

Research on Reduction of Harmonic Distortion of Inverter for Small Gas Engine Cogeneration System with Backup Function

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ABSTRACT

Research has been conducted to use an interconnection inverter for a stand-alone generator with an aim to provide a small gas engine cogeneration system with a backup function to serve as an emergency power generator in case of blackout. When a diode rectifier with a large capacitor (hereinafter referred to as a rectifier load) is connected to the interconnection inverter during backup operation, harmonic distortion of the output voltage becomes larger, and in some cases, resulting in miss operation of connected equipment.

In order to address this issue, types of connected loads were estimated by focusing on the crest factor of the inverter output current. The crest factor is the value in which the maximum current value is divided by the actual current value. When deterioration is identified in the output voltage harmonic distortion caused by rectifier loads, processes were conducted for dynamically varying the output current feedback relative to the normal set value and for approximating the output voltage to a sine wave by the output voltage feedback. By these methods, the total harmonic distortion of the output voltage at the rating during backup operation with a rectifier load was reduced by 4.7 points.

As a result, an inverter was realized which is capable of high-quality power supply even during backup operation without degrading the inverter performance in grid connection.

INTRODUCTION

With growing concerns on global warming in recent years, reduction of CO₂ emissions has become a critical issue for automobile and other industries. In the field where the usage of products is not limited to mobility applications, a small gas engine cogeneration system that generates electricity from primary energy sources such as natural and LP gases and utilizes the collected exhaust heat has been put into practical use from the viewpoint of the high-efficiency use of energy and reduction of CO₂ emissions in households ⁽¹⁾ ⁽²⁾. The small gas engine cogeneration system generates electricity synchronized with the utility grid through the inverter and supplies the electricity to household electrical equipment. It must be noted that the equipment should not be negatively affected during this operation ⁽³⁾. As for the interconnection inverter, attention should be paid to the harmonics of the output current in order to maintain high electricity quality. This is because the output current is controlled by regulating the inverter output voltage based on the grid voltage. Each country has imposed restrictions on the harmonics of the output current by issuing regulations including IEC61000-3-2 ⁽⁴⁾, IEEE1547 ⁽⁵⁾ and UL1741 ⁽⁶⁾ in the United States, and JEAC9701 ⁽⁷⁾ in Japan.

Meanwhile, there have recently been a series of massive blackouts as seen in the United States that has repeatedly been hit by hurricanes. Our modern life highly depends on electricity in pursuit of high efficiency and convenience. Stoppage of electricity supply caused by power failure may directly lead to degradation in convenience and, in some cases, to a matter of life and

death. Accordingly, demand for home emergency generators has increased. For generators, the quality of electricity also needs to be ensured in order to protect connected electrical equipment. For interconnection inverters, the current harmonics have been regulated, and for stand-alone generators, the voltage harmonics have been regulated by the above-mentioned UL1741, and UL2200⁽⁸⁾ in the United States. This is because generators have no grid voltage to be based on for controlling the output current, and only control the output voltage. In UL1741, for example, the total harmonic distortion of the output voltage shall not exceed 30 %. The total harmonic distortion is the ratio of the root-mean-square (rms) of the harmonic content to the rms value of the fundamental quantity, expressed as a percentage. And the rms voltage in any single harmonic shall not exceed 15% of the nominal fundamental rms output voltage rating.

As for technologies to control harmonics, there have been various study reports as follows: a method to control the harmonic current by detecting distortion components of the output current relative to the interconnection inverter and then controlling output waveforms so that only the detected distortion components will be cancelled⁽⁹⁾; a controlling method using an active filter relative to harmonic distortion of the power distribution system⁽¹⁰⁾. However, these study reports specialized in interconnection technologies and had no reference to technologies to control harmonics in the interconnection inverter equipped with a backup function.

In this report, research was conducted to use an interconnection inverter for a stand-alone generator with an aim to provide a small gas engine cogeneration system with a backup function to serve as an emergency power generator in case of blackout. This study also identified loads that deteriorate electricity quality when an interconnection inverter was used for a stand-alone generator, and consequently proposed methods to address the issue.

