Development of Inverter Control for Room Air Conditioners for Dealing with Voltage Distortions in Low Quality Power Supply Environments

KENICHI AIBA[*1] TAKAMASA WATANABE[*2]
MASAKAZU KUHARA[*3]

Inverters used for room air conditioners, which are household-use air conditioners, cause the outflow of harmonic current with a frequency other than the power supply frequency to the input current. This harmonic current is regulated and measures to meet the regulations are required and we have responded to the regulatory. On the other hand, if the waveform of the power supply voltage is distorted, the input current is distorted and the current increases and there are problems such as the deterioration of the efficiency and fuses blowout due to overcurrent in some cases. Therefore, Mitsubishi Heavy Industries Thermal Systems, Ltd. calculated the distortion factor of the input current and conducted control so as to reduce it. As a result, it was confirmed that the total distortion factor could be suppressed to 1/5 to 1/2 and reported.

1. Introduction

In recent years, the use of inverters has been expanding in the room air conditioner market including countries and regions with relatively low-quality power supply environments. In areas where the power supply is unstable, power outages occur frequently and therefore emergency power generators are installed as countermeasures in many cases. The power supply quality of such generators may even be worse than commercial power sources, so low-cost methods to protect electrical circuits from such poor power supply environments are required.

To meet this requirement, even in an environment where the power supply voltage is normally distorted, the cancellation of input current distortion and the establishment of stable operation have been made possible by calculating the distortion of the input current from the input current waveform and conducting control so as to improve the distortion. In addition, by detecting a momentary overcurrent from the input current waveform described above, the introduction of methods such as instantaneously adjusting the voltage amplitude modulation factor of converter control to suppress overcurrent or immediately stopping converter control was made possible. As a result, we established a circuit control method that realizes stronger circuit protection performance than before.

2. Inverter for room air conditioners

Room air conditioners use inverters to save energy. However, the inverter has a built-in converter that rectifies alternating-current power supply voltage and converts it into direct current and the converter causes the outflow of harmonic current to the power supply system. This harmonic current can interfere with other equipment.

In the case of business-use air conditioners used in buildings, etc., they are connected together with other non-air-conditioner equipment, so it is not necessary for all air conditioners to meet the regulation values. Therefore, active filters that can be added as optional equipment for inverters that require countermeasures against harmonic current have been developed (1).

On the other hand, every room air conditioner is required to meet harmonic regulation values such as IEC (International Electrotechnical Commission).

Our SRK series export room air conditioners meet these regulations. **Table 1** shows their specifications.

In order to satisfy the harmonic regulations, the converter of these products has two sets of

*1 Chief Staff Researcher, Electricity & Applied physics Research Department, Research & Innovation Center, Mitsubishi Heavy Industries, Ltd.
*2 Manager, Air-Conditioner Designing & Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.
*3 Air-Conditioner Designing & Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.

chopper circuits as shown in **Figure 1**. The voltage applied to the section indicated by the blue arrow in the figure, with respect to the power supply voltage applied to the section indicated by the red arrow, is controlled by controlling the converter. As a result, the voltage applied to the section indicated by the green arrow, which is the difference between the two, is applied to reactors L1 and L2 and the input current is controlled.

With these two sets of chopper circuit, in the case of no distortion in the power supply voltage shown in **Figure 2**(a), when the power supply voltage (red) is input, the converter is operated to output a sine wave (blue) for which the phase is shifted appropriately from that of the power supply voltage. As a result, a voltage (green) with a phase shift of approximately 90 degrees is applied to the reactor and a sinusoidal current with a power factor of approximately 1 flows. (In actual fact, the sinusoidal current is rectified by a diode, so the negative side of the waveform is folded back to the positive side.)

However, when the power supply voltage is distorted as shown in Figure 2(b), the voltage applied to the reactor is distorted and the input current is also distorted. The distorted input current causes extra harmonic current flow, which increases the loss and deteriorates the efficiency.

As a measure against this, by superimposing distortion responding to the distortion of the power supply voltage on the waveform output from the converter as shown in Figure 2(c), the voltage of the reactor can be made into a sine wave, which eliminates the distortion of the input current.

