Stability and EMI Evaluation of Power Grid System Using Inverter-Based Resources for Expansion of Distributed Renewable Energy

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論 文 名　：Stability and EMI Evaluation of Power Grid System Using Inverter-Based Resources for Expansion of Distributed Renewable Energy
（分散型再生可能エネルギーの拡大に対するインバータベースドリソースを用いた電力システムの安定性と EMI 評価に関する研究）

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論 文 内 容 の 要 旨

Against a background of concerns about global climate change due to CO2 emissions and fossil fuel resource depletion, distributed renewable energy power generation systems, such as solar power generation and wind power generation, have been developed in recent years.

In the power grid, the stability of the power system has been provided by the large inertial force of synchronous generators such as thermal power generation and hydroelectric power generation. Distributed power sources such as solar power, wind power, and battery energy storage system (BESS) are called IBR (Inverter-Based Resources) because they are connected to the power system via an inverter. Currently, most IBRs are connected to a commercial system via a GFL (Grid Following) inverter, but since the GFL inverter normally operates under constant output control, it cannot absorb the disturbance generated in the commercial system. Therefore, if the share of distributed renewable energy increases and the ratio of GFL inverters increases in the future, the inertial force of the power system may become insufficient and unstable. Recently, a self-sustaining and distributed energy system is strongly expected to be built. The energy system with a so-called black start function that can restore the power system without receiving power supply from the outside not only in remote areas and remote islands but also in the event of a widespread power outage due to a disaster.

A GFM (Grid Forming) inverter with a VSG (Virtual Synchronous Generator) function has been proposed to improve the stability of power systems that utilize IBR. Since the GFM inverter operates as a voltage source for the grid, it has a black start function even in the event of a grid power failure. The VSG function imitates the inertial characteristics of a synchronous generator and has external characteristics of active power-frequency control and reactive power-voltage control. Even if a large amount of IBR is introduced, the VSG function and GFM function can absorb the disturbance of the power system, so that the power system can be stabilized and can be operated independently.

Another issue related to the expansion of distributed renewable energy is the problem of electromagnetic interference (EMI). With the miniaturization and decentralization of IBR using renewable energy, the distance from broadcasting and communication equipment will be shorter than the large-capacity power supplies that have been installed in wide restricted areas, and there is concern about the occurrence of EMI. On the other hand, in order to comply with the EMI standard, the cost for evaluation and reduction against electromagnetic interference increases. In addition, excessive EMI reduction methods have the problem of increasing IBR energy loss.

In this thesis, we will discuss two major issues with the expansion of renewable energy distributed power sources. One is the system stability utilizing inverter-based distributed power sources. The other is the coexistence of distributed power sources and broadcasting communications.

The remainder of this thesis is organized as follows.

In Chapter 1, the importance of expansion of renewable energy sources is explained for reducing CO2 emissions, and the major issues due to inverter-based sources expansion are pointed out. The purpose of this research is clarified.

In Chapter 2, the basics of GFL inverter, GFM inverter and VSG which belongs to IBR were described. the control methods of the VSG domestic and foreign studies are reviewed, and the differences are organized. A GFM inverter with the battery energy storage system (BESS) with VSG applied that called GFM-BESS has been proposed, and its operating principle will be explained.

In Chapter 3, the operating characteristics of GFM-BESS were analyzed and evaluated under parallel conditions with different operating modes of synchronous generators. The existing literature mainly introduces various virtual synchronization control methods and their implementation methods, but there is no literature that demonstrates synchronization force and inertial force by operating in parallel with a synchronous generator having an internal combustion engine. In order to put GFM-BESS to practical use, it is necessary to appropriately evaluate the effect of the introduction of GFM-BESS on the grid in a microgrid that operates in parallel with a synchronous generator having an internal combustion engine. This study proposes a method for evaluating the effect of GFM-BESS on the system of a configuration from a synchronous generator with an internal combustion engine. We built an off-the-grid environment that operates in parallel with a diesel synchronous generator with an internal combustion engine and GFM-BESS. When the load in the off-grid was changed, the load sharing characteristics based on the frequency droop characteristics (droop control) of the GFM-BESS and the synchronous generator and the stability of the off-grid system frequency were evaluated. In addition, when the control of the diesel synchronous generator was switched between droop control and isochronous control and operated in parallel with GFM-BESS, the effect of inertial control of GFM-BESS was confirmed.

In Chapter 4, As a method for quantitatively measuring and evaluating the inertial force of GFM-BESS, we proposed a method for evaluating an actual machine that operates in parallel with a synchronous generator. A microgrid of the same scale as the microgrid "Mutsuzawa Smart Wellness Town" in Mutsuzawa Town, Chiba Prefecture has been constructed, and the combined IBR ratio of GFM-BESS and GFL-BESS has reached 44.4%. The test conditions were determined with reference to the data of the power demand, solar radiation intensity, and PV module temperature of the Mutsuzawa microgrid that is actually in operation. The load fluctuated, the ratio of GFM inverter and GFL inverter was changed for 5 BESS, and the frequency stability, load sharing, and synchronization power were verified on the actual machine. It was demonstrated that the introduction of GFM-BESS suppresses the decrease in system frequency from 2.4Hz (50.0Hz to 47.6Hz) to 0.6Hz (50.0Hz to 49.4Hz) when the load fluctuation is 50kW by 70%.

In Chapter 5, GFM-PV was evaluated, which is a GFM inverter with imitated inertia characteristics applied to photovoltaic power generation. We constructed a microgrid in which GFM-PV and a synchronous generator operate in parallel, and conducted a load sudden change test. It was demonstrated that GFM inverter control suppresses the decrease in system frequency from 1Hz (50.0Hz to 49.0Hz) to 0.7Hz (50.0Hz to 49.3Hz) by about 30% when the load fluctuation is 20kW. For GFM-PV, it is possible to contribute to frequency stability by providing inertial force only by updating the control software without adding an energy buffer to supply inertial force.

In Chapter 6, the electromagnetic interference of GFM-BESS was measured and reduction methods were taken. Conducted electromagnetic interference reduction methods have improved electromagnetic interference to meet CISPR 11 class A, which is intended for use in industrial environments. In addition, we analyzed the EMI generation mechanism of a general inverter, evaluated the EMI reduction effect by equilibrating the circuit in comparison with the reduction effect by the conventional noise filter, and confirmed the reduction effect by up to 20 dB.

In Chapter 7, in GFM-BESS, the effect of the inductance of the line filter and EMI filter on the transient load sharing of GFM-BESS will be evaluated. Since the synchronization force in GFM-BESS changes depending on the inductance value of the internal filter, the mounting status of the EMI filter and the synchronization force are related. Therefore, the relationship between the synchronization force and the EMI filter will be examined. A method of predicting the overload sharing immediately after the load fluctuation is presented by the synchronization force. Two microgrids consisting of a synchronous generator and GFM-BESS were evaluated by simulation and demonstration experiments.

In Chapter 8, this research is summarized and the remaining issues and future efforts are described.