1. INVERTER CONFIGURATION AND REQUIREMENTS

1.1 Inverter configuration

Figure 1 shows a block diagram of the configuration of the interconnection inverter with a backup function examined in this report. The configuration is as follows: an alternator, which converts the engine power into the electricity power; a rectifier, which converts AC into DC; a DC-DC converter, which boosts the DC voltage; a FET bridge, which converts DC voltage into rectangular voltage by carrying out pulse width modulation; an LC filter, which converts a rectangular voltage into a sine-wave voltage; a connection relay, which establishes the utility grid connection/disconnection; and a noise filter,

which reduces the noise. When a blackout occurs, the engine is started with electricity supplied from external power sources such as batteries.

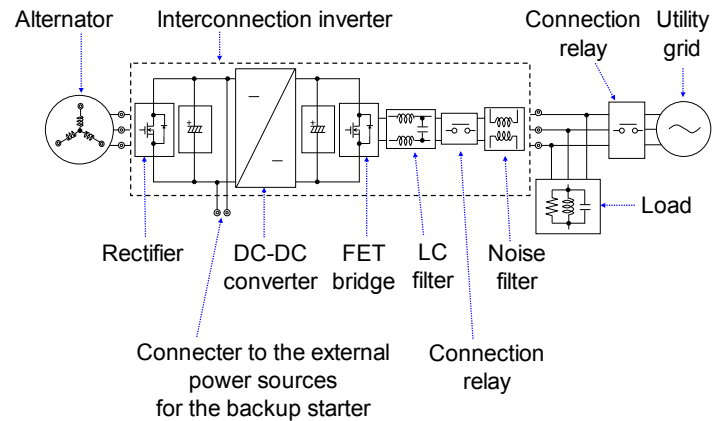


Fig.1 Interconnection inverter with backup function

1.2 Difference between inverters during interconnection and backup operation

During interconnection, a rectangular voltage which is generated in the FET bridge is output through the LC filter as a sine wave at the same voltage, frequency and phase as in the utility grid. Under these conditions, the inverter is connected to the utility grid, and the magnitude of the output current is controlled by the inverter output voltage. By appropriately setting constants of the LC filter, the output current can be generated as a sine wave that is synchronized with the utility grid voltage. As shown in Figure 2, frequency components higher than the cutoff frequency of f_c can be reduced in the LC filter. The f_c is represented as Equation (1). By setting the f_c at the lowest possible frequency without affecting the output frequency which is equal to the utility grid frequency (60Hz), harmonics in the inverter output can be reduced efficiently.

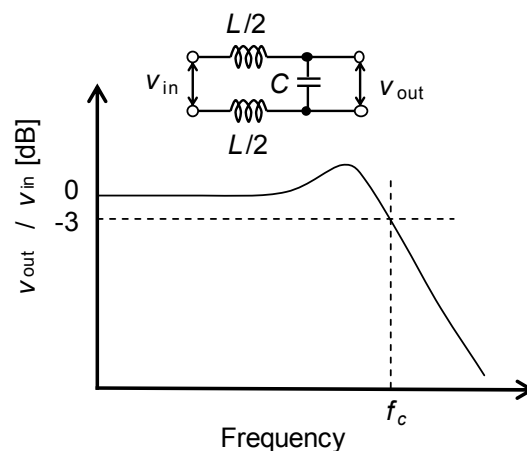


Fig.2 LC filter characteristic

$$f_c = 1/2\pi\sqrt{LC} \quad (1)$$

When Capacitance C in the LC filter is increased, the reactive current flowing through the C increases. In order to maintain a high power factor, it is necessary to cancel the reactive current, and accordingly, it is desirable to keep the C as small as possible. For that reason, in the interconnection inverter, Capacitance C is designed to be minimized while Inductance L is designed to be maximized. When the C is small, quick adaptation to load fluctuations becomes difficult, but this poses no problem because the shortage of electric power is compensated by power supply from the utility grid source during interconnection.

During backup operation, the interconnection inverter operates for the stand-alone generator. The rectangular voltage generated in the FET bridge is output through the LC filter as a sine-wave voltage, in the same manner as conducted during interconnection. However, because there is no grid voltage to be based on during backup operation, the output current cannot be controlled and therefore becomes dependent on connected loads. For the same reason as for during interconnection, it is desirable for Capacitance C in the LC filter to be small in some ways. However, in order to serve for the stand-alone generator, it is necessary to quickly adapt to load fluctuations, and the value of Capacitance C needs to be appropriately large enough to correspond to the output power of the generator and estimated loads.