Table 1 Outline specifications of SRK series export room air conditioners

Indoor unit				SRK63ZR-W	SRK71ZR-W	SRK80ZR-W
Outdoor unit				SRC63ZR-W	SRC71ZR-W	SRC80ZR-W
Power source				1 Phase, 220 - 240, 50Hz	1 Phase, 220 - 240, 50Hz	1 Phase, 220 - 240, 50Hz
Rated cooling capacity (Min to Max)			kW	6.3 (1.2 ~ 7.4)	7.1 (2.3 ~ 7.8)	8.0 (2.3 ~ 9.7)
Rated heating capacity (Min to Max)			kW	7.1 (0.8 ~ 9.3)	8.0 (2.0 ~ 10.8)	9.0 (2.1 ~ 11.2)
Power consumption		Cooling/Heating	kW	1.63/1.64	1.63/1.64	2.09/2.27
COP		Cooling/Heating		3.87/4.33	3.68/4.10	3.83/3.96
Maximum running current			A	14.5	17	17
Exterior dimensions	Indoor	Height x Width x Depth	mm	339 x 1197 x 262	339 x 1197 x 262	339 x 1197 x 262
	Outdoor			640 x 800(+71) x 290	750 x 880(+88) x 340	750 x 880(+88) x 340
Refrigerant		Type/GWP		R32/675	R32/675	R32/675
Refrigerant		Charge	kg/TCO2Eq	1.25/0.844	1.5/1.013	1.6/1.080
Outdoor operating temperature range		Cooling	°C	-15 ~ 46	-15 ~ 46	-15 ~ 46
		Heating		-15 ~ 24	-15 ~ 24	-15 ~ 24
Clean filter				Allergen Clear Filter x 1, Photocatalytic Washable Deodorizing Filter x 1	Allergen Clear Filter x 1, Photocatalytic Washable Deodorizing Filter x 1	Allergen Clear Filter x 1, Photocatalytic Washable Deodorizing Filter x 1
Energy class (cooling/heating)				A++/A++	A++/A+	A++/A+

- The data is measured under the following conditions(ISO-T1, H1). Cooling: Indoor temp. of 27°CDB, 19°CWB, and outdoor temp. of 35°CDB. Heating: Indoor temp. of 20°CDB, and outdoor temp. of 7°CDB, 6°CWB.
- 'Tonne(s) of CO_2 equivalent' means a quantity of greenhouse gases.

