Instantaneous Voltage Drop of Converter using a Special Winding Structure Transformer

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***Abstract*— In this study, an AC-DC converter is proposed to convert the 3-phase alternating current (AC) voltage provided by the grid into a 12-phase voltage using a 12-phase transformer with a special winding structure through which a Direct Current (DC) voltage is obtained by full-wave rectification. Therefore, there are concerns about the effects of certain phenomena, such as instantaneous voltage drops, voltage fluctuations, power failures, and missing phase, which occur in AC systems on the DC load side. Thus, in this study, we investigate the effect of an instantaneous voltage drop in the primary side 3-phase AC voltage of the proposed transformer on the DC voltage supplied to the load, as well as its effect on the DC load.**

Keywords—special winding structure transformer, instantaneous voltage drop, dc power supply.

I. INTRODUCTION

In recent years, the movement toward decarbonization as a countermeasure against global warming has gained momentum worldwide [1]. About 90% of Japan's greenhouse gas emissions are carbon dioxide, with approximately 40% of carbon dioxide emissions coming from the power sector and the remaining 60% from non-power sectors such as industry, transportation, and households use [2]. To achieve decarbonization, it is essential to reduce carbon dioxide emissions in each sector In the electric power sector, the aim of transforming primary power generation equipment to the use of renewable energy sources in order to reduce carbon dioxide emissions is being achieved. The primary power generation technologies that use renewable energy sources are solar, wind, hydroelectric, and geothermal power. In Japan, among the power generation devices that use renewable energy, photovoltaic power generation devices are the most widespread because they are not as limited in terms of installation location [3]. Photovoltaic (PV) power generation equipment generates direct current electricity from sunlight. Therefore, because the current grid power is AC, the generated power must be converted to AC power using a power conditioner, resulting in a conversion losses. Thus, in recent years, there has been focus on DC power feeding systems that are highly compatible with power generation systems based on renewable energy sources [4]-[9]. In a DC power supply system, AC power from the grid is converted to DC power in batches using an AC-DC converter, and DC power is supplied to each device by creating a DC bus. Therefore, by connecting a PV device to a DC bus, the generated power can be effectively used without converting it to AC. Based on the above, the authors believe that DC power supply systems will become more widespread in the future and will focus on AC/DC converters for connection to commercial grids.

AC-DC converters are broadly classified as transformer and switching types. In this study, we focused on the transformer type because it has no switching noise and can easily achieve a high withstand voltage. The authors have studied and proposed a transformer with a special winding structure that minimizes the increase in secondary-side windings during multi-phase and reduces costs. In addition, a transformer-type AC/DC converter was examined using a transformer with the special winding structure [10],[11]. The proposed AC/DC converter circuit using the transformer with special winding structure is shown in Fig. 1. In transformer-type AC/DC converters, when problems such as instantaneous voltage drops, voltage fluctuations, power failures, and missing phases occur in the AC system, there have been concerns about the effects on the DC load side. Therefore, this study examines the changes in DC voltage supplied to the load and their effects when an instantaneous voltage drop occurs in the primary side three-phase AC voltage of a transformer with a special winding structure used for AC-DC conversion.

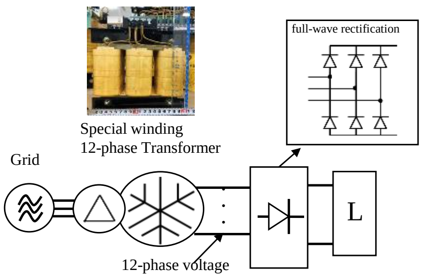

Figure 1. Proposed AC-DC converter structure

II. INSTANTANEOUS VOLTAGE DROP PHENOMENON

The instantaneous voltage drop phenomenon is a phenomenon in which the voltage drops instantaneously, as shown in Fig. 2. Normally, when a fault occurs on a transmission line, it takes from several tens of milliseconds to 2 s for the protective relay to detect the fault and release the circuit breakers at both ends of the transmission line. Therefore, the voltage drops around the fault point during the period until the circuit breakers remove the fault point, resulting in an instantaneous voltage drop phenomenon.