Figure 3 shows the areas of constants for the LC filter during interconnection and backup operations. Constants for the LC filter vary depending on whether it is interconnection or backup operation. When using the interconnection inverter for the stand-alone generator, it is not designed for the best values of Capacitance C and Inductance L in the LC filter to be used for backup operation. As a result, when rapidly-changing loads were connected, the voltage harmonics are expected to deteriorate.

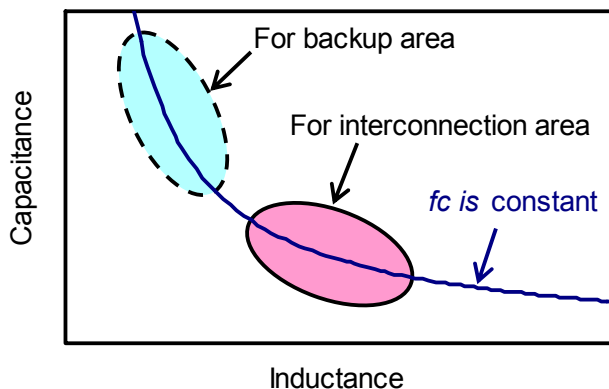


Fig.3 Constant areas of LC filter

2. TECHNOLOGY TO REDUCE THE VOLTAGE HARMONICS

2.1 Measurement of the voltage harmonic distortion during backup operation

The interconnection inverter was operated for a stand-alone generator under the best constants in the LC filter for interconnection, so that the harmonic current distortion during interconnection should not deteriorate. Figure 4 shows measured results of the total harmonic distortion of the output voltage at the rating with Resistance (R), Inductance (L), Capacitance (C) and rectifier loads respectively applied. When the total harmonic distortion is compared with regard to the R, L, C and rectifier loads, the distortion with rectifier loads was large, which was 13.9%. Figure 5 shows measured results of the voltage harmonic distortion components with a rectifier load at the rating. From the results, it is found that harmonic distortion was larger in odd-order components, especially in the 3rd, 5th, 11th and 13th components.

The target value of the harmonic distortion of the output voltage at the rating is set below 10% on the assumption of using precision equipment such as personal computers as loads.

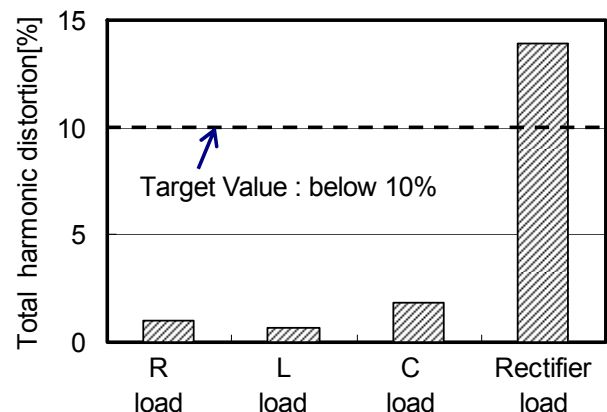


Fig.4 Output voltage total harmonic distortion

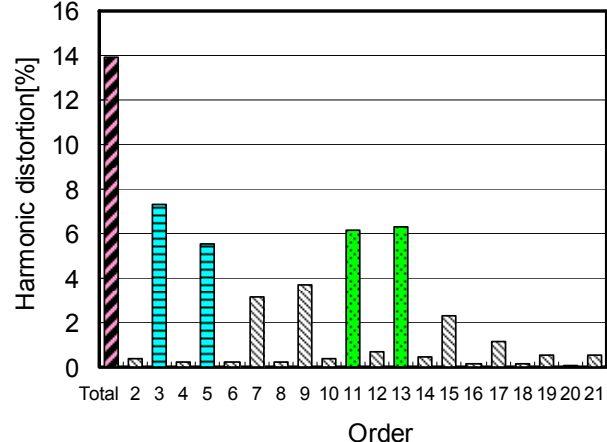


Fig.5 Output voltage harmonic distortion with rectifier load