MITSUBISHI ELECTRIC

INVERTER

TECHNICAL NOTE

No. 28

COMPLIANCE OF INVERTERS WITH HARMONIC SUPPRESSION GUIDELINES

CONTENTS

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INTRODUCTION

There were a relatively few instances of harmonics generated in power distribution systems before 1965, as harmonic generation sources were limited to mercury rectifiers, etc.
Around 1967, semiconductor application technology progressed remarkably and spread widely into factories, residential buildings and even houses. As a result, the number of occurrences of power system equipment affected by harmonics have increased year by year.
This harmonic problem has been examined in various ways by the government. In September 1994, the harmonic suppression guidelines were established by the Ministry of Economy, Trade and Industry (formerly the Ministry of International Trade and Industry) (in Japan).
Previously, inverter-induced harmonic malfunctions were not so common and harmonic suppression techniques were mainly used to protect the inverter from harmonics from equipment such as power factor correction capacitors and private generators within the same power distribution system.
With the establishment of the guidelines, consumers are advised to suppress outgoing harmonic currents in addition to protect on-site equipment.
This Technical Note shows how to calculate inverter-generated harmonics and how to provide suppression techniques in response to the guidelines. For full information on the selection and usage of harmonic suppression equipment, please contact respective manufacturers.

1. WHAT IS A HARMONIC?

1.1 Definition of harmonic

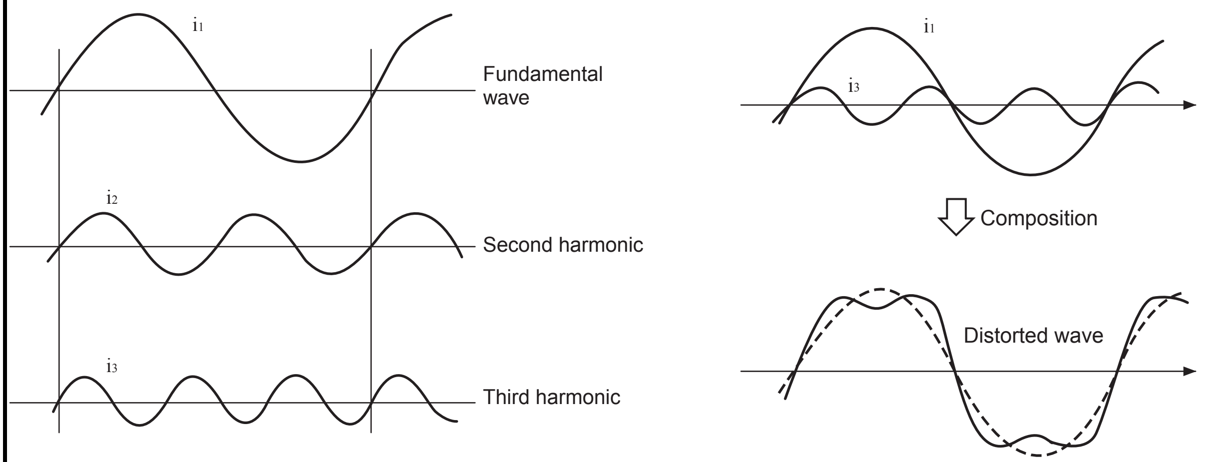
It is defined that a harmonic has a frequency that is an integral multiple of the fundamental wave (generally the power supply frequency). The composition of a single fundamental wave and several harmonics is called a distorted wave. (Refer to Fig. 1.1.)
A distorted wave generally includes harmonics in a high-frequency region (kHz to MHz order), but harmonics in a power distribution system are usually of up to 40th to 50th degrees (to several kHz).
Harmonics are different in nature from high-frequency problems such as noise and electromagnetic interference. This difference must be made clear. (Refer to Section 1.3.)

$$i = i_o + \sum_{n=1}^{\infty} i_n \cdot \sin(2\pi fnt + \varphi n)$$

$n = 1, 2, 3, \ldots\ldots\ldots\ldots$

i : Distorted wave (current)
i_o : DC component
i_t : Fundamental wave component
i_n : Harmonic component (n>2)
f = Fundamental frequency

(a) Fundamental equation



(b) Fundamental wave and harmonics

(c) Distorted wave

Fig. 1.1 Distorted Wave

1.2 Cause of harmonic generation

A harmonic source can be any type of equipment where a distorted-wave current flows through an application with a sine-wave commercial-power-supply voltage. The converter circuit (rectifying circuit) of an inverter is no exception.
The operation principle of a converter circuit is described below:

(1) Operation principle of a converter circuit

A transistorized inverter is designed as shown in Fig. 1.2 to output any frequency to run an induction motor at any speed.
Commercial AC power is rectified in the converter circuit to make DC power, which is then converted into any AC in the inverter circuit.

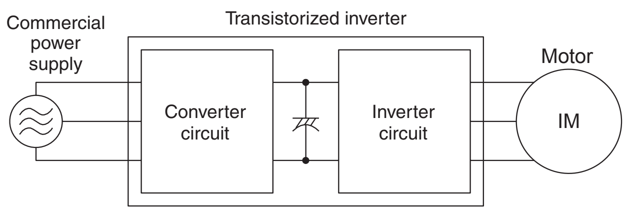


Fig. 1.2 Inverter Structure

Fig. 1.3 shows an input current waveform when DC is made from a single-phase AC supply.

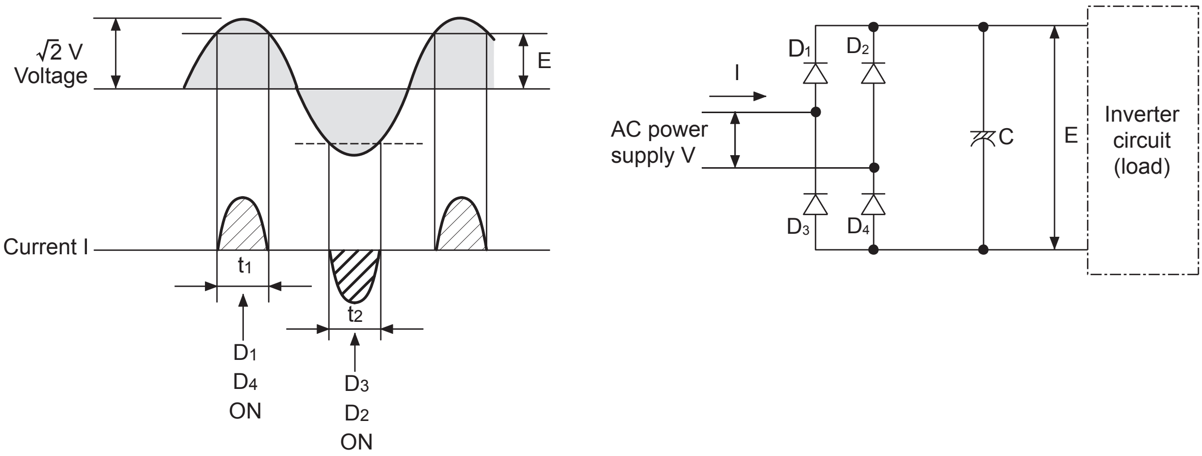


Fig. 1.3 Converter Principle

To keep a motor running, energy must be supplied from the power supply as a current.
However, current flows into the inverter [I] only while the power supply voltage is higher than the DC voltage [E] that is smoothed with a capacitor. (Period t1 and t2 in Fig. 1.3)
Because the energy must be supplied in a limited time period, peak currents flow.
This peak current causes power supply harmonics.

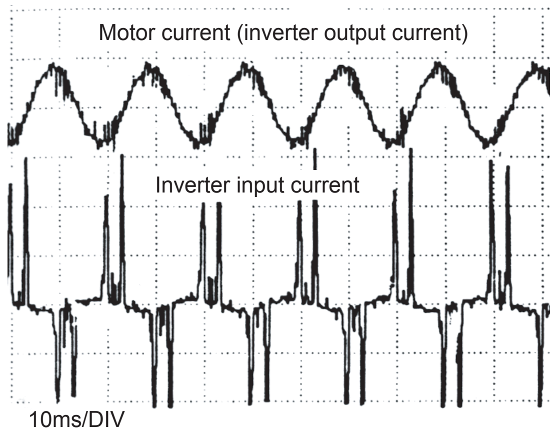


Fig. 1.4 Input/Output Current Waveform Measurement Example (50Hz)

The converter circuit of most transistorized inverters consists of a three-phase full-wave rectifying circuit and a smoothing capacitor as shown in Fig. 1.5, and the actual input current waveform is as shown in Fig. 1.4.

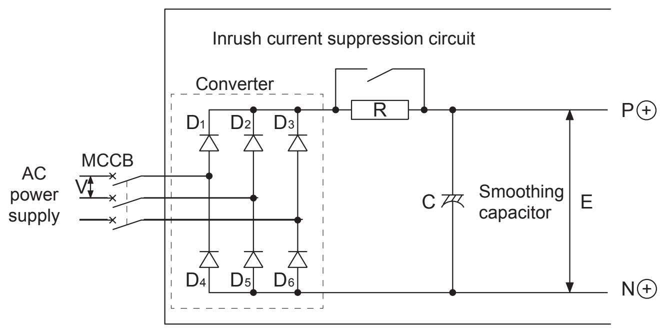


Fig. 1.5 Converter Circuit

∗ As described above, all the rectifying circuits including an inverter circuit can cause harmonics. DC voltage [E] becomes especially high when a smoothing capacitor is connected, allowing a limited time for the power supply. As a result, the amount of peak current increases, and that causes more harmonic currents.

1.3 Noise and harmonics

Table 1.1 Differences between Noise and Harmonics of an Inverter and Leakage Current

Item	Noise	Power Harmonics	Leakage Current
Frequency band	High frequency (Several 10kHz to 1GHz order)	Normally 40th to 50th degrees or less (3kHz or less)	(Several kHz to MHz order)
Source	Inverter circuit	Converter circuit	Inverter circuit
Cause	Transistor switching	Rectifying circuit commutation	Transistor switching
Generated amount	Depends on voltage variation ratio and switching frequency	Depends on current capacity	Depends on switching frequency and voltage
Propagation path	Electric channel, space, induction	Electric channel	Insulating material
Transmission amount	Distance, wiring route	Line impedance	Capacitance
Affected equipment and influence	Sensor, etc.: Mis-operation Radio, wireless equipment: Noise	Power factor correction capacitor: Heat generation Private generator: Heat generation	Earth leakage circuit breaker: Unnecessary operation Thermal relay: Unnecessary operation Output side device (e.g. CT, meter): Heat generation
Main remedy	Change the wiring route. Install a noise filter.	Install a reactor.	Change detection sensitivity. Change carrier frequency.

♦ For the influence of noise and leakage current, remedy, etc., refer to the Inverter Technical Note No. 21 "NOISE AND LEAKAGE CURRENT".

∗ High frequency

There is no set Hz to be defined as a high frequency. High frequency is a frequency higher than the normal frequency. For example:

- Most transistorized inverters are capable of outputting a frequency up to 400Hz. An inverter that outputs a frequency higher than that is called high-frequency inverter.
- Carrier frequency is about 1kHz for a low-acoustic-noise inverter. High carrier frequency is a frequency higher than that frequency.

2. INFLUENCE OF HARMONICS

2.1 Influence of harmonics

The following two points must be considered regarding the influence of inverter's power supply harmonics:

- Influence of the inverter's power supply harmonics on other peripheral devices
- Suppression of the outgoing harmonic current to the power receiving point for the consumer

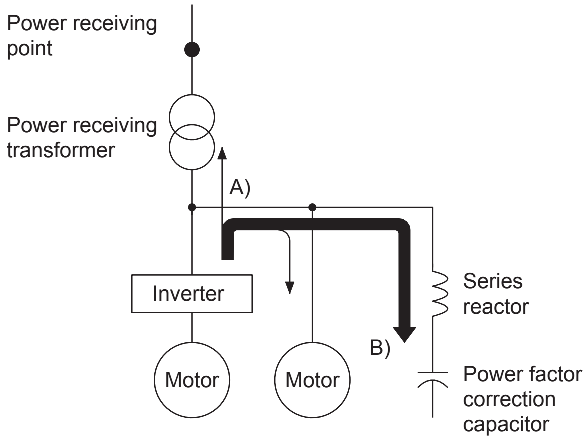


Fig. 2.1 System Diagram Example

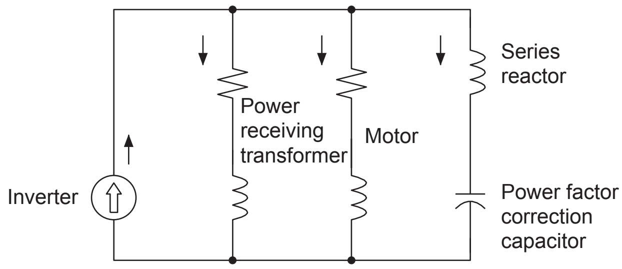


Fig. 2.2 Equivalent Circuit

Since harmonics are generated in the converter circuit (rectifying circuit) of the inverter, the inverter can be represented as a power supply in an equivalent circuit with regard to harmonics.
Fig. 2.2 is the equivalent circuit for the system shown in Fig. 2.1. Calculate the impedance of devices and lines at different branch circuits. With the obtained values, calculate the inverter-generated harmonic current at different harmonic degrees.