Instantaneous voltage drops may cause equipment utilized by consumers to shut down, and it is necessary to implement countermeasures using capacitors and storage batteries at consumers that require high-quality power [12],[13].

III. Materials and Methods

A. Special winding structure transformer

Fig. 3 shows wiring diagrams of a 12-phase transformer with special winding structures. Fig. 4 shows how the line voltage of a 12-phase transformer with a special winding structure was obtained. In this study, the secondary-side wiring of the transformer, as shown in Fig. 3, is called a special winding structure. The method of obtaining the line-to-line voltage in a transformer with a special winding structure differs from that of a conventional transformer. In a 12-phase transformer with a special winding structure, line-to-line voltages were obtained with respect to R1, S1, and T1, as shown in Fig. 4. As an example, the line-to-line voltages based on R1 are obtained as R1-S1, R1-S4, R1-R2, and R1-T3. When a 12-phase transformer is fabricated using the conventional method, four connections are required on the secondary side to obtain a line-to-line voltage of 12 phases with a phase difference of 15°. However, the special winding structure transformer obtains line-to-line voltage based on R1, S1, and T1; therefore only one secondary-side connection is required, which is advantageous in terms of cost. In the transformer with a special winding structure, the phase voltage values of the R2, S2, T2, R3, S3, T3, R4, S4, and T4 connections are reduced because the line voltage is obtained with reference to R1, S1, and T1, thus reducing the number of turns of the secondary side connections. In this study, it was been confirmed that the number of turns per transformer leg can be reduced by 22.39% by applying a special winding structure to a 6-phase transformer, and by 32.78% by applying a special winding structure to a 12-phase transformer.

B. Instantaneous voltage drop phenomenon in the proposed AC/DC converter

A three-phase AC voltage from the grid was applied to the primary side of the proposed AC-DC converter. The three-phase AC voltage from the grid was converted to a12-phase AC voltage using a 12-phase transformer with a special winding structure, and the 12-phase AC voltage is converted to a DC voltage by rectifying it with a full-wave rectifier circuit. Therefore, when an instantaneous voltage drop occurs in the grid voltage, the DC voltage output of the AC-DC converter may be affected. Therefore, this study examines the effects on the DC side and the effects on DC devices when an instantaneous voltage drop occurs in the primary side three-phase AC voltage of an AC-DC converter.

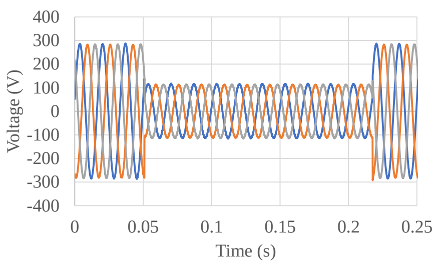

Figure 2. Instantaneous voltage drop phenomenon.

C. Experimental Methodology

The experimental circuit used in this study is shown in Fig. 5. The specifications of the transformer with the special winding structure used are a rated power of 700 VA, primary line-to-line rated voltage of 200 V, secondary line-to-line voltage of 200 V, primary side Δ-connection, and secondary-side special winding connection. In the experiment, a 100 Ω 1000 W enameled resistor and DC-powered LCD TV were used as the loads. Measurements were performed using a three-phase AC power supply to generate an instantaneous AC voltage drop on the primary side of the transformer; subsequently, the DC voltage and current after the rectifier circuit were measured. For the LCD TV, we visually confirmed the operation of the equipment when an instantaneous voltage drop occurred.

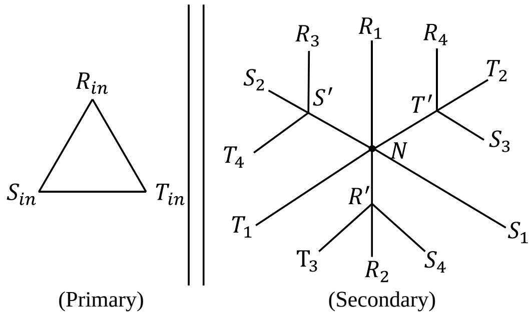

Figure 3. Wiring diagrams of 12-phase transformer with special winding structures.