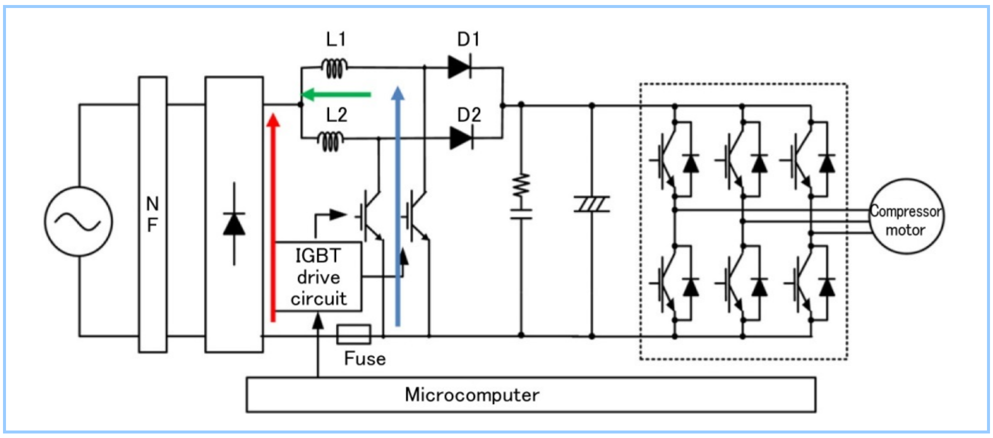

Figure 1 Main circuit configuration

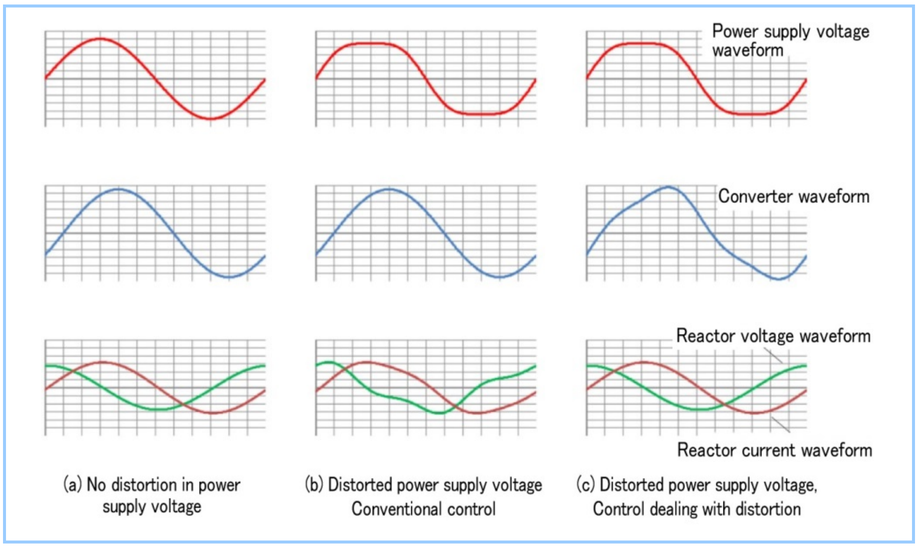

Figure 2 Converter that deals with distorted power supply voltage

3. Dealing with distorted power supply voltage

3.1 Converter control dealing with distortion

In the case of converter control that does not assume distortion in the power supply voltage waveform, the power supply voltage waveform is a sine wave as shown in Figure 2(a), so the parameter is only the phase caused by the voltage drop of the reactor.

This time, in order to deal with the distortion of the power supply voltage, we developed the method which harmonics are superimposed as distortion on the waveform of the converter to reduce the distortion of the input current by adjusting parameters.

The waveform on which the harmonics are superimposed is as shown by the red line in **Figure 3**. The fundamental wave phase and the superposition amount of the third order, the fifth order and so on are set as parameters as noted below.

f1t: Fundamental wave phase [degree] (blue dotted line)

f3s, f3c: 3rd-order sin component (green dotted line) amplitude, 3rd-order cos component (purple dotted line) amplitude [%]

f5s, f5c: 5th-order sin component amplitude, 5th-order cos component amplitude [%]

Distortion is calculated from the relationship between the effective value obtained from the detected input current and the fundamental wave. Then, using this distortion as index J, these parameters are changed and adjusted to the combination with which the distortion becomes smallest.

There are various methods to adjust the parameters to the optimum combination, but we applied a hill climbing method, which does not take much time and there is no need for a CPU change as such. This allows for quick parameter convergence and the parameter adjustment methods shown in **Figure 4** were adopted in a combined manner.

Method (a) changes one of the parameters from the original parameter value (red) in the increasing direction or the decreasing direction, whichever improves index J (blue) and based on that parameter value, changes the parameter value of the next parameter. In this case, all parameters are changed uniformly and adjusted without priority (parameter adjustment without priority).

On the other hand, method (b) changes one of the parameters from the original value (red) continuously toward the parameter value that best improves index J (blue) with the parameter values of the other parameters fixed and then adjusts the subsequent other parameters in the same way. In this case, a parameter that has a large influence on index J is adjusted preferentially (parameter adjustment with priority).

Parameter adjustment without priority adjusts all parameters uniformly, so the distortion decreasing speed from a large distorted state is slow. On the other hand, parameter adjustment with priority adjusts a parameter that has a large influence is adjusted preferentially, so distortion can be reduced quickly.

However, when the distortion becomes small to a certain extent, mutual interference between parameters occurs. For this reason, in the case of parameter adjustment with priority, there are parameters for which the waiting time for adjustment is long. This slows down the distortion decreasing speed.

Therefore, all the parameters are initially adjusted by parameter adjustment with priority to a certain extent and then adjusted by parameter adjustment without priority.

As a result, even if the power supply voltage is distorted, the distortion of the input current can be quickly reduced.