(1) Influence of inverter's power supply harmonics on peripheral devices

- When a power factor correction capacitor is connected to the power supply side of the inverter
  Since frequency is higher in harmonics than in the power supply, the impedance of the power factor correction capacitor decreases. In other words, power harmonics generated by the inverter concentrate in the power factor correction capacitor in route B) in Fig. 2.1. As the result, the power factor correction capacitor will overheat and fail.
  Installation of DC reactors, which increase the impedance of the power factor correction capacitor, and power factor improving AC reactors, which control the harmonic current in the inverter, is an effective countermeasure.
- When the power supply is a private generator
  When an "n"th harmonic affects a generator, a rotary magnetic field "n" times larger than the fundamental wave will take place and induced currents will be generated in brake windings and field windings which may lead to reduced output, shorter life or damage due to heat generation.
  This influence can be calculated as an equivalent opposite-phase current. JEM1354 requires the opposite-phase current of a generator to be 15% or lower of a rated output current.
  When using a private generator, installation of a power factor improving reactor, which suppresses the harmonic currents of the inverter, is also effective.

(2) Suppression of outgoing harmonic currents to power receiving point

The specific consumer guideline established in September 1994 requires the suppression of the harmonic currents escaping from the power receiving point to the power supply side in the system (harmonic content at power receiving point).
The point is how a consumer will suppress/absorb inverter-generated power supply harmonics to reduce harmonic currents at the power receiving point in the route A) in Fig. 2.1.
The consumer may need to install a reactor, an AC filter, or an active filter as a countermeasure.

2.2 Harmonic generating equipment

As described in Section 1.2, equipment containing rectifying circuits are the primary cause of harmonic distortion. In addition to inverters, household appliances and office automation equipment such as televisions and personal computers generate harmonics as indicated in Table 2.1. The harmonics generated from these appliances have become a troublesome issue in recent years.
In actual systems, multiple-sources of harmonics often affect each other in a complicated manner.

Table 2.1 Sources of Harmonic Currents

Cause	Equipment	Main Site
Semiconductor application equipment	High-frequency induction furnace	Ironworks, foundry
	DC motor power supply	Lift, container crane
	VVVF power supply	Pumping plant
	CVCF power supply	Bank, office, factory
	Inverter power supply	General factory
	Rectifier for electric railway	Electric railway substation
	Rectifier for chemistry	Smelting/plating factories
	Office automation/household appliance	Office, home television, etc.
Transformer	On-pole transformer Industrial transformer	Wiring line Factory, substation
Equipment such as fluorescent lamp, magnetic amplifier	Fluorescent lamp	Factory, office, household
Electric furnace such as arc furnace	—	Iron mill
Rotary machine	High-voltage induction motor	Factory, etc.

2.3 Conditions of harmonic interference

As shown in Table 2.2, the following types of equipment are affected by harmonics:

Table 2.2 Influence of Harmonics (Excerpts from Electricity Joint Research Vol. 46, No. 2)

Affected Equipment		Conditions	Ratio (%)
Power Capacitor	Equipment itself, series reactor	Occurrence of burnout, overheat, vibration and/or noise due to excessive current	75
	Fuse	Fusing or malfunction due to excessive current	1
Breaker for motor Earth leakage circuit breaker		Malfunction	3
Household appliances	Stereo Television	Noise / inteference Video jitter / picture deterioration	3
Others	Motor Elevator Various control equipment Harmonic filter	Vibration, noise Vibration, stop Malfunction Failure due to excessive current	18

2.4 Harmonic measurement

Harmonics in circuits may be measured in any of the following methods:

(1) FFT analyzer

Use an FFT (Fast Fourier Transform) analyzer with a current detection circuit to measure the current of each frequency component, compare it with the fundamental wave component, and find a content.

(2) Harmonic monitoring system

- Monitoring system using harmonic transducer
  Transducer dedicated to harmonics is under development.
- Harmonic current monitoring using B/NET system
  Harmonic current monitoring using Mitsubishi B/NET system
  * Refer to the B/NET system catalog.

(3) Simple measuring instrument

A portable harmonic measuring instrument which can easily measure and record a harmonic content is available on the market.
Example: Harmonic monitor HM2300: made by Shizuki Electric

3. HARMONIC GUIDELINES

3.1 Types of the harmonic guidelines

In September 1994, the two following power harmonic suppression guidelines were established by the Agency of Natural Resources and Energy in Ministry of Economy, Trade and Industry (formerly the Ministry of International Trade and Industry) in Japan.

- <Harmonic suppression guideline for household appliances and general-purpose products>
  Hereinafter referred to as "household appliance and general-purpose product guideline".
- <Harmonic suppression guideline for consumers receiving power of high voltage or specially high voltage>
  Hereinafter referred to as "specific consumer guideline".

3.2 Harmonic guideline relating to inverters

Inverters were excluded from the target products of the "household appliance and general-purpose product guideline" in January 2004. All the inverters, which are used by specific consumers, have become the target products of the "specific consumer guideline."
The following table shows the transition of applicable guidelines.

Table 3.1 Transition of Applicable Guidelines

<table>
<tr><th></th><th>Three-phase 200V class 3.7kW or lower
Single-phase 200V class 2.2kW or lower
Single-phase 100V class 0.75kW or lower</th><th>Inverters not listed on the left</th></tr>
<tr><td>September 1994
to
December 2003</td><td>Household appliance and general-purpose product guideline
Amended in September 1997
Amended in October 1999
Amended in December 2000</td><td rowspan="2">Specific consumer guideline</td></tr>
<tr><td>January 2004
to</td><td>Specific consumer guideline</td></tr>
</table>

3.3 "Household appliance and general-purpose product guideline"

This guideline mainly applies to appliance manufacturers. Inverters were excluded from the target products of this guideline in January 2004.
(Note)
As the inverters were excluded from the target products, the Japan Electrical Manufacturers' Association has established its own harmonic suppression guideline in order to encourage users and manufacturers to continue their harmonic-suppression efforts. This guideline has been compiled on the basis of the household appliance and general-purpose product guidelines. Users are recommended to take harmonic suppression measures for the equipment, whenever possible.

- The technical data JEM-TR226 of the Japan Electrical Manufacturers' Association defines the harmonic suppression guideline for transistorized inverters (with 20A or lower input current).

3.4 "Specific consumer guideline"

This specific consumer guideline mainly applies to specific consumers.

(1) Overview of the specific consumer guideline

1. PURPOSE

This guideline explains harmonic-current suppression requirements for the specific consumers who receive high voltage or special high voltage from a commercial power supply (hereinafter referred to as "specific consumers"). The guideline is written in compliance with the regulations of the Electricity Enterprises Act in Japan, and it includes the target harmonic values for the systems with commercial power supply (hereinafter referred to as "system") in consideration of the environment.

2. SCOPE

(1) This guideline applies to a specific consumer who has any of the following "equivalent capacity." "Equivalent capacity" is a total equivalent capacity of harmonic-generating devices that are used in a system.

1) Consumers who receive power from high voltage systems
6.6kV system .... 50kVA or more

2) Consumers who receive power from specially high voltage systems
22kV or 33kV .... 300kVA or more
System with 66kV or more........................ 2000kVA or more

(2) Equipment covered by (1) shall be all harmonic generating equipment with the exception of the equipment covered by the "harmonic suppression guideline for household appliances and general-purpose products".

(3) Any new harmonic generating equipment installed or added/renewed is covered by this guideline when the sum of equivalent capacities satisfies the value indicated above in (1) after installation, addition or renewal.

3. SUPPRESSION OF HARMONIC CURRENTS

Multiply "the maximum outgoing harmonic current per contracted kW" shown in Table 3.2 by "the contracted power of the specific consumer." If the obtained value exceeds "the maximum outgoing harmonic current at the power receiving point" of a specific consumer, take a countermeasure.

4. CALCULATION OF OUTGOING HARMONIC CURRENTS

Outgoing harmonic currents at a power receiving point shall be as follows:

(1) Only the calculated magnitude of the 40th and less degrees an outgoing harmonic current shall be covered by this guideline.

(2) An outgoing harmonic current at a power receiving point is found by summing up harmonic currents generated in the rated operating range of individual harmonic generating equipment and multiplying the sum by the maximum operation ratio of the harmonic generating equipment.
If the consumer has a facility to reduce harmonic currents, its effect may be taken into consideration.

5. OTHER REFERENCES

(1) Contracted power
Use the following value as the contracted power if a consumer has a power supplier, who agrees to provide power but does not agree with a definite "contracted power," or has several power suppliers.

1) Use the contracted equipment power for the calculation when the power cost is calculated by the "actual usage power amount" and using 500kW or lower power for an industrial purpose.

2) Use the maximum contracted power when there are several power contracts including a hourly rate contract.

(2) Maximum operation ratio of harmonic generating equipment
The "maximum operation ratio of harmonic generating equipment" indicates the ratio of the maximum actual operation capacity (average of 30 minutes) to the sum of capacities of the harmonic generating equipment.

Table 3.2 Maximum Outgoing Harmonic Current per 1kW Contracted Power (Unit: mA/kW)

Received Power Voltage	5th	7th	11th	13th	17th	19th	23rd	Over 23rd
6.6kV	3.50	2.50	1.60	1.30	1.00	0.90	0.760	0.700
22 kV	1.80	1.30	0.82	0.69	0.53	0.47	0.39	0.36
33 kV	1.20	0.86	0.55	0.46	0.35	0.32	0.26	0.24
66 kV	0.59	0.42	0.27	0.23	0.17	0.16	0.13	0.12
77 kV	0.50	0.36	0.23	0.19	0.15	0.13	0.11	0.10
110 kV	0.35	0.25	0.16	0.13	0.10	0.09	0.07	0.07
154 kV	0.25	0.18	0.11	0.09	0.07	0.06	0.05	0.05
220 kV	0.17	0.12	0.08	0.06	0.05	0.04	0.03	0.03
275 kV	0.14	0.10	0.06	0.05	0.04	0.03	0.03	0.02

4. EXAMINATION OF INVERTER HARMONICS ACCORDING TO THE SPECIFIC CONSUMER GUIDELINE

4.1 Application of the specific consumer guideline

(1) Examination items

Whether or not a harmonic suppression technique is required by the "specific consumer guideline" is examined in the following procedure:

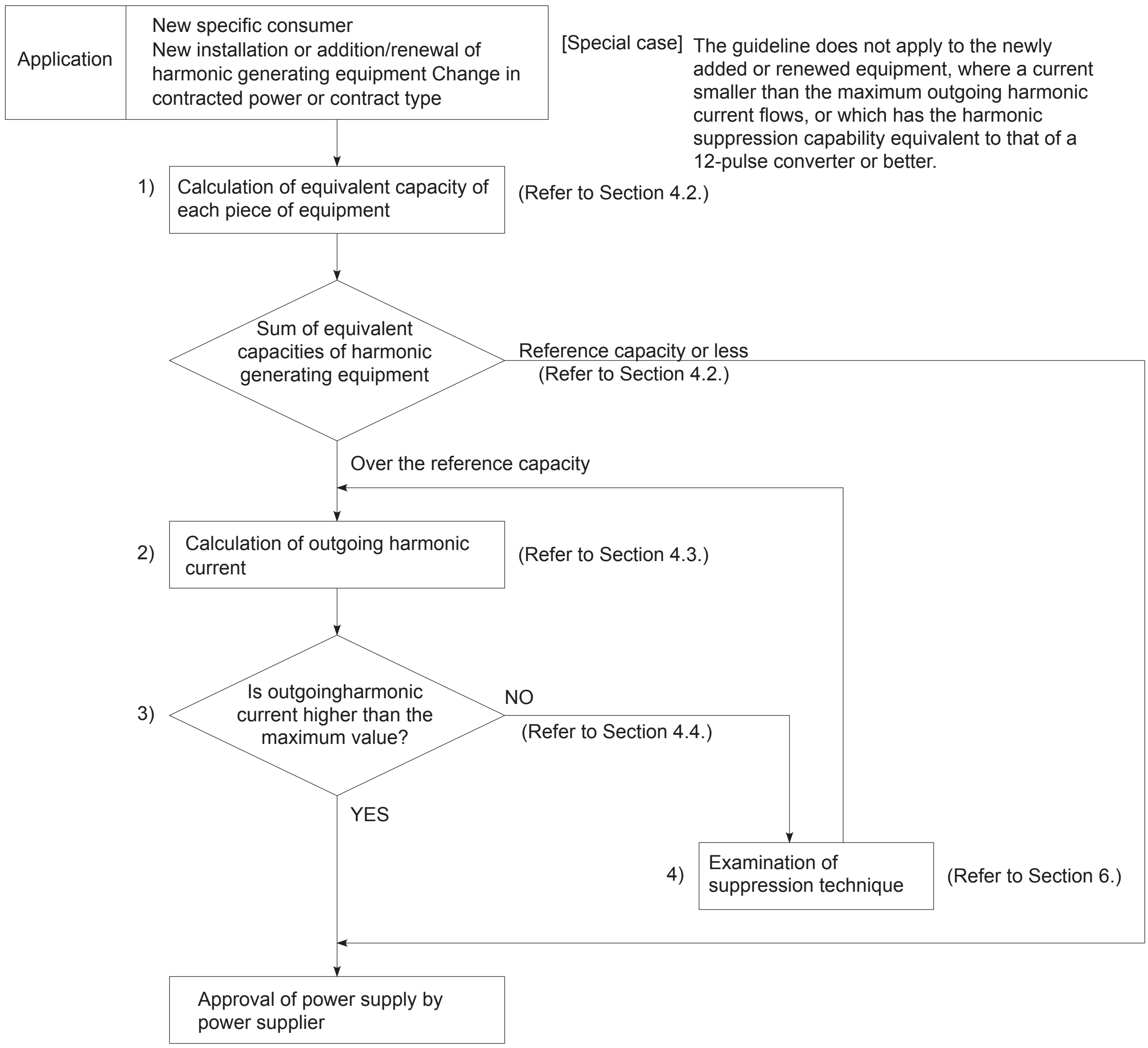


Fig. 4.1 Harmonic Examination Flowchart

(2) Scope of guideline application to inverters

All the inverters, which are used by specific consumers, are the target products of the "specific consumer guideline."