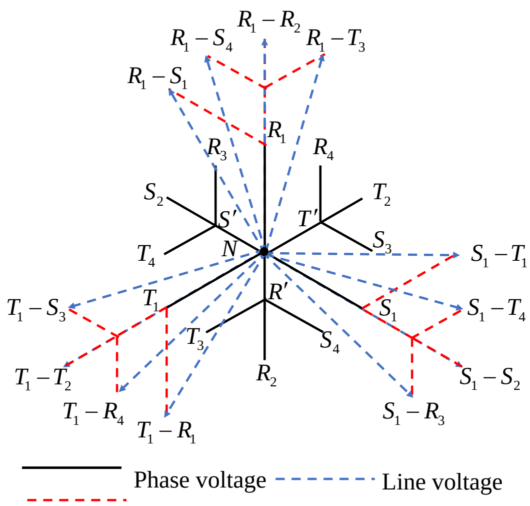

Figure 4. Method used to obtain line-to-line voltage.

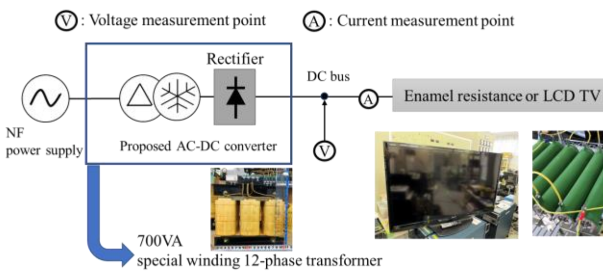

Figure 5. Experiment circuit.

IV. RESULT AND DISCUSSION

A. Measured results under enamel resistance load

Fig. 6 shows the 12-phase voltage on the secondary side of a 12-phase transformer with a special winding structure when instantaneous low voltage occurs. Fig. 7 shows the output voltage after rectification. From the experiment, it was found that when an instantaneous voltage drop occurs in the primary three-phase AC voltage of the proposed AC/DC converter, the secondary 12-phase voltage decrease, and the DC voltage after rectification decrease accordingly. The rate of decrease in the output voltage after rectification depends on the rate of decrease in the primary three-phase AC voltage.

Fig. 8 shows the change in the DC voltage after rectification with respect to the rate of decrease of the input voltage. The measurement results indicate that the output voltage after rectification decreased as the input voltage decreased. In this study circuit, no capacitor is connected beyond the output voltage after rectification, so the secondary side voltage of the 12-phase transformer with a special winding structure decrease as the input voltage drops. Then, the reduced 12-phase AC voltage is full-wave rectified and voltage is applied to the load as is; therefore, the lower the input voltage, the lower the output voltage after rectification. Fig. 9 also shows the change in output voltage after rectification when the instantaneous voltage drop duration is varied at a constant input voltage drop rate. The measurement results showed that when the drop rate of the input voltage was constant, the output voltage after rectification had an almost constant value regardless of the duration of the instantaneous voltage drop, and the rate of decrease of the output voltage after rectification did not change with the duration of the instantaneous voltage drop.

B. Measured results under LCD TV load

Table 1 lists the operating characteristics of the LCD TV when an instantaneous voltage drop occurs in the primary three-phase voltage of the proposed AC/DC converter. The △ in Table 1 indicates that the screen flickered momentarily during the instantaneous voltage drop, and the ▲ indicates that only the screen was off, and only the audio was operational during the instantaneous voltage drop. In addition, ● indicates that an error occurred on the LCD TV during the instantaneous voltage drop and that it was not restored within 10 s, while ○ indicates that the screen and sound were turned off during the instantaneous voltage drop and that the operation was restored after 10 s without user intervention. The measurement results show that the behavior of the LCD TVs used in this experiment during instantaneous voltage drops changes for an instantaneous voltage drop duration of around 200 ms.

