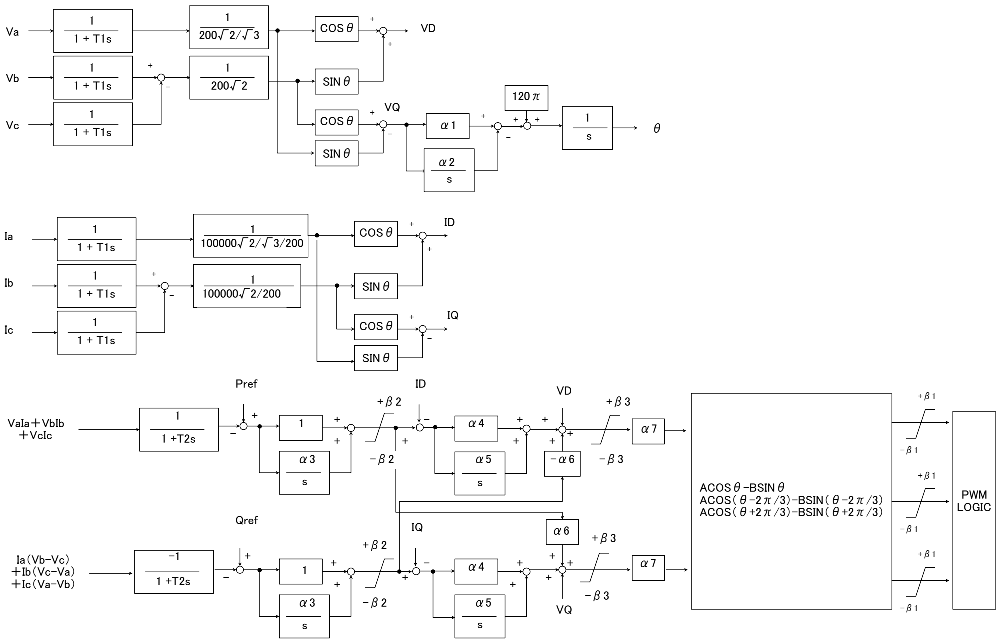

Fig. 4 PV inverter control block

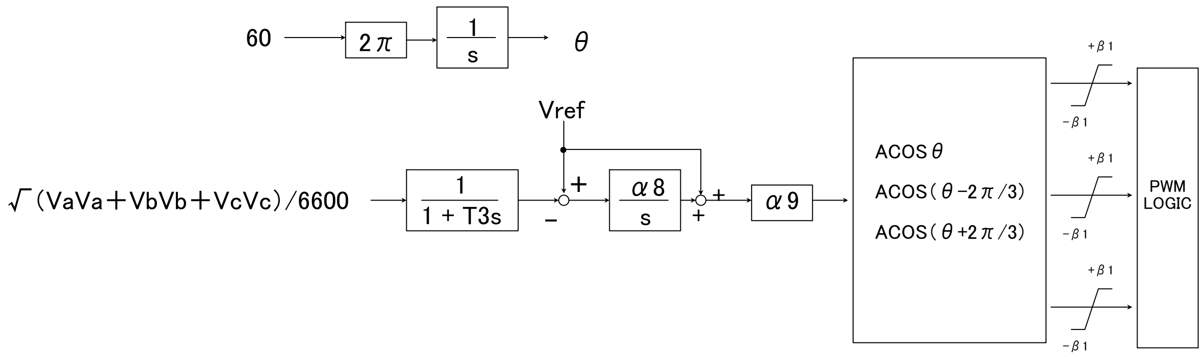

Fig. 6 PV inverter control block

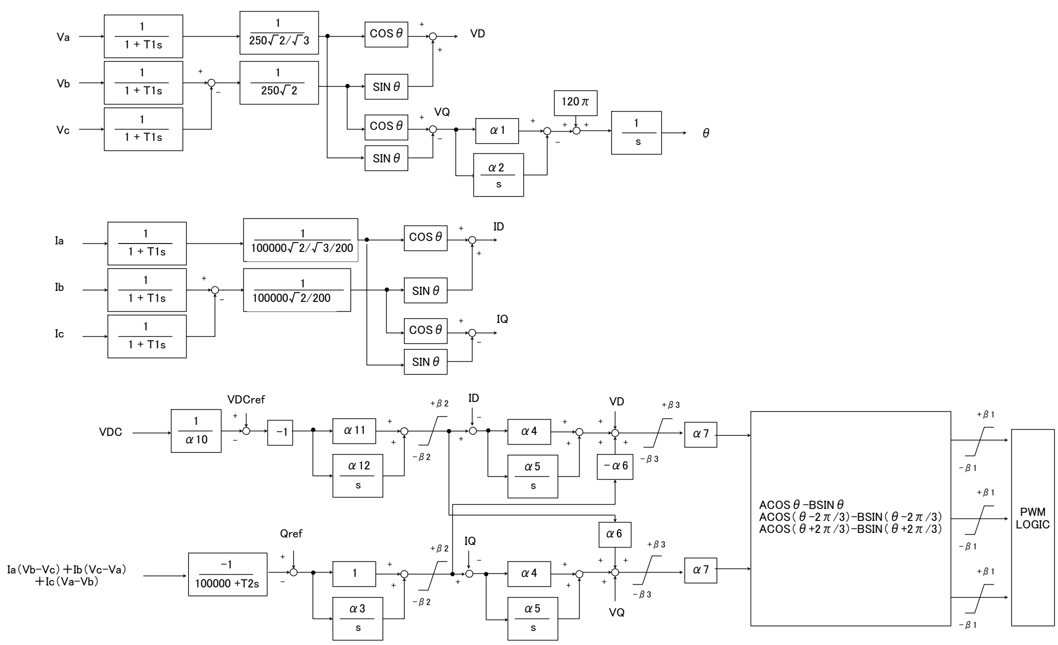

Fig. 8 WP inverter control block

3. Constant load simulation

3.1. Simulation conditions

Load is simulated by resistance, and the load is constant at 150 kW.

3.2. Simulation results

PV output, WP output, and battery output are shown in Fig. 11, and the system voltage at U3 is shown in Fig. 12. In Fig. 11, PV and WP output 50kW of active power according to the designated value respectively, and the remaining 50kW is output by the battery. Also, it can be confirmed in Fig. 12 that the system voltage is kept constant and stable.

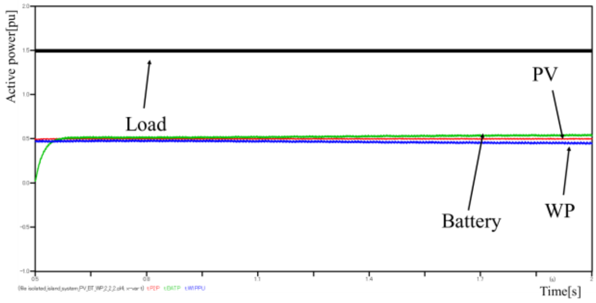

Fig. 11 Active power

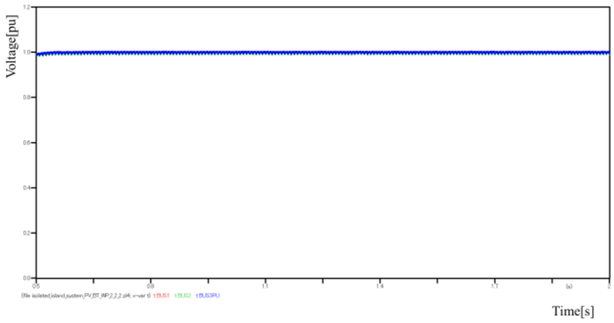

Fig.12 System voltage (U3)

4. Load change simulation (one battery)

4.1. Simulation conditions

In the system model (1) shown in Fig. 1, load is simulated by resistance, and load change is simulated by changing its resistance in steps of 200 kW, 50 kW, 200 kW. PV output and WP output remains 50kW, 50kW, respectively. Battery output changes according to the load change.

4.2. Simulation results

PV output, WP output, and battery output are shown in Fig. 13, and the system voltage at U3 is shown in Fig. 14. In Fig. 13, PV output and WP output remain 50kW and battery is charging/discharging according to the load change. In Fig. 14, the system voltage is stable. It can be said that the inverter power source can continue stable operation against load change. As for the overcurrent suppression control, since the output current of the inverter does not exceed 600 A from Fig. 15, as seen in Fig. 16, the voltage signal remains constant at 1 pu. It is proved that the inverter power source can continue stable operation against load fluctuations.