4.2 Calculation of equivalent capacities of harmonic generating equipment

The "equivalent capacity" is the sum of [6-pulse converter] capacities converted from the capacities of a consumer's harmonic generating equipment such as inverters, and is calculated in the following procedure:

* 6-pulse converter: This name is derived from the fact that a pulse current flows six times during one power cycle in a three-phase full-wave rectifying circuit.

(1) Determine the rated capacity Pi [kVA] of each equipment

Use Pi to determine whether the calculation of outgoing harmonic current for the "specific consumer guideline" is required or not.

Regardless of the inverter model and manufacturer and whether it has a reactor or not, find its rated capacity [kVA] in Table 4.1 according to the motor capacity.

Table 4.1 Fundamental Wave Currents and Rated Capacities of Inverters

(Excerpts from the technical data JEM-TR201 of the Japan Electrical Manufacturers' Association)

Motor Capacity [kW]	Input fundamental wave current I1 [A]		Rated input capacity Pi [kVA]	
	200V	400V	200V	400V
0.1	0.61	0.30	0.22	
0.2	0.98	0.49	0.35	
0.4	1.61	0.81	0.57	
0.75	2.74	1.37	0.97	
1.5	5.50	2.75	1.95	
2.2	7.93	3.96	2.81	
3.7	13.0	6.50	4.61	
5.5	19.1	9.55	6.77	
7.5	25.6	12.8	9.07	
11	36.9	18.5	13.1	
15	49.8	24.9	17.6	
18.5	61.4	30.7	21.8	
22	73.1	36.6	25.9	
30	98.0	49.0	34.7	
37	121	60.4	42.8	
45	147	73.5	52.1	
55	180	89.9	63.7	
75	245	123	87.2	
90	293	147	104	
110	357	179	127	
132	Not applicable	216	Not applicable	153
160		258		183
200		323		229
220		355		252
250		403		286
280		450		319
315		506		359
355		571		405
400		643		456
450		723		512
500		804		570
530		852		604
560		900		638
630		1013		718

Calculate the input fundamental wave current I1 with the following formula:

$$I_1 = \frac{P_M \times 1000}{\sqrt{3} \times V_i \times \eta a \times \eta b} \quad \text{[A]}$$

P_M : Rated motor current [kW]
V_i : AC power supply voltage [V]
ηa : Motor efficiency
ηb : Inverter efficiency

Calculate the motor and inverter efficiencies with the standard value of the capacity that is released by the domestic manufacturer.
Calculate the rated input capacity Pi with the following formula:

$$P_i = \frac{\sqrt{3} \times V_i \times I_1 \times 1.0228}{1000} \quad \text{[kVA]}$$

♦ The rated capacities Pi in Table 4.1 are values used for calculation to determine whether the inverters are covered by the harmonic guideline.
Therefore, fully note that they are different from capacities of power supply equipment (such as power transformers) that are required for use of actual inverters.
The power supply equipment capacity required is 1.3 to 1.6 times greater than the above rated capacity (for specific values, refer to the inverter catalog).

(2) Calculation of equivalent capacity P_o [kVA]

- Equivalent capacity: $P_o = \Sigma(K_i \times P_i)$..[Equation 4.1]
  - Ki: Conversion factor (refer to Table 4.2)
  - Pi: Rated input capacity of each piece of equipment

Table 4.2 Conversion Factors (Excerpts from appended documents to the guideline)

Circuit Type		Conversion Factor Ki	Main Application Example
Three-phase bridge	6-pulse converter	K11 = 1	DC railway substation, electro-chemistry, other general applications
	12-pulse converter	K12 = 0.5	
	24-pulse converter	K13 = 0.25	
Three-phase bridge (smoothing capacitor)	Without reactor	K31 = 3.4	Transistorized inverter, servo, elevator, refrigerator air conditioner, other general applications
	With reactor (AC side)	K32 = 1.8	
	With reactor (DC side)	K33 = 1.8	
	With reactor (AC, DC sides)	K34 = 1.4	
Single-phase bridge (smoothing capacitor)	Without reactor	K41 = 2.3 (Note)	Transistorized inverter
	With reactor (AC side)	K42 = 0.35 (Note)	

(Note) K41=2.3 and K42=0.35 are values when the reactor value is 20%. Since a 20% reactor is large and considered to be not practical, K41=3.32 and K42=1.67 are written as conversion factor for a 5% reactor in the technical data JEM-TR201 of The Japan Electrical Manufacturers' Association and this value is recommended for calculation for the actual practice.

♦ If the equivalent capacity obtained with Equation 4.1 exceeds the reference capacity in Table 4.3 determined by the received power voltage, the outgoing harmonic current must be calculated according to Section 4.3.

Table 4.3 Equivalent Capacity Reference

Received Power Voltage	Reference Capacity
6.6kV system	50kVA
22kV or 33kV	300kVA
System with 66kV or higher	2000kVA

4.3 Calculation of outgoing harmonic current

Calculate the specific outgoing harmonic current of a consumer using the following procedure:

(1) Rated current converted from received power voltage

- Rated current converted from received power voltage
  = fundamental wave current × (inverter power supply voltage/received power voltage) [A]
  .... [Equation 4.2]
  - Fundamental wave current : Find the value in Table 4.1.
  - Received power voltage : Consumer's received power voltage [V]
  - Inverter power supply voltage : Since the fundamental wave current in Table 4.1 is the value at the power supply voltage of 200V or 400V, use 200V or 400V for calculation if the actual operating voltage is 220V or 460V.

(2) Outgoing harmonic current

- Outgoing harmonic current
  = rated current × harmonic content × maximum operation ratio × 10^3
  × reduction equipment effect [mA].. [Equation 4.3]
  - Rated current : Input current of each piece of equipment converted from received power voltage
  - Harmonic content : Use the value in <Table 4.4 Harmonic contents>.
    For three-phase power input inverters, refer to the circuit type under the three-phase bridge (capacitor smoothing).]
  - Maximum operation ratio : Find an average operation ratio during 30 minutes under the most severe operating conditions.
    [Average operation ratio = actual load factor × operation time ratio during the 30 minutes]
  - Reduction equipment effect : Multiply by this value when harmonic reduction equipment is installed in the system.*
    Example: For multi-phased operation using a combination of Δ-Δ and ⅄-Δ transformers (refer to Section 6.4), harmonics may be reduced down to half.

∗ Harmonic reduction equipment
- Absorption effects by filter, private generator, power factor improving capacitor (including low-voltage), motor, etc.
- Cancel effects by ⅄-Δ combination, active filter, etc.
- Effect of the number of arc furnaces

Table 4.4 Harmonic Contents (Excerpts from appended documents to the specific consumer guideline)

(Unit: %)

Circuit Type	5	7	11	13	17	19	23	25
Three-phase bridge								
• 6-pulse converter	17.5	11.0	4.5	3.0	1.5	1.25	0.75	0.75
• 12-pulse converter	2.0	1.5	4.5	3.0	0.2	0.15	0.75	0.75
• 24-pulse converter	2.0	1.5	1.0	0.75	0.2	0.15	0.75	0.75
Three-phase bridge (smoothing capacitor)								
• Without reactor	65	41	8.5	7.7	4.3	3.1	2.6	1.8
• With reactor (AC side)	38	14.5	7.4	3.4	3.2	1.9	1.7	1.3
• With reactor (DC side)	30	13	8.4	5.0	4.7	3.2	3.0	2.2
• With reactor (AC, DC sides)	28	9.1	7.2	4.1	3.2	2.4	1.6	1.4
Single-phase bridge (smoothing capacitor)								
• Without reactor	50	24	5.1	4.0	1.5	1.4	—	—
• With reactor (AC side) (Note)	6.0	3.9	1.6	1.2	0.6	0.1	—	—

(Note) The harmonic contents for "single-phase bridge/with reactor" in the table 4 are values when the reactor value is 20%. Since a 20% reactor is large and considered to be not practical, harmonic contents when a 5% reactor is used is written in the technical data JEM-TR201 of The Japan Electrical Manufacturers' Association and this value is recommended for calculation for the actual practice.

Table 4.5 Harmonic Content for the System with "Single-phase Bridge and Capacitor" Written in the Technical Data JEM-TR201 of the Japan Electrical Manufacturers' Association

(Unit: %)

Circuit Type	5	7	11	13	17	19	23	25
Single-phase bridge (smoothing capacitor)								
• With reactor (AC side)	39.9	11.0	4.5	3.0	1.5	1.25	—	—

4.4 Judging whether harmonic suppression technique is required or not

With the following procedure, check whether or not the outgoing harmonic current obtained in Section 4.3 is higher than the maximum value that is specified in the specific consumer guideline:

(1) Calculation of maximum outgoing harmonic current

According to the specific consumer guideline, the contracted power of the consumer determines the permissible outgoing harmonic current. Obtain the value with the Equation 4.4:

● Maximum outgoing harmonic current
= maximum value per 1kW contracted power × contracted power [mA]............................. [Equation 4.4]

- Maximum value per 1kW contracted power: Refer to overview of the specific consumer guideline (refer to Table 3.2) [mA/kW]
- Contract power: Refer to overview of the specific consumer guideline (in Section 3.4) [kW]

(2) Examining whether suppression technique is required or not

Check that the outgoing harmonic current obtained in Equation 4.3 is within the maximum outgoing harmonic current obtained in Equation 4.4. Check at different ordinal numbers of harmonic current.

1) When "outgoing harmonic current < maximum outgoing harmonic current"
No harmonic suppression technique is required because the maximum value is not exceeded

2) When "outgoing harmonic current > maximum outgoing harmonic current"
Harmonic suppression techniques are required if the maximum value is exceeded.
After taking the required measures (installation of harmonic suppression equipment), consider the effects of the reduction equipment and repeat examination according to the procedures given in Section 4.3.

5. SPECIFIC CALCULATION EXAMPLES

When examining whether a harmonic suppression technique is required or not, the electric power supplier will request the consumer to present an outgoing harmonic current calculation sheet. Make specific examination in the given format (refer to Section 9.1).