To examine the factors affecting the operation of the LCD TV, Fig. 10 shows a comparison of the output voltage waveforms after rectification when the instantaneous voltage drop duration was 200 ms and the AC voltage drop rate was 40%, and when the instantaneous voltage drop duration was 80 ms and the AC voltage drop rate was 90%. When the AC voltage reduction rate is 40%, the peak AC voltage on the secondary side of the 12-phase transformer with a special winding structure was approximately 167 V. In the case of a wound resistive load, the DC voltage drops to a value equal to the peak AC voltage on the secondary side of the 12-phase

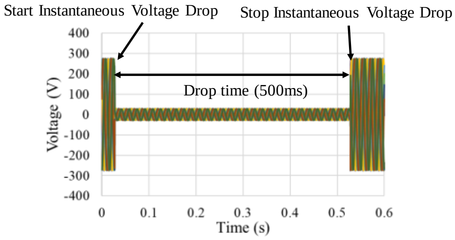

Figure 6. 12-phase voltage when instantaneous low voltage occurs.

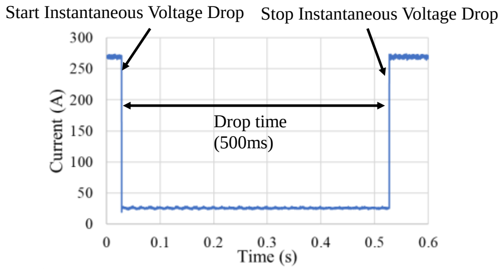

Figure 7. Output voltage after rectification when instantaneous low voltage occurs.

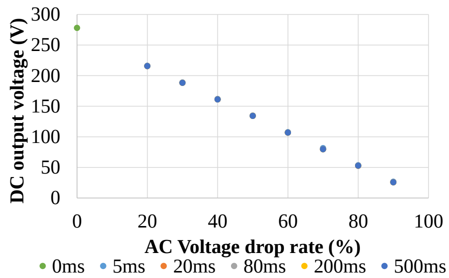

Figure 8. DC voltage after rectification relative to the rate of voltage drop of the input voltage.

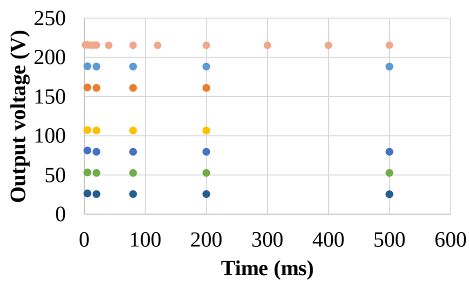

Figure 9. The change in DC voltage after rectification with respect to the duration of instantaneous voltage drop.

Table 1. Operating characteristics of the LCD TV when an instantaneous voltage drops occurred

Based voltage 200V		Instantaneous voltage drop time (ms)				
		5	20	80	200	500
3-phase AC supply Voltage drop rate (%)	20	—	—	—	—	○
	30	—	—	—	—	○
	40	—	—	—	△	○
	50	—	—	—	▲	○
	60	—	—	—	●	●
	70	—	—	—	●	●
	80	—	—	—	●	●
	90	—	—	—	●	●

— : No change △ : The screen flickers for a moment ▲ : Screen off, sound only
● : Power lamp blinks(Error message and reboot required) ○ : Screen off, sound off (Restored after 10 seconds)

transformer momentarily after the instantaneous voltage drop occurs, but in the case of an LCD TV, the DC voltage drops owing to the presence of a capacitor on the LCD TV's DC input section.

However, when the AC voltage reduction rate is 90%, the peak AC voltage on the secondary side of the 12-phase transformer with a special winding structure is 27.9 V. Therefore, the output voltage after rectification decreases toward 27.9 V after the instantaneous voltage drop occurs. However, a capacitor is installed on the DC input section of the LCD TV, and unlike the case of a hollow resistor, the voltage decreases slowly. Therefore, the instantaneous voltage drop ended before the output voltage reached 27.9 V, and the output voltage decreased to 146.5 V and then returned to the original voltage value. The lower limit of the output voltage in the case of 90% and 80 ms was smaller than that in the case of 40% and 200 ms, but the operation of the LCD TV was not affected in the case of 90% and 80 ms, while the operation of the LCD TV was affected in the case of 40% and 200 ms. Therefore, the operation of the equipment was observed to be affected when the voltage input to the equipment remained below the threshold voltage for a certain time period.