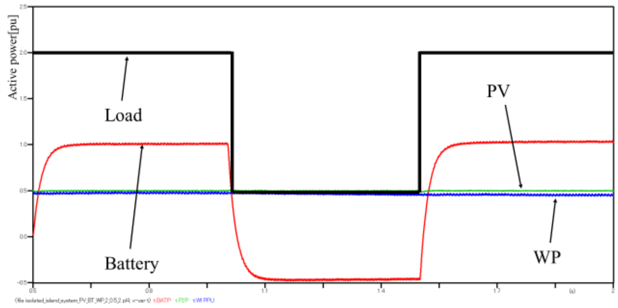

Fig. 13 Active power

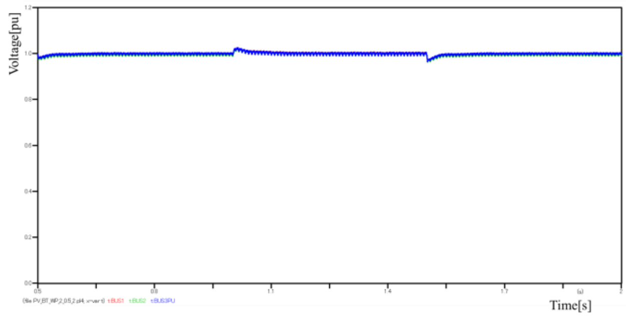

Fig. 14 System voltage (U3)

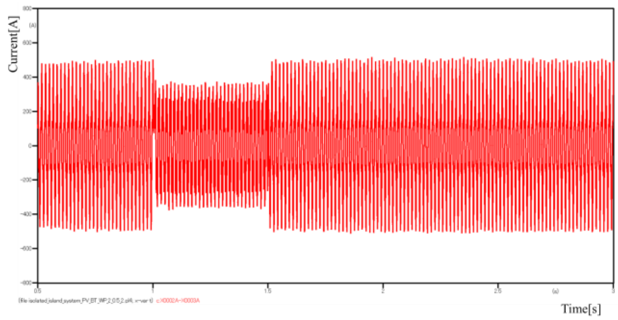

Fig. 15 Battery output current

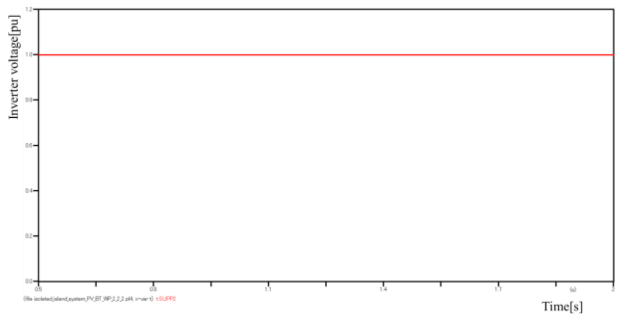

Fig. 16 Overcurrent suppression signal

5. Load change simulation (two batteries)

5.1. Simulation conditions

In the system model (2) shown in Fig. 2, the load is simulated by changing its resistance from 100 kW to 150 kW in 1.0 seconds. Fig. 17 shows the drooping characteristics of the master and the slave inverter to share two batteries output used in this study. When the active power output of the master inverter changes, its frequency changes by -4 %/pu. The slave inverter detects a frequency change and changes its active power by 4 %/pu. In this way, the load is shared. In this simulation, Battery 1 output increases by 25 kW when the load changes, and Battery 2 outputs the remaining load. PV output is maintained at 50 kW.

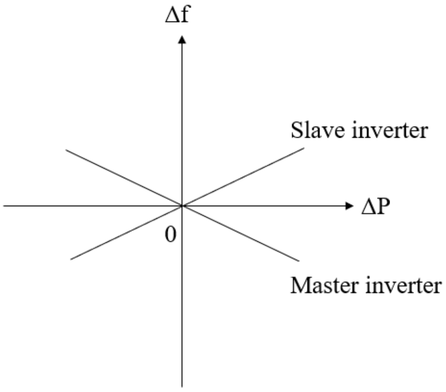

Fig. 17 drooping characteristics

5.2. Simulation results

PV and each battery output are shown in Fig. 18, and the system voltage at U3 is shown in Fig. 19. In Fig. 18, the PV output remains 50 kW and the battery outputs change according to the load change. At first, Battery 1 is discharging 50 kW. After load change, Battery 1 increases its output by 25 kW, and its frequency is reduced according to the drooping characteristics shown in Fig. 17. Battery 2 outputs the remaining load. The system voltage is stable as seen in Fig. 19. From Fig. 20, the system frequency starts to fall at 1 second when the load changes. According to this frequency change in Fig. 20. Battery 2 outputs with the drooping characteristics. As seen in Fig. 18, Battery 2 output increases with some delay just after Battery 1 output change. The frequency has not returned to its original value. This is because the Battery 1 outputs 25 kW, whereas the Battery 2 output is a little less than 75 kW. This frequency error is unavoidable because load sharing between batteries depends on the drooping characteristics. It is necessary to restore the frequency to the original value.