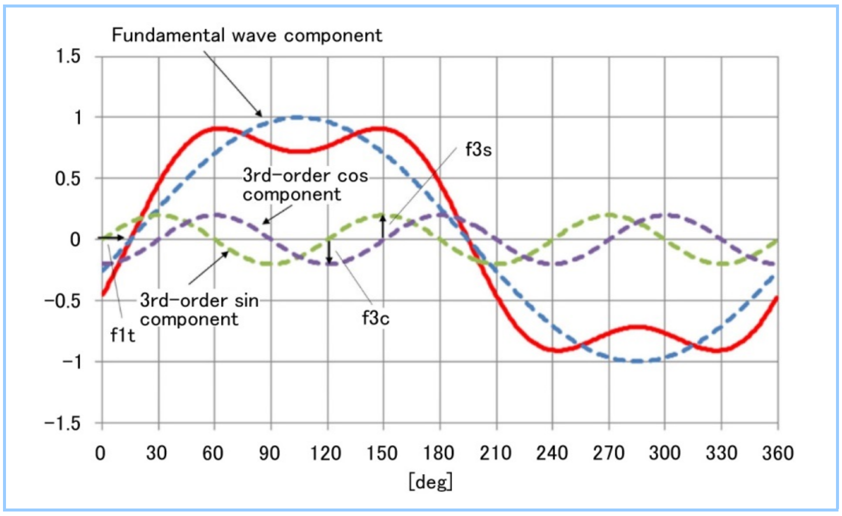

Figure 3　Converter waveform (superimposed with harmonics)

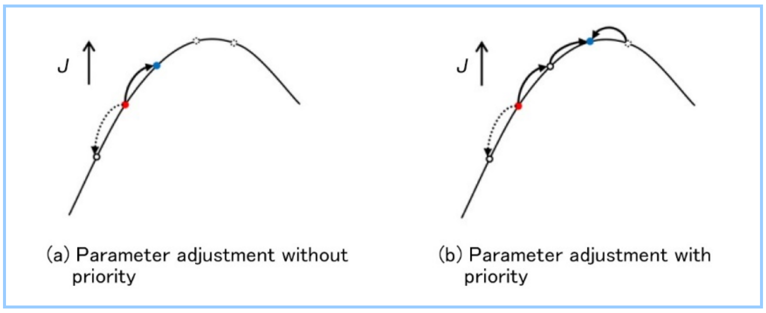

Figure 4　Parameter adjustment

3.2　Analytical and measured waveforms

Figure 5 shows the results of a simulation of the distortion factor reducing effect of converter control dealing with distortion. Since the third-order distortion was superimposed on the power supply voltage waveform by 11%, the total distortion factor (THD: Total Harmonic Distortion) of the input current waveform before adjustment by the control dealing with distortion was 28%. After adjustment (b), however, the distortion of the input current almost disappeared and the distortion factor has decreased to 3%.

In addition, it can be seen that by combining the adjustment order, the distortion factor decreases rapidly to 10% or less in dozen seconds after the adjustment and then stabilizes in about 30 seconds.

Figure 6 shows waveforms in which 11% of the 3rd- and 5th-order distortions are superimposed on the power supply voltage waveform by applying this converter control dealing with distortion to a room air conditioner.

When the adjustment by converter control dealing with distortion was not made, the input current was distorted as shown in (a) and (c) and the total distortion factor THD was 8% and 29%, respectively. However, by making the adjustment by converter control dealing with distortion, the distortion became smaller as shown in (b) and (d) and the distortion factor decreased to half, 3% and to one fifth, 6%, respectively. The order components of each harmonic also satisfied the IEC standard.