5.1 Calculation example using calculation sheet (part 1)

- Examination conditions

  The following table shows examples of the examination that are required for a specific consumer who operates a system with:
  - Received power voltage: 6.6kV
  - Contracted power: 400kW
  - One 30kW400V ventilating fan (with FR-A740-30K inverter + FR-HAL-H30K AC reactor)
  - Two 7.5kW400V conveyors (with FR-A740-7.5K inverters)

No.	Item	For Ventilation Fan	For Conveyor
1)	Application of specific consumer guideline	Specific consumer guideline applies	
2)	Rated capacity of inverter (from Table 4.1)	34.7 [kVA]	2 × 9.07 = 18.14 [kVA]
3)	Conversion factor	K32 = 1.8	K31 = 3.4
4)	Equivalent capacity = rated capacity × conversion factor [Equation 4.1]	34.7 × 1.8 = 62.46 [kVA]	18.14 × 3.4 = 61.68 [kVA]
	The total of equivalent capacities exceeds 50 [kVA]. Proceed to the second step and calculate the outgoing harmonic current.		
5)	Rated current converted from received power voltage [Equation 4.2]	49.0 × 400/6600 = 2.97 [A]	2 × 12.8 × 400/6600 = 1.55 [A]
6)	Assume the operation ratio.	80%	50%
7)	Outgoing harmonic current (for fifth degree) [Equation 4.3]	2.97 × 0.8 × 0.38 × 10^3 = 903 [mA]	1.55 × 0.5 × 0.65 × 10^3 = 504 [mA]
	Sum (for fifth degree)	903 + 504 = 1407 [mA]	
8)	Maximum outgoing harmonic current (for fifth degree) [Equation 4.4]	3.5 × 400 = 1400 [mA]	
9)	Examination of harmonic suppression technique requirement (for fifth degree) (Section 4.4 (2))	Since "1407 [mA] > 1400 [mA]", harmonic suppression technique is required.	

The calculation sheet shown below is a translation by Mitsubishi. The original calculation sheet is in Japanese.

1) Enter the harmonic generating equipment name.
2) Enter the rated capacity
3) Conversion factor
4) Equivalent capacity
5) Rated current converted from received power voltage
6) Operation ratio
7) Outgoing harmonic current

Calculation sheet for outgoing harmonic currents from harmonic generating equipment (Part 1)

Customer name		Business Category		Received Power Voltage	kV	Contracted (equipment) power	kW

Date of Application	
Application No.	
Date of Acceptance	

STEP 1 HARMONIC GENERATING EQUIPMENT PARTICULARS										STEP 2 GENERATED HARMONIC CURRENT CALCULATION									
Harmonic Generating Equipment				2) Rated Capacity	3) Qty (Newly added or renewed units)	4)(2)× 3)) Total Capacity	5) Circuit Class No.	6) 6-Pulse Conversion Factor	7)(4)× 6)) 6-Pulse Equivalent Capacity	8)(4)× k)) Rated Current Converted from Received Power Voltage	9) Max. Equipment Operation Ratio	10)(8)× 9) × 10)) Outgoing Harmonic Current by Degrees							
No.	Equipment name	Manufacturer	Model	(kVA)		(kVA)		Ki	(kVA)	(mA)	(%)	5 th	7 th	11 th	13 th	17 th	19 th	23 th	25 th
1	Inverter for ventilation fan	Mitsubishi Electric	FR-A740-30K	34.7	1	34.7	32	1.8	62.46	2970	80	903	345	176	81	76	45	40	31
2																			
3	Inverter for conveyor	Mitsubishi Electric	FR-A740-7.5K	9.07	2	18.14	31	3.4	61.68	1550	50	504	318	66	60	33	24	20	14
4																			
5																			
6																			
7																			
8																			
9																			
10																			
11																			
12																			
13																			
14																			
15																			
16																			
17																			
					Sum of 6-pulse equivalent capacities				124.14	Total	—	1407	663	242	141	109	69	60	45
										Judgment of technique requirement	—	YES	NO	NO	NO	NO	NO	NO	NO

To customer

Refer to the entry method described on the back, and complete the columns under STEP 1

If the sum of 6-pulse equivalent capacities satisfies the following conditions based on the values written under STEP 1, complete the columns under STEP 2.

Received power voltage	6.6kV	22 to 33kV	66kV or more
Sum of 6-pulse equivalent apacities	Exceeds 50kVA	Exceeds 300kVA	Exceeds 2000kVA

* "a)" indicates the harmonic current occurrence ratio, "b)" indicates the maximum outgoing harmonic current per 1kW contracted power, and "k" indicates the rated current per 1kVA equipment power. Find more details on the back.

11) Maximum outgoing harmonic current (1) × b))								
Degree	5 th	7 th	11 th	13 th	17 th	19 th	23 th	25 th
Maximum current value (mA)	1400	1000	640	520	400	360	304	280

Chief engineer		TEL
Construction company	Person in charge	TEL

9) Requirement of harmonic suppression technique
8) Maximum outgoing harmonic current value

In this case, a suppression technique (AC reactor connection to FR-A740-7.5K, etc.) is required for the fifth harmonic.

6. HARMONIC SUPPRESSION TECHNIQUES

6.1 Overview of harmonic suppression techniques

The following table lists an overview of principles, features, etc. of harmonic suppression and absorption techniques. For more information, refer to Sections 6.2 to 6.6.

Table 6.1 List of Harmonic Suppression Techniques

No.	Item	Description	Selection Points, Precautions, etc.	Effects, Etc.
1)	Reactors for inverter (FR-HAL, FR-HEL)	Connect an AC reactor on the power supply side of the inverter or a DC reactor on its DC side or both to increase the circuit impedance, suppressing harmonic currents.	Select according to motor capacity. • AC reactor Model: FR-HAL • DC reactor Model: FR-HEL	Harmonic currents are suppressed to about 1/2.
2)	High power factor converter (FR-HC, FR-HC2)	This converter trims the current waveform to be a sine waveform by switching in the rectifier circuit (converter module) with transistors. Doing so suppresses the generated harmonic amount significantly. Connect it to the DC area of an inverter.	Connectable to the inverters that are compatible with high power factor converters	Harmonic current is suppressed to almost zero.
3)	Power factor improving capacitor	A power factor improving capacitor is small in impedance to high frequency components. When used with a series reactor, it has an effect of absorbing harmonic currents. This capacitor may be installed in either a high or low voltage side.	Harmonics may increase depending on the series reactor value.	The absorbing effect is greater in the low voltage line.
4)	Transformer multi-phase operation	When two or more transformers are used, connecting them with a phase angle difference of 30° as in 人-Δ, Δ-Δ combination will cause a timing shift to suppress peak currents, providing an effect, equivalent to that of a 12-pulse bridge.	Since 人-人 combination provides third outgoing harmonics, use Δ connection for either of the primary or secondary windings.	If the capacity of the 人-Δ, Δ-Δ combination differs, an effect equivalent to that of a 12-pulse brige can be expected for the smaller one, and harmonic currents can be suppressed to about 1/2.
5)	AC filter	As in a power factor improving capacitor, a capacitor and series reactor are used together to reduce impedance to a specific frequency (degree), absorbing harmonic currents greatly.	When there is more than one excessive harmonic, an AC filter must be installed for each degree.	Produces a great suppression effect. (Can satisfy the requirements of the guideline.)
6)	Active filter	This filter detects the current of a circuit generating a harmonic current and generates a harmonic current equivalent to a difference between that current and a fundamental wave current to suppress a harmonic current at a detection point.	One filter can provide effects on more than one harmonic degree. Select according to the capacity of excessive harmonics.	Provides a great suppression effect. (Can satisfy the requirements of the guideline.) As this filter corrects the whole waveform, a power factor improving effect is also expected.

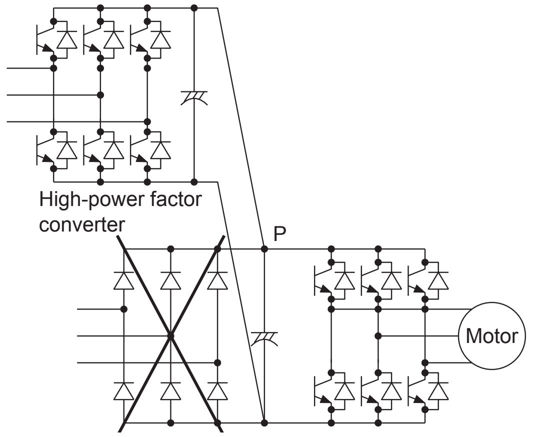
- The techniques above are advantageous in the following order (highest to lowest):
  - For suppression effect: 6) or 2), 5), 4), 3) and 1).
  - For cost: 1), 2), 3), 4), 5) and 6).

6.2 Harmonic suppression techniques at the inverter side

(1) High-power factor converter

High power factor converters perform switching operation with transistors in the rectifying circuit (converter circuit) in order to shape a current waveform to a sine wave. Harmonics can be reduced most significantly with this method. An inverter can satisfy the requirements of the guideline without any other suppression techniques.
This is the best technique to suppress inverter-generated harmonics.
However, the switching operation in the rectifying circuit at a high-frequency range may increase noise.

- **High-power factor inverter circuit example**

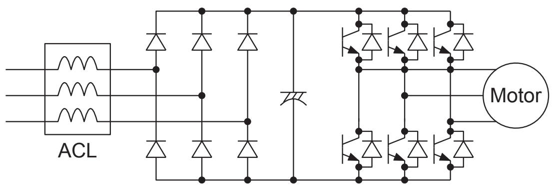


(2) AC reactor

Install an AC reactor to the power supply side of the inverter to increase line impedance, suppressing harmonics.

1) Features
An AC reactor can also be used to improve the input power factor at an inverter operation.
Approximately 88% of the power factor improving effect can be obtained (92.3% when calculated with 1 power factor for the fundamental wave according to the Architectural Standard Specifications (Electrical Installation) (2010 revision) supervised by the Ministry of Land, Infrastructure, Transport and Tourism of Japan)

- **ACL connection example**



2) Selection method
Select the model according to the capacity of the motor connected to the inverter.

FR-HAL-H30K

Basic model name

Capacity .... Motor capacity [kW]

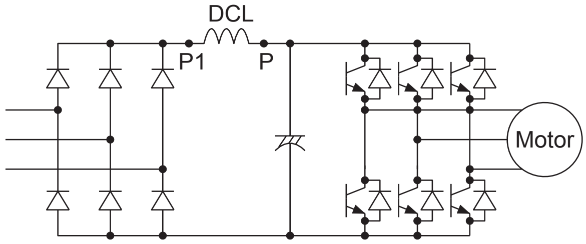
Voltage class .... • 200V: None • 400V: H

3) Note
- Factors such as a voltage drop (by approx. 2%) at the power supply side may cause torque shortage of the motor and other malfunctions.
- If simply installing an AC reactor does not allow the inverter to satisfy the requirements of the guideline, use other techniques.

(3) DC reactor

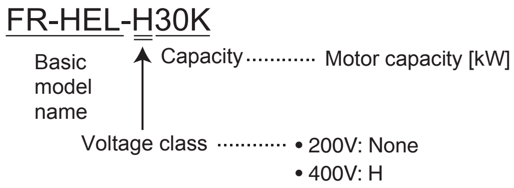
Install a DC reactor in the DC circuit of the inverter to increase impedance, suppressing harmonics.

- **DCL connection example**



1) Features
- A DC reactor can also be used to improve the input power factor during inverter operation. Approximately 93% of the power factor improving effect can be obtained (94.4% when calculated with 1 power factor for the fundamental wave according to the architectural standard specifications (electrical installation) (2010 revision) supervised by the Ministry of Land, Infrastructure, Transport and Tourism of Japan).
- Since a DC reactor is connected in the DC circuit, a voltage drop is only that of the DC resistance (1% or less). Therefore, the DC reactor hardly has any influence such as motor torque shortage and yields many advantages.
- A DC reactor is smaller, lighter and produces a greater power factor improving effect than an AC rector.

2) Selection method
Select the model according to the capacity of the motor connected to the inverter.



3) Note
- Connected in the DC circuit of the inverter, the DC reactor cannot be used with a model which does not have terminals P and P1.
- Dedicated DC reactors are equipped for the FR-A700 (75K or higher), F700P (75K or higher), and V500L series inverters.
- If simply installing a DC reactor does not allow the inverter to satisfy the requirements of the guideline, use other techniques described on page 16.

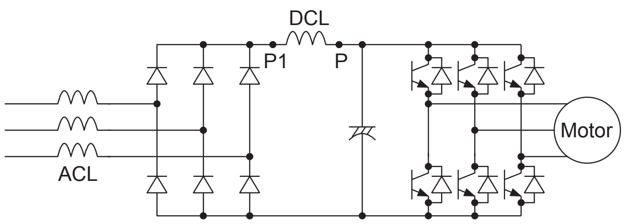
(4) AC and DC reactors used together

Install an AC reactor in the power supply side and a DC reactor in the DC circuit to increase impedance, suppressing harmonics.

1) Feature
- Using the AC and DC reactors together increases the harmonic suppression effect.

2) Selection method
Select the AC and DC reactors individually according to the motor capacity.
For more detail, refer to Sections (2) and (3).

- **Example of using ACL and DCL together**



3) Note
- Factors such as a voltage drop (by approx. 2%) at the power supply side may cause torque shortage of the motor and other malfunctions.
- If simply installing AC and DC reactors does not allow the inverter to satisfy the requirement of the guideline, use other techniques described on page 16.