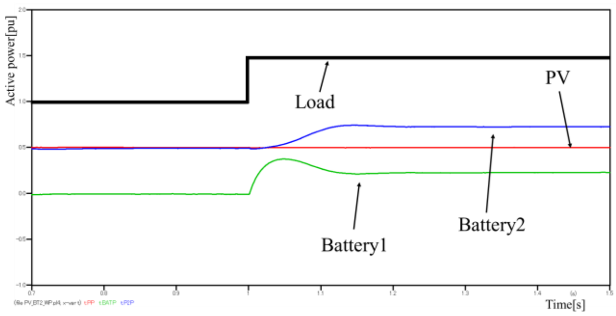

Fig. 18 Active power

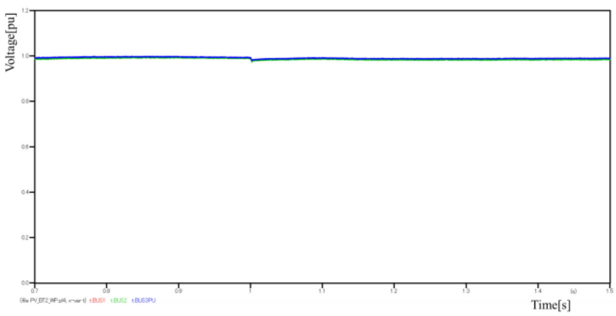

Fig. 19 System voltage (U3)

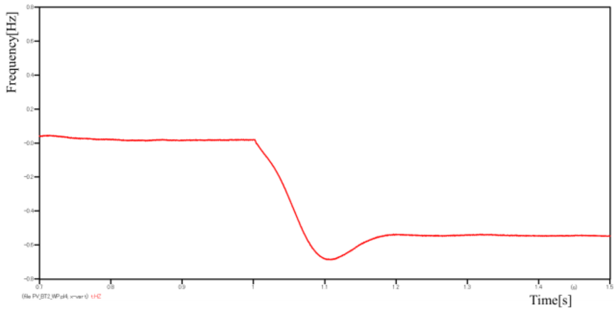

Fig. 20 System frequency

6. Fault simulation

6.1. Simulation conditions

System fault is the most severe three-phase ground fault at L1-1 in Fig. 1. Fault is cleared in 200 ms after fault.

6.2. Simulation results

System voltage at U3 is shown in Fig. 21, and battery output current is shown in Fig. 22. From these, it can be seen that overvoltage and overcurrent occur due to the fault. In order to continue the inverter power supply, the control shown in Fig. 9 is applied to suppress the current without blocking the inverter. It reduces the AC voltage generated by the inverter. The output suppression duration time is 200 ms which means fault clearing time. After fault clearing, the inverter restores the output voltage. Fig. 23, Fig. 24, and Fig. 25 show the voltage signal for suppressing overcurrent, the system voltage, and the inverter output current, respectively. The voltage signal for suppressing the overcurrent approaches nearly zero immediately after the fault. After another T_0 ms, it restores to the normal voltage linearly. From Fig. 24 and Fig. 25, it can be confirmed that the output current of the inverter is suppressed immediately after the fault, and that it has recovered stably after fault clearing. It is necessary to take measures against temporal overcurrent just after the fault seen in Fig. 25.

In addition, arresters may be necessary against temporal overvoltage seen in Fig. 24.

Fig. 26 shows that the system frequency is changed by about 1 Hz after fault, but return to the 60 Hz after fault clearing. From the above results, the inverter power sources can continue to operate against the most severe three-phase ground fault.

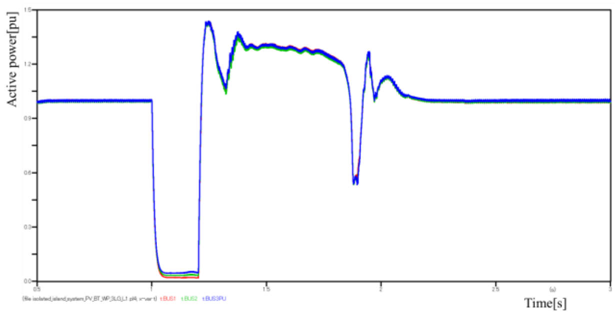

Fig. 21 System voltage (U3)