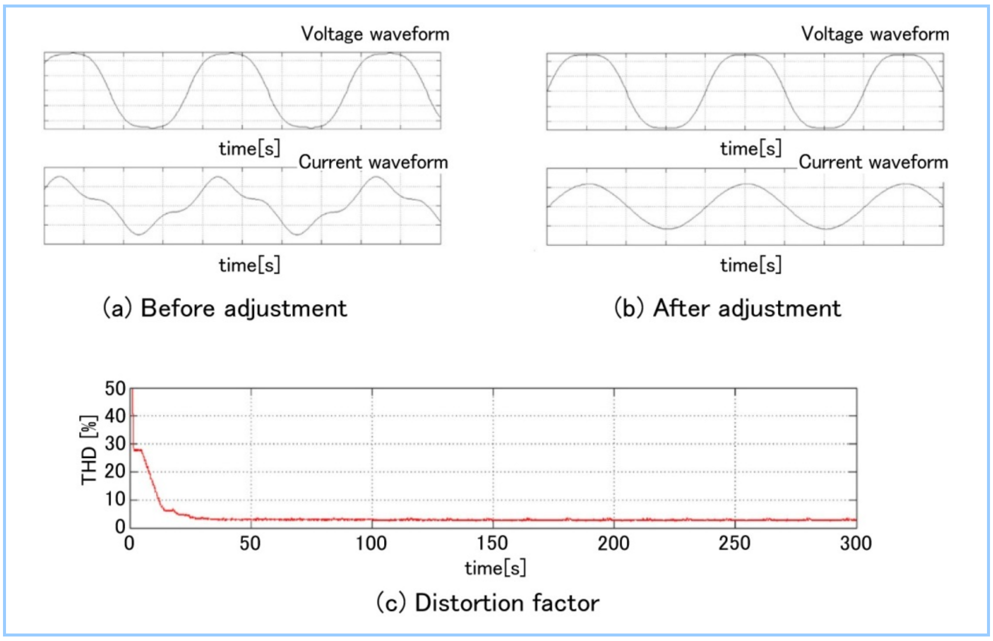

Figure 5 Simulation waveform

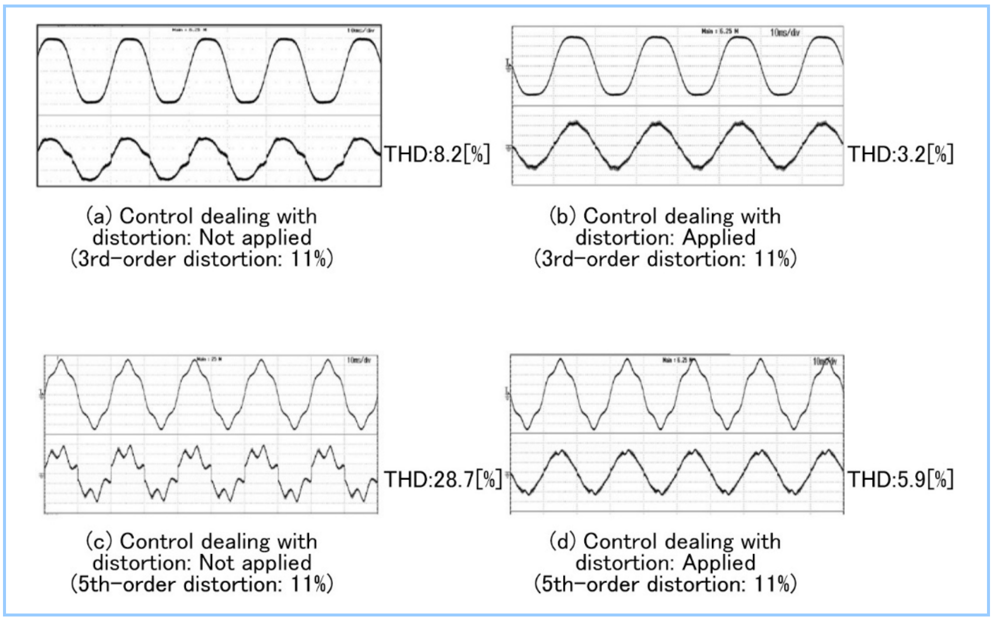

Figure 6 Measured waveform

4. Conclusion

In order to reduce the energy consumption of room air conditioners, an inverter is used for higher efficiency, but the inverter causes the outflow of harmonic current to the input current system as distortion. Until now, as one of the methods to reduce it, a method to make the input current waveform sinusoidal by switching chopper circuits has been adopted. However, there is a problem that when the power supply voltage waveform is distorted, the input current cannot be controlled to be sinusoidal wave-shaped.

Therefore, this report described the development and this result of converter control dealing with distortion that can be realized even with an embedded CPU. By installing this control, it is made possible to reduce the harmonic current even when the power supply voltage is distorted, which eliminates extra input current and achieved high efficiency.

References

(1) Kenichi Aiba et. al, Development of Large Current Capacity Active Filter with Current Prediction Method for Heat Pump Chiller, Mitsubishi Heavy Industries Technical Review Vol. 56 No. 1 (2019)