Table 6.2 Comparison between AC Reactor (FR-HAL) and DC Rector (FR-HEL) (for 0.4 to 55kW)

No.	Item	AC Reactor	DC Reactor
1)	Reactor model	FR-HAL-(H) □□ K	FR-HEL-(H) □□ K
2)	Installation area ratio	1	0.37 to 0.88
3)	Weight ratio	1	0.4 to 0.87
4)	Harmonic content (for fifth degree)	Reduced to 38%	Reduced to 30%
5)	Inverter input power factor	Approximately 88% of the power factor improving effect can be obtained (92.3% when calculated with 1 power factor for the fundamental wave according to the Architectural Standard Specifications (Electrical Installation) (2010 revision) supervised by the Ministry of Land, Infrastructure, Transport and Tourism of Japan).)	Approximately 93% of the power factor improving effect can be obtained (94.4% when calculated with 1 power factor for the fundamental wave according to the Architectural Standard Specifications (Electrical Installation) (2010 revision) supervised by the Ministry of Land, Infrastructure, Transport and Tourism of Japan).)
6)	Power coordination effect	Yes	Yes
7)	Voltage drop	About 2%	1% or less
8)	Standard price ratio (catalog value)	1	0.43 to 0.75
9)	Applicable inverter	All the FR series inverters (The FR-A701 series inverters have built-in AC reactors.)	All the FR series inverters (except the FR-A701 series and the single-phase 100V power input models)

6.3 Harmonic suppression technique using power factor improving capacitor

(1) Outline

A power factor improving capacitor has small impedance for harmonics, so harmonic currents concentrate on that capacitor. Using a power factor improving capacitor with a series reactor absorbs harmonic current escaping to a power receiving point.
A power factor correction capacitor may either be installed in the high or low voltage side. A power factor correction capacitor installed in the low voltage side has a higher (about twice as large) absorption effect than a power factor correction capacitor of the same capacity installed on the high voltage side.

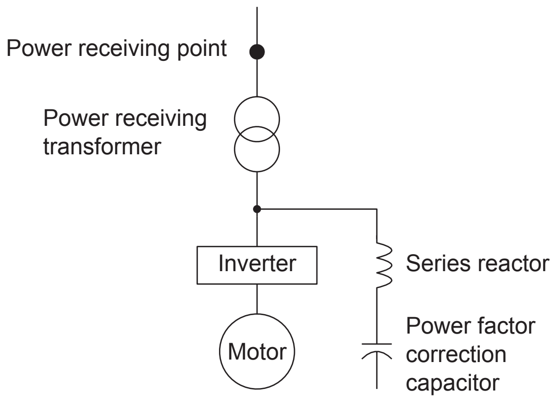


Fig. 6.1 System Example

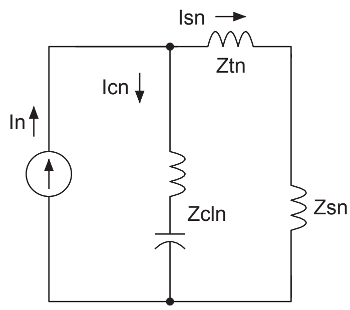


Fig. 6.2 Equivalent Circuit

(2) Absorption effect

The harmonic current absorption effect of the equivalent circuit in Fig. 6.2 is represented by the following equations:

1) High-voltage power factor correction capacitor

$$I_{sn} = I_n \times \frac{Z_{cln}}{Z_{sn} \times Z_{cln}}$$

2) Low-voltage power factor correction capacitor

$$I_{sn} = I_n \times \frac{Z_{cln}}{Z_{sn} + Z_{tn} + Z_{cln}}$$

(3) Precautions for use

1) High-voltage power factor correction capacitor
   - A series reactor must be installed. Harmonics may increase depending on the reactance value.

Reactance of Series Reactor	Permissible Fifth Voltage Distortion Factor when IC5 = 35%	Fifth Harmonic Current Content when V5 = 3.5%	Harmonic increase		Remarks
			Third	Fifth or more	
6%	3.5%	35.0%	May increase	No increase	Conventional series reactor
8%	7.6%	16.1%	May increase	No increase	About twice the suppression effect Slightly larger size and higher cost
13%	18.1%	6.8%	No increase	No increase	About five times the suppression effect Considerably larger size and higher cost

2) Low-voltage power factor correction capacitor
   - Select a power factor correction capacitor capacity appropriate for the load (guide to a low-voltage capacitor capacity is 1/3 of transformer capacity).
   - Select an inverter capacity to satisfy the condition that the series reactor is not overloaded (permissible limit: 35%) by absorbed harmonics.
   - To prevent a leading power factor under light load, adopt automatic power factor control.

6.4 Harmonic suppression technique using multi-phase transformers

(1) Configuration

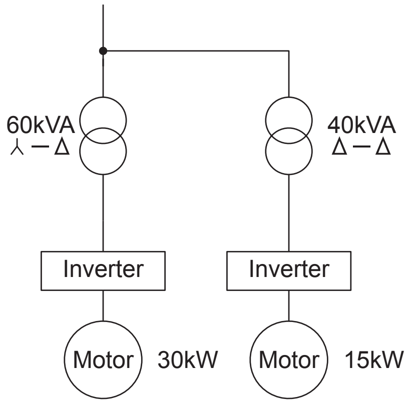


Fig. 6.3 Multi-Phase Operation Example

Use two or more transforms at 30° phase-angle differences, such as ⅄-Δ and Δ-Δ. Different peak current timings of the transforms produce a harmonic suppression effect equivalent to that of a 12-pulse converter.
Even if different-capacity transforms (imbalanced loads) are used, the smaller transformer produces an effect equivalent to that of a 12-pulse converter. Thus, harmonics are suppressed.
Same-capacity transformers suppress harmonic currents to about half.
Simply using multi-phase transformers with the inverter may not satisfy the requirements of the specific consumer guideline. Use other techniques in that case.

(2) Points about reduction effect

When 30kW and 15kW motors are driven by inverters as shown above:

1) When there is one 100kVA power transformer
Since currents from the power supply flow to both lines at the same time, the sum of escaping harmonic currents for the 30kW and 15kW (45kW) inverter-driven motors must be calculated.
2) When there are two ⅄-Δ and Δ-Δ power transformers
Since currents from the power supply flow at 30° phase-angle differences, escaping harmonic currents of two lines need not be summed. The outgoing harmonic current of the larger capacity line (i.e. 30kW) is only calculated.

When the two lines have the same capacity, outgoing harmonic currents are suppressed to 1/2.

(3) Precautions for application

1) ⅄-⅄ transformer
As the third harmonics escape to the system, it is wiser to use a Δ connection transformer for either of the primary or secondary winding, with the exception for small capacities.
2) Δ connection 400V circuit
Use transformers equipped with short-circuit prevention plates for a 400V circuit with primary winding of high-voltage and secondary winding of Δ connection.

6.5 Harmonic suppression technique using AC filter

(1) Outline

Like the power factor improving capacitor, a capacitor and a reactor are used together to make up an AC filter so that impedance is minimized by series resonance at specific frequencies (degrees) to satisfy the requirements of the specific consumer guideline. The AC filter will produce a large harmonic current absorption effect.

When there is more than one excessive harmonic, an AC filter must be installed for each degree. This allows the inverter to satisfy the requirements of the specific consumer guideline.

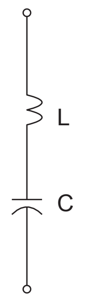


Fig. 6.4 Basic Circuit of AC Filter

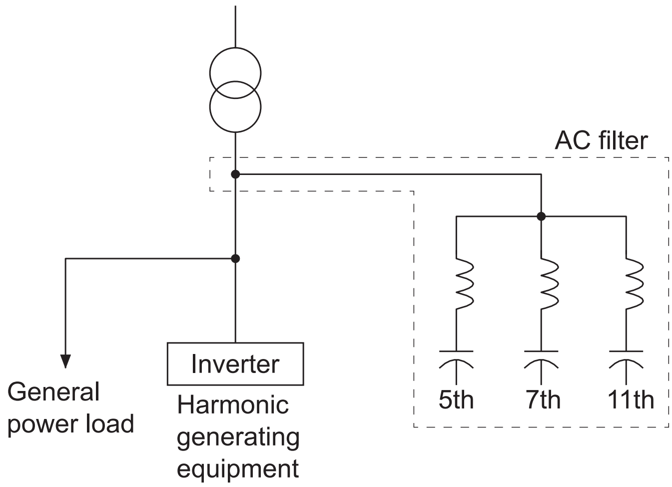


Fig. 6.5 AC Filter Connection Side

(2) Model selection

Select a combination of capacitor and reactor for a harmonic of each degree requiring the suppression technique.

1) Selection method
   Specify the following items:
   - Voltage : Voltage of the circuit in which the AC filter will be connected [V]
   - Capacity : Capacity of the motor driven by the inverter [kW]
   - Degree : Degree of harmonic which must be suppressed

2) Recommended AC filter model
   - RG-2 capacitor of Shizuki Electric
   - LR-L reactor of Shizuki Electric

(3) Precautions

1) The AC filter can be made more compact by using ACL or DCL with the inverter.
2) To prevent a leading power factor, it is desirable to switch the AC filter ON/OFF according to inverter operation.

6.6 Harmonic suppression technique using active filter

(1) Outline

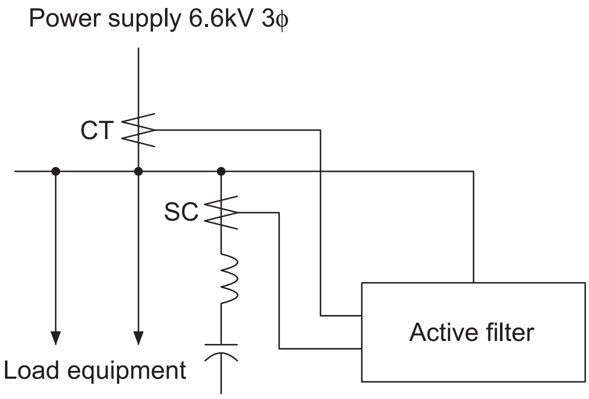


Fig. 6.6 Active Filter Connection Example

An active filter detects the current of a harmonic current generating circuit and generates a harmonic current equivalent to a difference between the detected harmonic current and fundamental wave current to suppress the harmonic current at the detection point.
Compensating for a whole waveform, a single filter can be used for suppression of more than one harmonic degree.
An active filter's harmonic absorption capacity decreases at an inflow of excessive harmonic current. However, it is resistant to overheating and burning because it is equipped with the protective function.

The active filter can allow the inverter satisfy the requirements of the specific consumer guideline.

(2) Capacity selection

Select the capacity of the active filter according to the magnitude of an excess harmonic*, not according to that of a circuit current.

Active filter capacity = $\sqrt{3}$ × overall harmonic current [A] × circuit voltage [kV] × absorption factor

* Excess harmonic: Harmonic component in excess of the maximum guideline value

1) Recommended active filter model
   MELACT-3100H series of
   TOSHIBA MITSUBISHI-ELECTRIC INDUSTRIAL SYSTEMS CORPORATION
   Precautions for use
   - Harmonic degrees that may be suspended are second to 25th degrees.
   - If an instantaneous power failure occurs, the active filter restarts automatically when power restores.
   - When a capacitor is connected below the load current detection circuit, a capacitor load current signal must be input to prevent an unstable operation.

* Refer below for more information on the active filter, such as specific capacity selection:
TOSHIBA MITSUBISHI-ELECTRIC INDUSTRIAL SYSTEMS CORPORATION

7. GUIDELINE ENFORCEMENTS (IN JAPAN)

The "harmonic suppression guideline for consumers receiving power of high voltage or specially high voltage" established in September, 1994 is not a regulation and does not have penal provisions. A consumer, however, must consult an electric power supplier when the consumer requests power supply or in other occasions.

(1) Consultation with electric power supplier

As a consultation process, each electric power supplier provides the following forms (refer to the Appendices) to consumers and requires them to submit the completed forms.

1) Calculation sheet for outgoing harmonic currents from harmonic generating equipment (Part 1)
   A consumer who will install new harmonic generating equipment must make calculations and submit this sheet.
   (For specific entry example, refer to Section 5.1.)

2) Data of outgoing harmonic currents from harmonic generating equipment
   This data is used for reference to make calculations and has values needed to calculate outgoing harmonic currents. For transistorized inverters, a calculation method is defined separately by the Japan Electrical Manufacturers' Association and this data need not be referred to.
   For specific calculation, refer to Sections 4, and 5 in this Technical Note.

3) Calculation sheet for outgoing harmonic currents from harmonic generating equipment (Part 2)
   A consumer who already has equipment which suppresses/absorbs harmonics must make calculations and submit this sheet.

4) Harmonic generating equipment manufacturer's application
   A consumer who will use any equipment that has a special circuit structure not set forth in the guideline should submit this application made by an equipment manufacturer. For transistorized inverters, this application need not to be submitted.

When a consumer makes calculations according to this data, whether or not a harmonic suppression technique is required will be made clear. When a suppression technique is required, a specific method and schedule will be discussed between the electric power supplier and consumer.