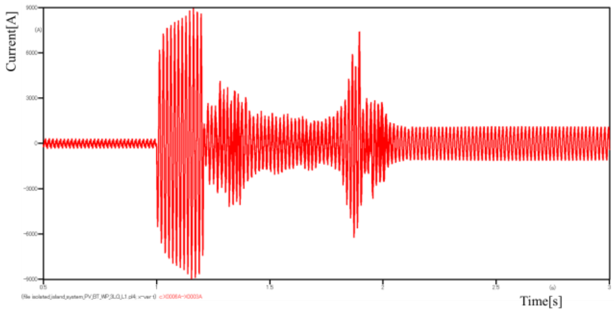

Fig. 22 Battery output current

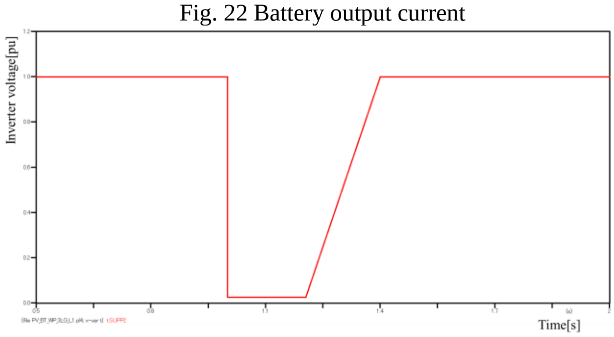

Fig. 23 Overcurrent suppression signal

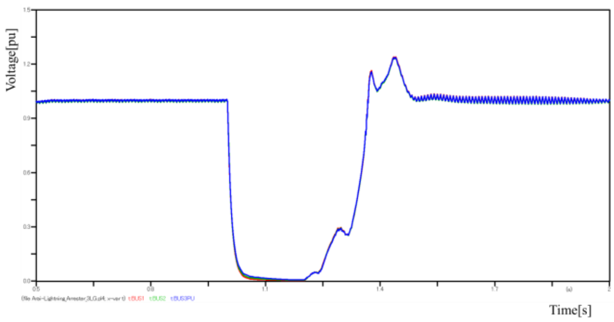

Fig. 24 System voltage (U3)

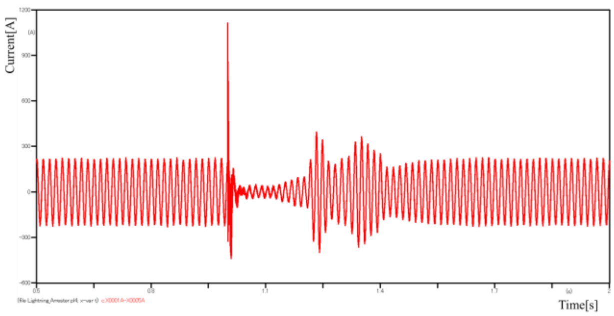

Fig. 25 Battery output current

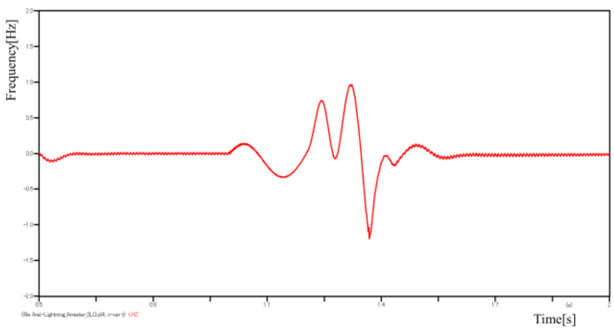

Fig. 26 System frequency

7. Conclusion

In a small-scale power system like a remote island, an all-inverter power supply system is one of promising solutions. Transient analysis of the power system with all inverter power sources has been performed when a load change or a three-phase ground fault occurs. It has become clear that the inverter power supply can continue to operate stably against above disturbances.

Future tasks will require analysis of existing various type of inverters for more realistic simulations.

References

(1) http://www.env.go.jp/nature/biodic/ecdisso2014/pdf/subcommittee2/simabukuro.pdf (in Japanese)

(2) Amir Parham, Ali Yazdian: "EMTP Model of Inverter", ICEE2014, May 20-22, 2014

(3) S. Naoi, J. Arai, Y. Noro: "Control for Inverter Power Sources in a Standalone Microgrid (in Japanese)", IEEJ Transactions on Power and Energy Vol. 137 No. 6 pp. 426-433, 2016