Fig. 11 also shows the change in DC voltage after rectification when the rate of decrease of the primary-side AC voltage is varied under the condition of a 500 ms instantaneous voltage drop time. It can be seen that the DC voltage decreases from the instantaneous voltage drop, and the slope at this time is constant regardless of the rate of decrease of the primary-side AC voltage. The time at which the DC voltage starts to become constant is determined by the rate of decrease of the primary-side AC voltage. The smaller the rate of decrease, the earlier the time at which the DC voltage becomes constant; the larger the rate of decrease, the later the time at which the DC voltage becomes constant. This is believed to be because a capacitor is connected to the input of the LCD TV, so that even if the secondary 12-phase AC voltage of the 12-phase transformer with special winding structure drops, the DC voltage input to the LCD TV does not change instantaneously but drops gradually due to the capacitor.

Fig. 12 also shows the change in the DC voltage when the instantaneous low-duration time is changed while the AC voltage reduction rate is kept constant at 90%. Fig. 12 shows that the slope of the DC voltage drop is the same when the instant-drop time duration is changed, indicating that the DC voltage rises at each instant in time in the 500 ms waveform. From the above, it is considered that an instantaneous voltage drop can be guaranteed by installing a capacitor after the rectifier circuit to decrease the gradient of the DC voltage drop.

V. Conclusion

This study investigated the effect of changes in the DC voltage supplied to a load on the DC load when an instantaneous voltage drop occurs in the primary three-phase AC voltage of a transformer with a special winding structure that is used for the AC-DC conversion. The results demonstrated that when no capacitor was used in the DC part, the DC voltage after rectification decreased proportionally with the instantaneous voltage drop, and remained constant

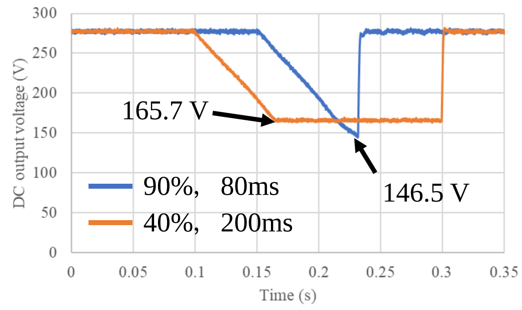

Figure 10. The output voltage waveforms after rectification when the instantaneous voltage drop duration

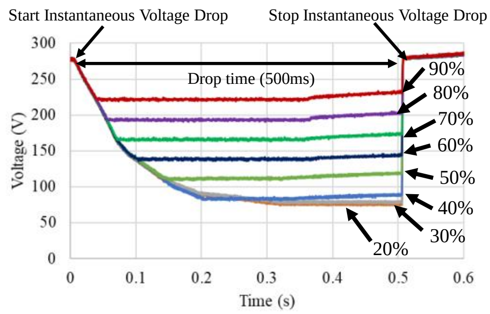

Figure 11. DC voltage after rectification in relative to the rate of voltage drop of the input voltage.

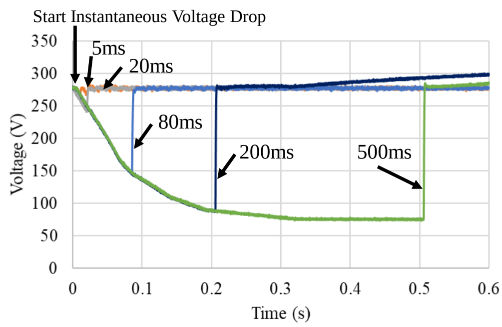

Figure 12 The change in DC voltage after rectification relative to the duration of the instantaneous voltage drop.

regardless of the duration of instantaneous voltage drop. In addition, when an LCD TV was used as the load, we observed that the operation of the device was affected when the voltage input to the device remained below the threshold voltage over a certain period. In the future, we plan to study the optimal capacitor capacitance required to prevent momentary voltage drops.

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