8. QUESTIONS AND ANSWERS

Category	No.	Question	Answer
Application of guideline	1	When the motor and inverter are different in capacity, how far will the household appliance and general-purpose product guideline apply?	Inverters were excluded from the target products of the "household appliance and general-purpose product guideline" in January 2004, and all the models have become the target products of the "specific consumer guideline".
	2	When the motor and inverter are different in capacity, how should I calculate outgoing harmonic currents?	Calculate outgoing harmonic currents according to the motor capacity. (Example) When using a 5.5kW motor and a 7.5K inverter, calculate with the fundamental wave current of 5.5kW.
	3	How do generated harmonics change depending on the inverter series?	It is assumed to be the same regardless of the inverter series.
	4	When two or more motors are connected to one inverter, how should I calculate?	Calculate with the sum of capacities of motors connected to one inverter.
	5	How should I calculate the operation ratio for repeated operation?	Calculate the operation time ratio of the most-operated 30 minutes, then multiply the ratio by the load condition.
	6	How does the guideline apply to a power regenerative converter?	Applies in a similar manner for an inverter.
	7	When the motor capacity is one other than those given in Table 4.1, how should I calculate the rated capacity and fundamental wave current?	Use the closest capacity in Table 4.1 as a reference and calculate the values in proportion to the values of the closest capacity.
Harmonic suppression technique	8	Even when the active filter or AC filter is used for suppression, is the AC or DC reactor required?	It will be more advantageous to use a reactor with the inverter as the capacity of the active filter or AC filter can be reduced.
	9	Why is the harmonic content different between the AC and DC reactors?	Harmonic contents are different because the circuit configurations and inductances are different for AC and DC reactors.
	10	Which manufacturer's reactor is recommended?	We recommend our optional reactor.
Contracted power	11	How are high voltage and specially high voltage categorized?	3.3kV and 6.6kV are defined as high voltage and 11kV and higher as specially high voltage.

9. APPENDICES

9.1 Examination formats (in JAPAN)

Calculation sheet for outgoing harmonic currents from harmonic generating equipment (Part 1)

Customer name		Business Category		Received Power Voltage	kV	Contracted (equipment) power	kW

Date of Application	
Application No.	
Date of Acceptance	

STEP 1 HARMONIC GENERATING EQUIPMENT PARTICULARS											STEP 2 GENERATED HARMONIC CURRENT CALCULATION									
Harmonic Generating Equipment				2) Rated Capacity	3) Qty (Newly added or renewed units)	4) (2) × 3)) Total Capacity	5) Circuit Class No.	6) 6-Pulse Conversion Factor	7) (4) × 6)) 6-Pulse Equivalent Capacity		8) (4) × k)) Rated Current Converted from Received Power Voltage	9) Max. Equipment Operation Ratio	10) (8) × 9) × 10)) Outgoing Harmonic Current by Degrees							
No.	Equipment name	Manufacturer	Model	(kVA)		(kVA)		Ki	(kVA)		(mA)	(%)	5 th	7 th	th	th	th	th	th	th
1																				
2																				
3																				
4																				
5																				
6																				
7																				
8																				
9																				
10																				
11																				
12																				
13																				
14																				
15																				
16																				
17																				
					Sum of 6-pulse equivalent capacities						Total									
											Judgment of technique requirement									

To customer

Refer to the entry method described on the back, and complete the columns under STEP 1

If the sum of 6-pulse equivalent capacities satisfies the following conditions based on the values written under STEP 1, complete the columns under STEP 2.

Received power voltage	6.6kV	22 to 33kV	66kV or more
Sum of 6-pulse equivalent apacities	Exceeds 50kVA	Exceeds 300kVA	Exceeds 2000kVA

* "a)" indicates the harmonic current occurrence ratio, "b)" indicates the maximum outgoing harmonic current per 1kW contracted power, and "k" indicates the rated current per 1kVA equipment power. Find more details on the back.

11) Maximum outgoing harmonic current (1) × b))								
Degree	5 th	7 th	th	th	th	th	th	th
Maximum current value (mA)								

Chief engineer		TEL
Construction company	Person in charge	TEL

Calculation sheet for outgoing harmonic currents from harmonic generating equipment (Part 2)

Date of Application	
Application No.	
Date of Acceptance	

Customer name		Business Category		Received Power Voltage	kV	Contracted (equipment) power	kW

In-Plant Single-Wire Connection Diagram	[Write down installation areas, characteristics, and electric constants, etc. of the devices which suppress (divide) or enhance harmonic current. Examples include harmonic generating devices and power receiving point transformers.]

Detailed calculation method of the outgoing harmonic current	[Specifically write down the calculation method of the outgoing harmonic current. The calculation method should include equipment that suppresses (enhances) harmonic current and effects of flow-dividing techniques.]

Degree	5 th	7 th	th	th	th	th	th	th
Outgoing harmonic current in calculation sheet (part 1) (mA)								
Outgoing harmonic current after consideration of reduction effect (mA)								
Maximum outgoing harmonic current value (mA)								
Judgment of suppression technique requirement								

* Note: If it is difficult to draw an in-plant single-line diagram or a detailed calculation method of the harmonic current in this format, please write them down on a separate sheet and attach the sheet as reference material. If the outgoing harmonic current still exceeds the maximum outgoing harmonic current in any harmonic degree even after taking suppression measures, additional measure is required.

Chief engineer		TEL
Construction company	Person in charge	TEL

Harmonic generating equipment manufacturer's application

Harmonic generating equipment No.	
Harmonic generating equipment name	

Customer name	
Business Category	

Date of Application	
Application No.	
Date of Acceptance	

HARMONIC GENERATING EQUIPMENT SPECIFICATIONS				Generation Ratio of Harmonic Current to Fundamental Wave Current (%)								
Manufacturer Name	Model	Rated Capacity (kVA)	Operating Voltage (V)	Degree (n)	5th	7th	th	th	th	th	th	th
				Generation ratio (%in)								

6-Pulse Conversion Factor Ki

Basic Circuit Diagram of Equipment	[Please draw the diagram focusing on the harmonic-generating equipment.]

*The 6-pulse conversion factor Ki is found by the following equation:

$$Ki = \frac{\sqrt{\Sigma(n \times \%In)^2}}{139}$$

Spectrum Representing the Amount of Harmonic Components Generated

Written by	Person in charge	TEL

9.2 Inverter-generated harmonic amount charts

The following charts list outgoing harmonic currents per motor.
When the motor capacity has been determined, escaping harmonic currents from the inverter can be found easily by the following equation without needing to make complicated calculation:

- **Outgoing harmonic current = (outgoing harmonic current of corresponding degree in the chart) × quantity × operation ratio (fraction) [mA]**

  Example: When two 45kW motors are run by the inverter at the operation ratio of 35%, the fifth outgoing harmonic current converted from 6.6kV is as follows:

  $I_5 = 2896 \times 2 \times 0.35 = 2027.2$ [mA]

(1) 200V transistorized inverter without reactor

- Conditions:

  Received power voltage: 6.6kV Max. operation ratio: 100%

STEP 1 HARMONIC GENERATING EQUIPMENT PARTICULARS										STEP 2 GENERATED HARMONIC CURRENT CALCULATION										
	Harmonic Generating Equipment			Rated Capacity (kVA)	Qty	Total Capacity Pi (kVA)	Circuit Class No	6-Pulse Conversion Factor	6-Pulse Equivalent Capacity (kVA)	Rated Current Converted from Received Power Voltage (6.6kV) (mA)	Max. Equipment Operation Ratio (%)	Outgoing Harmonic Current by Degrees								
No.	Equipment name	Manufacturer	Motor capacity									5th	7th	11th	13th	17th	19th	23rd	25th
1	200V transistorized inverter without reactor		0.4kW	0.57	1	0.57	31	3.4	1.9	49	100	31.9	20.1	4.2	3.8	2.1	1.5	1.3	0.9
2			0.75kW	0.97	1	0.97	31	3.4	3.3	83	100	54.0	34.0	7.1	6.4	3.6	2.6	2.2	1.5
3			1.5kW	1.95	1	1.95	31	3.4	6.6	167	100	109	68.5	14.2	12.9	7.2	5.2	4.3	3.0
4			2.2kW	2.81	1	2.81	31	3.4	9.6	240	100	156	98.4	20.4	18.5	10.3	7.4	6.2	4.3
5			3.7kW	4.61	1	4.61	31	3.4	15.7	394	100	256	162	33.5	30.3	16.9	12.2	10.2	7.1
6			5.5kW	6.77	1	6.77	31	3.4	23.0	579	100	376	237	49.2	44.6	24.9	17.9	15.1	10.4
7			7.5kW	9.07	1	9.07	31	3.4	30.8	776	100	504	318	66.0	59.8	33.4	24.1	20.2	14.0
8			11kW	13.1	1	13.1	31	3.4	44.5	1118	100	727	458	95.0	86.1	48.1	34.7	29.1	20.1
9			15kW	17.6	1	17.6	31	3.4	59.8	1509	100	981	619	128	116	64.9	46.8	39.2	27.2
10			18.5kW	21.8	1	21.8	31	3.4	74.1	1861	100	1210	763	158	143	80.0	57.7	48.4	33.5
11			22kW	25.9	1	25.9	31	3.4	88.1	2215	100	1440	908	188	171	95.2	68.7	57.6	39.9
12			30kW	34.7	1	34.7	31	3.4	118	2970	100	1931	1218	252	229	128	92.1	77.2	53.5
13			37kW	42.8	1	42.8	31	3.4	146	3667	100	2384	1503	312	282	158	114	95.3	66.0
14			45kW	52.1	1	52.1	31	3.4	177	4455	100	2896	1827	379	343	192	138	116	80.2
15			55kW	63.7	1	63.7	31	3.4	217	5455	100	3546	2237	464	420	235	169	142	98.2
16			75kW	87.2	1	87.2	31	3.4	296	7424	100	4826	3044	631	572	319	230	193	134
17			90kW	104	1	104	31	3.4	354	8879	100	5771	3640	755	684	382	275	231	160
18			110kW	127	1	127	31	3.4	432	10818	100	7032	4435	920	833	465	335	281	195

	5th	7th	11th	13th	17th	19th	23rd	25th
Maximum outgoing harmonic current value (mA/kW)	3.5	2.5	1.6	1.3	1.0	0.9	0.76	0.70
Harmonic current content (%)	65	41	8.5	7.7	4.3	3.1	2.6	1.8

(2) 200V transistorized inverter with AC reactor

- Conditions:

  Received power voltage: 6.6kV   Max. operation ratio: 100%

STEP 1 HARMONIC GENERATING EQUIPMENT PARTICULARS										STEP 2 GENERATED HARMONIC CURRENT CALCULATION										
	Harmonic Generating Equipment			Rated Capacity (kVA)	Qty	Total Capacity Pi (kVA)	Circuit Class No.	6-Pulse Conversion Factor	6-Pulse Equivalent Capacity (kVA)	Rated Current Converted from Received Power Voltage (6.6kV) (mA)	Max. Equipment Operation Ratio (%)	Outgoing Harmonic Current by Degrees								
No.	Equipment name	Manufacturer	Motor capacity									5th	7th	11th	13th	17th	19th	23rd	25th
1	200V transistorized inverter with AC reactor		0.4kW	0.57	1	0.57	32	1.8	1.0	49	100	18.6	7.1	3.6	1.7	1.6	0.9	0.8	0.6
2			0.75kW	0.97	1	0.97	32	1.8	1.7	83	100	31.5	12.0	6.1	2.8	2.7	1.6	1.4	1.1
3			1.5kW	1.95	1	1.95	32	1.8	3.5	167	100	63.5	24.2	12.4	5.7	5.3	3.2	2.8	2.2
4			2.2kW	2.81	1	2.81	32	1.8	5.1	240	100	91.2	34.8	17.8	8.2	7.7	4.6	4.1	3.1
5			3.7kW	4.61	1	4.61	32	1.8	8.3	394	100	150	57.1	29.2	13.4	12.6	7.5	6.7	5.1
6			5.5kW	6.77	1	6.77	32	1.8	12.2	579	100	220	84.0	42.8	19.7	18.5	11.0	9.8	7.5
7			7.5kW	9.07	1	9.07	32	1.8	16.3	776	100	295	113	57.4	26.4	24.8	14.7	13.2	10.1
8			11kW	13.1	1	13.1	32	1.8	23.6	1118	100	425	162	82.7	38.0	35.8	21.2	19.0	14.5
9			15kW	17.6	1	17.6	32	1.8	31.7	1509	100	573	219	112	51.3	48.3	28.7	25.7	19.6
10			18.5kW	21.8	1	21.8	32	1.8	39.2	1861	100	707	270	138	63.3	59.6	35.4	31.6	24.2
11			22kW	25.9	1	25.9	32	1.8	46.6	2215	100	842	321	164	75.3	70.9	42.1	37.7	28.8
12			30kW	34.7	1	34.7	32	1.8	62.5	2970	100	1129	431	220	101	95.0	56.4	50.5	38.6
13			37kW	42.8	1	42.8	32	1.8	77.0	3667	100	1393	532	271	125	117	69.7	62.3	47.7
14			45kW	52.1	1	52.1	32	1.8	93.8	4455	100	1693	646	330	151	143	84.6	75.7	57.9
15			55kW	63.7	1	63.7	32	1.8	115	5455	100	2073	791	404	185	175	104	92.7	70.9
16			75kW	87.2	1	87.2	32	1.8	157	7424	100	2821	1076	549	252	238	141	126	96.5
17			90kW	104	1	104	32	1.8	187	8879	100	3374	1287	657	302	284	169	151	115
18			110kW	127	1	127	32	1.8	229	10818	100	4111	1569	801	368	346	206	184	141

	5th	7th	11th	13th	17th	19th	23rd	25th
Maximum outgoing harmonic current value (mA/kW)	3.5	2.5	1.6	1.3	1.0	0.9	0.76	0.70
Harmonic current content (%)	38	14.5	7.4	3.4	3.2	1.9	1.7	1.3

(3) 200V transistorized inverter with DC reactor

- Conditions:

  Received power voltage: 6.6kV   Max. operation ratio: 100%

STEP 1 HARMONIC GENERATING EQUIPMENT PARTICULARS											STEP 2 GENERATED HARMONIC CURRENT CALCULATION									
	Harmonic Generating Equipment									Rated Current Converted from Received Power Voltage (6.6kV) (mA)	Max. Equipment Operation Ratio (%)	Outgoing Harmonic Current by Degrees							
No.	Equipment name	Manufacturer	Motor capacity	Rated Capacity (kVA)	Qty	Total Capacity Pi (kVA)	Circuit Class No.	6-Pulse Conversion Factor	6-Pulse Equivalent Capacity (kVA)			5th	7th	11th	13th	17th	19th	23rd	25th
1	200V transistorized inverter with DC reactor		0.4kW	0.57	1	0.57	33	1.8	1.0	49	100	14.7	6.4	4.1	2.5	2.3	1.6	1.5	1.1
2			0.75kW	0.97	1	0.97	33	1.8	1.7	83	100	24.9	10.8	7.0	4.2	3.9	2.7	2.5	1.8
3			1.5kW	1.95	1	1.95	33	1.8	3.5	167	100	50.1	21.7	14.0	8.4	7.8	5.3	5.0	3.7
4			2.2kW	2.81	1	2.81	33	1.8	5.1	240	100	72.0	31.2	20.2	12.0	11.3	7.7	7.2	5.3
5			3.7kW	4.61	1	4.61	33	1.8	8.3	394	100	118	51.2	33.1	19.7	18.5	12.6	11.8	8.7
6			5.5kW	6.77	1	6.77	33	1.8	12.2	579	100	174	75.3	48.6	29.0	27.2	18.5	17.4	12.7
7			7.5kW	9.07	1	9.07	33	1.8	16.3	776	100	233	101	65.2	38.8	36.5	24.8	23.3	17.1
8			11kW	13.1	1	13.1	33	1.8	23.6	1118	100	335	145	93.9	55.9	52.5	35.8	33.5	24.6
9			15kW	17.6	1	17.6	33	1.8	31.7	1509	100	453	196	127	75.5	70.9	48.3	45.3	33.2
10			18.5kW	21.8	1	21.8	33	1.8	39.2	1861	100	558	242	156	93.1	87.5	59.6	55.8	40.9
11			22kW	25.9	1	25.9	33	1.8	46.6	2215	100	665	288	186	111	104	70.9	66.5	48.7
12			30kW	34.7	1	34.7	33	1.8	62.5	2970	100	891	386	249	149	140	95.0	89.1	65.3
13			37kW	42.8	1	42.8	33	1.8	77.0	3667	100	1100	477	308	183	172	117	110	80.7
14			45kW	52.1	1	52.1	33	1.8	93.8	4455	100	1337	579	374	223	209	143	134	98.0
15			55kW	63.7	1	63.7	33	1.8	115	5455	100	1637	709	458	273	256	175	164	120
16			75kW	87.2	1	87.2	33	1.8	157	7424	100	2227	965	624	371	349	238	223	163
17			90kW	104	1	104	33	1.8	187	8879	100	2664	1154	746	444	417	284	266	195
18			110kW	127	1	127	33	1.8	229	10818	100	3245	1406	909	541	508	346	325	238

	5th	7th	11th	13th	17th	19th	23rd	25th
Maximum outgoing harmonic current value (mA/kW)	3.5	2.5	1.6	1.3	1.0	0.9	0.76	0.70
Harmonic current content (%)	30	13	8.4	5.0	4.7	3.2	3.0	2.2

(4) 200V transistorized inverter with AC and DC reactors

- Conditions:

  Received power voltage: 6.6kV   Max. operation ratio: 100%

STEP 1 HARMONIC GENERATING EQUIPMENT PARTICULARS											STEP 2 GENERATED HARMONIC CURRENT CALCULATION										
No.	Harmonic Generating Equipment: Equipment name	Manufacturer	Motor capacity	Rated Capacity (kVA)	Qty	Total Capacity Pi (kVA)	Circuit Class No.	6-Pulse Conversion Factor	6-Pulse Equivalent Capacity (kVA)		Rated Current Converted from Received Power Voltage (6.6kV) (mA)	Max. Equipment Operation Ratio (%)	Outgoing Harmonic Current by Degrees: 5th	7th	11th	13th	17th	19th	23rd	25th	
1	200V transistorized inverter		0.4kW	0.57	1	0.57	34	1.4	0.8		49	100	13.7	4.5	3.5	2.0	1.6	1.2	0.8	0.7	
2	with AC and DC reactors		0.75kW	0.97	1	0.97	34	1.4	1.4		83	100	23.2	7.6	6.0	3.4	2.7	2.0	1.3	1.2	
3			1.5kW	1.95	1	1.95	34	1.4	2.7		167	100	46.8	15.2	12.0	6.8	5.3	4.0	2.7	2.3	
4			2.2kW	2.81	1	2.81	34	1.4	3.9		240	100	67.2	21.8	17.3	9.8	7.7	5.8	3.8	3.4	
5			3.7kW	4.61	1	4.61	34	1.4	6.5		394	100	110	35.9	28.4	16.2	12.6	9.5	6.3	5.5	
6			5.5kW	6.77	1	6.77	34	1.4	9.5		579	100	162	52.7	41.7	23.7	18.5	13.9	9.3	8.1	
7			7.5kW	9.07	1	9.07	34	1.4	12.7		776	100	217	70.6	55.9	31.8	24.8	18.6	12.4	10.9	
8			11kW	13.1	1	13.1	34	1.4	18.3		1118	100	313	102	80.5	45.8	35.8	26.8	17.9	15.7	
9			15kW	17.6	1	17.6	34	1.4	24.6		1509	100	423	137	109	61.9	48.3	36.2	24.1	21.1	
10			18.5kW	21.8	1	21.8	34	1.4	30.5		1861	100	521	169	134	76.3	59.6	44.7	29.8	26.1	
11			22kW	25.9	1	25.9	34	1.4	36.3		2215	100	620	202	159	90.8	70.9	53.2	35.4	31.0	
12			30kW	34.7	1	34.7	34	1.4	48.6		2970	100	832	270	214	122	95.0	71.3	47.5	41.6	
13			37kW	42.8	1	42.8	34	1.4	59.9		3667	100	1027	334	264	150	117	88.0	58.7	51.3	
14			45kW	52.1	1	52.1	34	1.4	72.9		4455	100	1247	405	321	183	143	107	71.3	62.4	
15			55kW	63.7	1	63.7	34	1.4	89.2		5455	100	1527	496	393	224	175	131	87.3	76.4	
16			75kW	87.2	1	87.2	34	1.4	122		7424	100	2079	676	535	304	238	178	119	104	
17			90kW	104	1	104	34	1.4	146		8879	100	2486	808	639	364	284	213	142	124	
18			110kW	127	1	127	34	1.4	178		10818	100	3029	984	779	444	346	260	173	151	

	5th	7th	11th	13th	17th	19th	23rd	25th
Maximum outgoing harmonic current value (mA/kW)	3.5	2.5	1.6	1.3	1.0	0.9	0.76	0.70
Harmonic current content (%)	28	9.1	7.2	4.1	3.2	2.4	1.6	1.4

(5) 400V transistorized inverter without reactor

- Conditions:

  Received power voltage: 6.6kV   Max. operation ratio: 100%

STEP 1 HARMONIC GENERATING EQUIPMENT PARTICULARS										STEP 2 GENERATED HARMONIC CURRENT CALCULATION										
	Harmonic Generating Equipment											Outgoing Harmonic Current by Degrees								
No.	Equipment name	Manufacturer	Motor capacity	Rated Capacity (kVA)	Qty	Total Capacity Pi (kVA)	Circuit Class No.	6-Pulse Conversion Factor	6-Pulse Equivalent Capacity (kVA)	Rated Current Converted from Received Power Voltage (6.6kV) (mA)	Max. Equipment Operation Ratio (%)	5th	7th	11th	13th	17th	19th	23rd	25th
1	400V transistorized inverter without reactor		0.4kW	0.57	1	0.57	31	3.4	1.9	49	100	31.9	20.1	4.2	3.8	2.1	1.5	1.3	0.9
2			0.75kW	0.97	1	0.97	31	3.4	3.3	83	100	54.0	34.0	7.1	6.4	3.6	2.6	2.2	1.5
3			1.5kW	1.95	1	1.95	31	3.4	6.6	167	100	109	68.5	14.2	12.9	7.2	5.2	4.3	3.0
4			2.2kW	2.81	1	2.81	31	3.4	9.6	240	100	156	98.4	20.4	18.5	10.3	7.4	6.2	4.3
5			3.7kW	4.61	1	4.61	31	3.4	15.7	394	100	256	162	33.5	30.3	16.9	12.2	10.2	7.1
6			5.5kW	6.77	1	6.77	31	3.4	23.0	579	100	376	237	49.2	44.6	24.9	17.9	15.1	10.4
7			7.5kW	9.07	1	9.07	31	3.4	30.8	776	100	504	318	66.0	59.8	33.4	24.1	20.2	14.0
8			11kW	13.1	1	13.1	31	3.4	44.5	1121	100	729	460	95.3	86.3	48.2	34.8	29.1	20.2
9			15kW	17.6	1	17.6	31	3.4	59.8	1509	100	981	619	128	116	64.9	46.8	39.2	27.2
10			18.5kW	21.8	1	21.8	31	3.4	74.1	1861	100	1210	763	158	143	80.0	57.7	48.4	33.5
11			22kW	25.9	1	25.9	31	3.4	88.1	2218	100	1442	909	189	171	95.4	68.8	57.7	39.9
12			30kW	34.7	1	34.7	31	3.4	118	2970	100	1931	1218	252	229	128	92.1	77.2	53.5
13			37kW	42.8	1	42.8	31	3.4	146	3661	100	2380	1501	311	282	157	113	95.2	65.9
14			45kW	52.1	1	52.1	31	3.4	177	4455	100	2896	1827	379	343	192	138	116	80.2
15			55kW	63.7	1	63.7	31	3.4	217	5448	100	3541	2234	463	419	234	169	142	98.1
16			75kW	87.2	1	87.2	31	3.4	296	7455	100	4846	3057	634	574	321	231	194	134
17			90kW	104	1	104	31	3.4	354	8909	100	5791	3653	757	686	383	276	232	160
18			110kW	127	1	127	31	3.4	432	10848	100	7051	4448	922	835	466	336	282	195
19			132kW	153	1	153	31	3.4	520	13091	100	8509	5367	1113	1008	563	406	340	236
20			160kW	183	1	183	31	3.4	622	15636	100	10163	6411	1329	1204	672	485	407	281
21			200kW	229	1	229	31	3.4	779	19576	100	12724	8026	1664	1507	842	607	509	352
22			220kW	252	1	252	31	3.4	857	21515	100	13985	8821	1829	1657	925	667	559	387
23			250kW	286	1	286	31	3.4	972	24424	100	15876	10014	2076	1881	1050	757	635	440
24			280kW	319	1	319	31	3.4	1085	27273	100	17727	11182	2318	2100	1173	845	709	491

	5th	7th	11th	13th	17th	19th	23rd	25th
Maximum outgoing harmonic current value (mA/kW)	3.5	2.5	1.6	1.3	1.0	0.9	0.76	0.70
Harmonic current content (%)	65	41	8.5	7.7	4.3	3.1	2.6	1.8

(6) 400V transistorized inverter with AC reactor

- Conditions:

  Received power voltage: 6.6kV   Max. operation ratio: 100%

STEP 1 HARMONIC GENERATING EQUIPMENT PARTICULARS											STEP 2 GENERATED HARMONIC CURRENT CALCULATION										
	Harmonic Generating Equipment			Rated Capacity (kVA)	Qty	Total Capacity Pi (kVA)	Circuit Class No.	6-Pulse Conversion Factor	6-Pulse Equivalent Capacity (kVA)		Rated Current Converted from Received Power Voltage (6.6kV) (mA)	Max. Equipment Operation Ratio (%)	Outgoing Harmonic Current by Degrees								
No.	Equipment name	Manufacturer	Motor capacity										5th	7th	11th	13th	17th	19th	23rd	25th	
1	400V transistorized inverter with AC reactor		0.4kW	0.57	1	0.57	32	1.8	1.0		49	100	18.6	7.1	3.6	1.7	1.6	0.9	0.8	0.6	
2			0.75kW	0.97	1	0.97	32	1.8	1.7		83	100	31.5	12.0	6.1	2.8	2.7	1.6	1.4	1.1	
3			1.5kW	1.95	1	1.95	32	1.8	3.5		167	100	63.5	24.2	12.4	5.7	5.3	3.2	2.8	2.2	
4			2.2kW	2.81	1	2.81	32	1.8	5.1		240	100	91.2	34.8	17.8	8.2	7.7	4.6	4.1	3.1	
5			3.7kW	4.61	1	4.61	32	1.8	8.3		394	100	150	57.1	29.2	13.4	12.6	7.5	6.7	5.1	
6			5.5kW	6.77	1	6.77	32	1.8	12.2		579	100	220	84.0	42.8	19.7	18.5	11.0	9.8	7.5	
7			7.5kW	9.07	1	9.07	32	1.8	16.3		776	100	295	113	57.4	26.4	24.8	14.7	13.2	10.1	
8			11kW	13.1	1	13.1	32	1.8	23.6		1121	100	426	163	83.0	38.1	35.9	21.3	19.1	14.6	
9			15kW	17.6	1	17.6	32	1.8	31.7		1509	100	573	219	112	51.3	48.3	28.7	25.7	19.6	
10			18.5kW	21.8	1	21.8	32	1.8	39.2		1861	100	707	270	138	63.3	59.6	35.4	31.6	24.2	
11			22kW	25.9	1	25.9	32	1.8	46.6		2218	100	843	322	164	75.4	71.0	42.1	37.7	28.8	
12			30kW	34.7	1	34.7	32	1.8	62.5		2970	100	1129	431	220	101	95.0	56.4	50.5	38.6	
13			37kW	42.8	1	42.8	32	1.8	77.0		3661	100	1391	531	271	124	117	69.6	62.2	47.6	
14			45kW	52.1	1	52.1	32	1.8	93.8		4455	100	1693	646	330	151	143	84.6	75.7	57.9	
15			55kW	63.7	1	63.7	32	1.8	115		5448	100	2070	790	403	185	174	104	92.6	70.8	
16			75kW	87.2	1	87.2	32	1.8	157		7455	100	2833	1081	552	253	239	142	127	96.9	
17			90kW	104	1	104	32	1.8	187		8909	100	3385	1292	659	303	285	169	151	116	
18			110kW	127	1	127	32	1.8	229		10848	100	4122	1573	803	369	347	206	184	141	
19			132kW	153	1	153	32	1.8	275		13091	100	4975	1898	969	445	419	249	223	170	
20			160kW	183	1	183	32	1.8	329		15636	100	5942	2267	1157	532	500	297	266	203	
21			200kW	229	1	229	32	1.8	412		19576	100	7439	2839	1449	666	626	372	333	254	
22			220kW	252	1	252	32	1.8	454		21515	100	8176	3120	1592	732	688	409	366	280	
23			250kW	286	1	286	32	1.8	515		24424	100	9281	3541	1807	830	782	464	415	318	
24			280kW	319	1	319	32	1.8	574		27273	100	10364	3955	2018	927	873	518	464	355	

	5th	7th	11th	13th	17th	19th	23rd	25th
Maximum outgoing harmonic current value (mA/kW)	3.5	2.5	1.6	1.3	1.0	0.9	0.76	0.70
Harmonic current content (%)	38	14.5	7.4	3.4	3.2	1.9	1.7	1.3

(7) 400V transistorized inverter with DC reactor

- Conditions:

  Received power voltage: 6.6kV   Max. operation ratio: 100%

STEP 1 HARMONIC GENERATING EQUIPMENT PARTICULARS										STEP 2 GENERATED HARMONIC CURRENT CALCULATION										
	Harmonic Generating Equipment			Rated Capacity (kVA)	Qty	Total Capacity Pi (kVA)	Circuit Class No.	6-Pulse Conversion Factor	6-Pulse Equivalent Capacity (kVA)	Rated Current Converted from Received Power Voltage (6.6kV) (mA)	Max. Equipment Operation Ratio (%)	Outgoing Harmonic Current by Degrees								
No.	Equipment name	Manufacturer	Motor capacity									5th	7th	11th	13th	17th	19th	23rd	25th
1	400V transistorized inverter with DC reactor		0.4kW	0.57	1	0.57	33	1.8	1.0	49	100	14.7	6.4	4.1	2.5	2.3	1.6	1.5	1.1
2			0.75kW	0.97	1	0.97	33	1.8	1.7	83	100	24.9	10.8	7.0	4.2	3.9	2.7	2.5	1.8
3			1.5kW	1.95	1	1.95	33	1.8	3.5	167	100	50.1	21.7	14.0	8.4	7.8	5.3	5.0	3.7
4			2.2kW	2.81	1	2.81	33	1.8	5.1	240	100	72.0	31.2	20.2	12.0	11.3	7.7	7.2	5.3
5			3.7kW	4.61	1	4.61	33	1.8	8.3	394	100	118	51.2	33.1	19.7	18.5	12.6	11.8	8.7
6			5.5kW	6.77	1	6.77	33	1.8	12.2	579	100	174	75.3	48.6	29.0	27.2	18.5	17.4	12.7
7			7.5kW	9.07	1	9.07	33	1.8	16.3	776	100	233	101	65.2	38.8	36.5	24.8	23.3	17.1
8			11kW	13.1	1	13.1	33	1.8	23.6	1121	100	336	146	94.2	56.1	52.7	35.9	33.6	24.7
9			15kW	17.6	1	17.6	33	1.8	31.7	1509	100	453	196	127	75.5	70.9	48.3	45.3	33.2
10			18.5kW	21.8	1	21.8	33	1.8	39.2	1861	100	558	242	156	93.1	87.5	59.6	55.8	40.9
11			22kW	25.9	1	25.9	33	1.8	46.6	2218	100	665	288	186	111	104	71.0	66.5	48.8
12			30kW	34.7	1	34.7	33	1.8	62.5	2970	100	891	386	249	149	140	95.0	89.1	65.3
13			37kW	42.8	1	42.8	33	1.8	77.0	3661	100	1098	476	308	183	172	117	110	80.5
14			45kW	52.1	1	52.1	33	1.8	93.8	4455	100	1337	579	374	223	209	143	134	98.0
15			55kW	63.7	1	63.7	33	1.8	115	5448	100	1634	708	458	272	256	174	163	120
16			75kW	87.2	1	87.2	33	1.8	157	7455	100	2237	969	626	373	350	239	224	164
17			90kW	104	1	104	33	1.8	187	8909	100	2673	1158	748	445	419	285	267	196
18			110kW	127	1	127	33	1.8	229	10848	100	3254	1410	911	542	510	347	325	239
19			132kW	153	1	153	33	1.8	275	13091	100	3927	1702	1100	655	615	419	393	288
20			160kW	183	1	183	33	1.8	329	15636	100	4691	2033	1313	782	735	500	469	344
21			200kW	229	1	229	33	1.8	412	19576	100	5873	2545	1644	979	920	626	587	431
22			220kW	252	1	252	33	1.8	454	21515	100	6455	2797	1807	1076	1011	688	645	473
23			250kW	286	1	286	33	1.8	515	24424	100	7327	3175	2052	1221	1148	782	733	537
24			280kW	319	1	319	33	1.8	574	27273	100	8182	3545	2291	1364	1282	873	818	600

	5th	7th	11th	13th	17th	11th	23rd	25th
Maximum outgoing harmonic current value (mA/kW)	3.5	2.5	1.6	1.3	1.0	0.9	0.76	0.70
Harmonic current content (%)	30	13	8.4	5.0	4.7	3.2	3.0	2.2

(8) 400V transistorized inverter with AC and DC reactors

- Conditions:

  Received power voltage: 6.6kV   Max. operation ratio: 100%

STEP 1 HARMONIC GENERATING EQUIPMENT PARTICULARS											STEP 2 GENERATED HARMONIC CURRENT CALCULATION									
	Harmonic Generating Equipment												Outgoing Harmonic Current by Degrees							
No.	Equipment name	Manufacturer	Motor capacity	Rated Capacity (kVA)	Qty	Total Capacity Pi (kVA)	Circuit Class No.	6-Pulse Conversion Factor	6-Pulse Equivalent Capacity (kVA)	Rated Current Converted from Received Power Voltage (6.6kV) (mA)	Max. Equipment Operation Ratio (%)	5th	7th	11th	13th	17th	19th	23rd	25h
1	400V transistorized inverter		0.4kW	0.57	1	0.57	34	1.4	0.8	49	100	13.7	4.5	3.5	2.0	1.6	1.2	0.8	0.7
2	with AC and DC reactors		0.75kW	0.97	1	0.97	34	1.4	1.4	83	100	23.2	7.6	6.0	3.4	2.7	2.0	1.3	1.2
3			1.5kW	1.95	1	1.95	34	1.4	2.7	167	100	46.8	15.2	12.0	6.8	5.3	4.0	2.7	2.3
4			2.2kW	2.81	1	2.81	34	1.4	3.9	240	100	67.2	21.8	17.3	9.8	7.7	5.8	3.8	3.4
5			3.7kW	4.61	1	4.61	34	1.4	6.5	394	100	110	35.9	28.4	16.2	12.6	9.5	6.3	5.5
6			5.5kW	6.77	1	6.77	34	1.4	9.5	579	100	162	52.7	41.7	23.7	18.5	13.9	9.3	8.1
7			7.5kW	9.07	1	9.07	34	1.4	12.7	776	100	217	70.6	55.9	31.8	24.8	18.6	12.4	10.9
8			11kW	13.1	1	13.1	34	1.4	18.3	1121	100	314	102	80.7	46.0	35.9	26.9	17.9	15.7
9			15kW	17.6	1	17.6	34	1.4	24.6	1509	100	423	137	109	61.9	48.3	36.2	24.1	21.1
10			18.5kW	21.8	1	21.8	34	1.4	30.5	1861	100	521	169	134	76.3	59.6	44.7	29.8	26.1
11			22kW	25.9	1	25.9	34	1.4	36.3	2218	100	621	202	160	90.9	71.0	53.2	35.5	31.1
12			30kW	34.7	1	34.7	34	1.4	48.6	2970	100	832	270	214	122	95.0	71.3	47.5	41.6
13			37kW	42.8	1	42.8	34	1.4	59.6	3661	100	1025	333	264	150	117	87.9	58.6	51.3
14			45kW	52.1	1	52.1	34	1.4	72.9	4455	100	1247	405	321	183	143	107	71.3	62.4
15			55kW	63.7	1	63.7	34	1.4	89.2	5448	100	1525	496	392	223	174	131	87.2	76.3
16			75kW	87.2	1	87.2	34	1.4	122	7455	100	2087	678	537	306	239	179	119	104
17			90kW	104	1	104	34	1.4	146	8909	100	2495	811	641	365	285	214	143	125
18			110kW	127	1	127	34	1.4	178	10848	100	3037	987	781	445	347	260	174	152
19			132kW	153	1	153	34	1.4	214	13091	100	3665	1191	943	537	419	314	209	183
20			160kW	183	1	183	34	1.4	256	15636	100	4378	1423	1126	641	500	375	250	219
21			200kW	229	1	229	34	1.4	321	19576	100	5481	1781	1409	803	626	470	313	274
22			220kW	252	1	252	34	1.4	353	21515	100	6024	1958	1549	882	688	516	344	301
23			250kW	286	1	286	34	1.4	400	24424	100	6839	2223	1759	1001	782	586	391	342
24			280kW	319	1	319	34	1.4	447	27273	100	7636	2482	1964	1118	873	655	436	382

	5th	7th	11th	13th	17th	19th	23rd	25th
Maximum outgoing harmonic current value (mA/kW)	3.5	2.5	1.6	1.3	1.0	0.9	0.76	0.70
Harmonic current content (%)	28	9.1	7.2	4.1	3.2	2.4	1.6	1.4

INVERTER