ADJUSTABLE SPEED DRIVES APPLICATION CONSIDERATIONS

DUPONT CANADA WORKSHOP

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1.0 INTRODUCTION

The use of adjustable speed drives (ASD) in industry is increasing and this trend is expected to continue, because of good economical advantages. This presentation covers the application of ASD to constant torque, variable torque and constant horsepower applications. It describes the principles of ASD, the use of solid state switching devices for power conversion and the basic types of ASD. It also highlights the harmonic problems encountered when using ASD for new or retrofit application and offers some possible solutions. Field harmonic measurements and heat run tests for constant torque application are discussed. The revised IEEE 519 standard for harmonic guidelines and Ontario Hydro harmonic requirements are reviewed.

2.0 PRINCIPLES OF ADJUSTABLE SPEED DRIVES

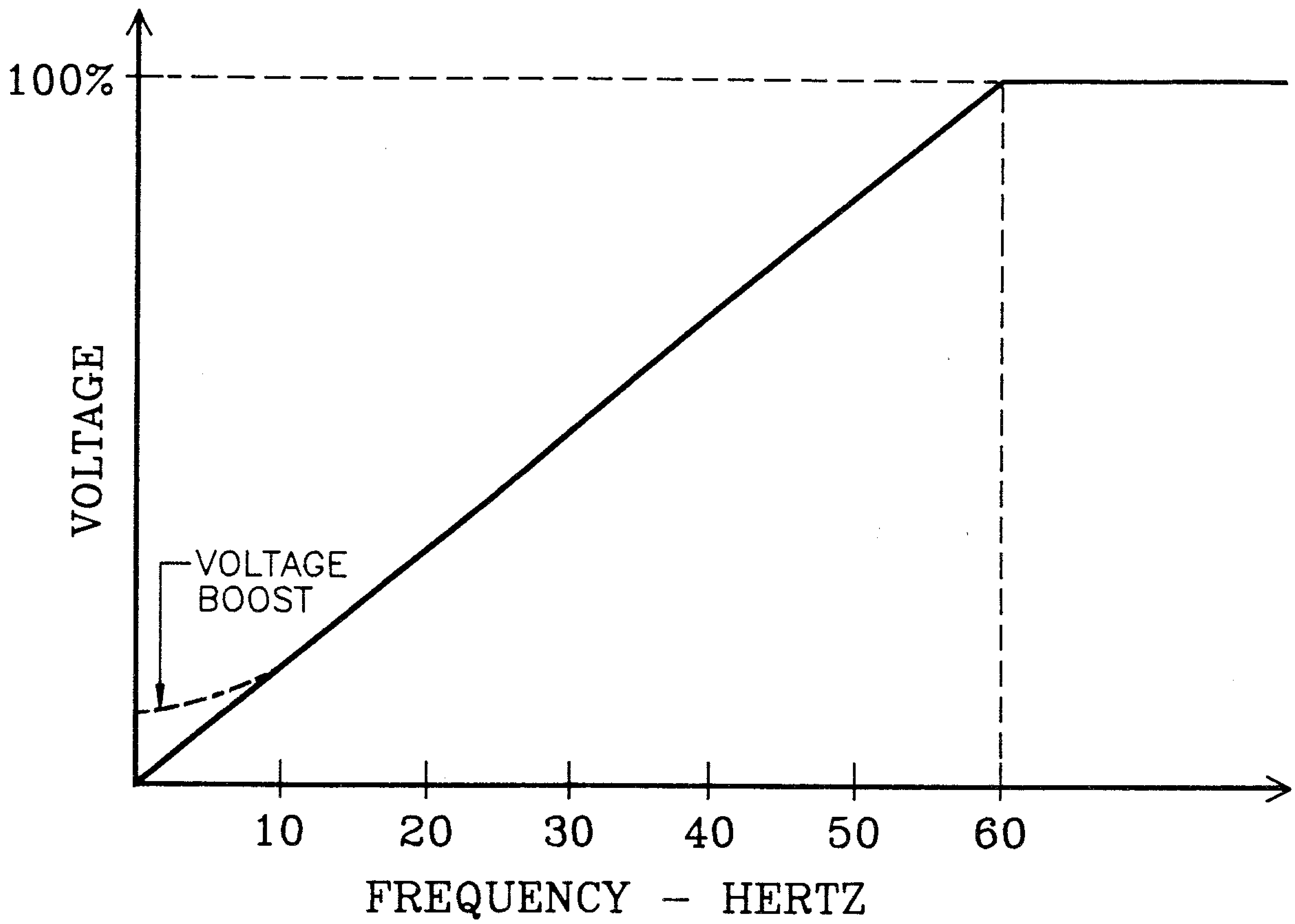
Solid state adjustable speed drives used with AC motor produce variable voltage and frequency to control the motors. Frequency is controlled in order to vary the speed of the motor:

$$\text{Speed} = \frac{120 \times \text{Frequency}}{\text{No. of Poles}}$$

Voltage is varied along with the frequency so that the flux density in the air gap between the rotor and stator, and therefore, the torque produced by the motor can be controlled. A constant relationship between voltage and frequency (volts/Hertz) must be maintained, see Figure 1, to optimize motor utilization and keep constant rated flux. At low frequency (below 10 Hz) voltage boost is necessary to compensate for voltage drop in the motor winding resistance. Higher or lower volts/Hertz ratio would result in over-excited or under-excited motor respectively, and improper motor utilization. For 575V motors the volts/Hertz ratio is 9.6 from low frequency to 60 Hz. Above 60 Hz the voltage is kept constant at rated value and only frequency is linearly increased, and this results in constant horsepower. The torque, in this case, is inversely proportional to speed, but their product is equal to constant horsepower.

FIG. 1

VOLTS / HERTZ REQUIREMENT FOR ASD



* REQUIREMENTS OF CONSTANT VOLTS / HERTZ APPLIES TO ALL TYPES OF ASD TO PRODUCE CONSTANT TORQUE CAPABILITY

* MOTOR SPEED = $\frac{120 \times \text{FREQUENCY}}{\text{NUMBER OF POLES}}$

Figure 2 shows the torque speed characteristics of an induction motor at different supply frequencies and constant volts/Hertz ratio.

3.0 SEMI-CONDUCTOR DEVICES

Power conversion in an adjustable speed drive is typically achieved by using one of the following four solid state switching devices in the inverter circuit.

- Thyristor
- Gate turn-off Thyristor (GTO)
- Bi-Polar transistor
- Insulated gate bi-polar transistor (IGBT).

The main difference between these switching devices are their ability to operate at higher voltage and current, with lower conduction and switching losses along with shorter switching times. The choice between devices depends largely on the manufacturer's experiences and drive size. For ASD application, one can essentially classify all semi-conductor devices into two broad categories:

1. Those devices which only require an impulse on their gate to be turned on. These are Thyristor type devices. Their primary limitation has traditionally been their switching speeds and switching losses. In addition, they may require some rather sophisticated external circuitry to allow their extinction as required by the control strategy to be fulfilled. The gate turn-off thyristor, featuring a second gate which allows it to be conveniently turned off, has not been universally accepted, probably due to the rather high gate current required by the turn off functionality.

2. Those devices which require a permanent current at their gate to keep them in the conducting state. These are the transistor type devices. While they require no external circuitry for turn on or turn off purposes, they have suffered, particularly at the higher unimpressive current gains. In addition, they have not enjoyed sufficiently high voltage ratings to be universally accepted.

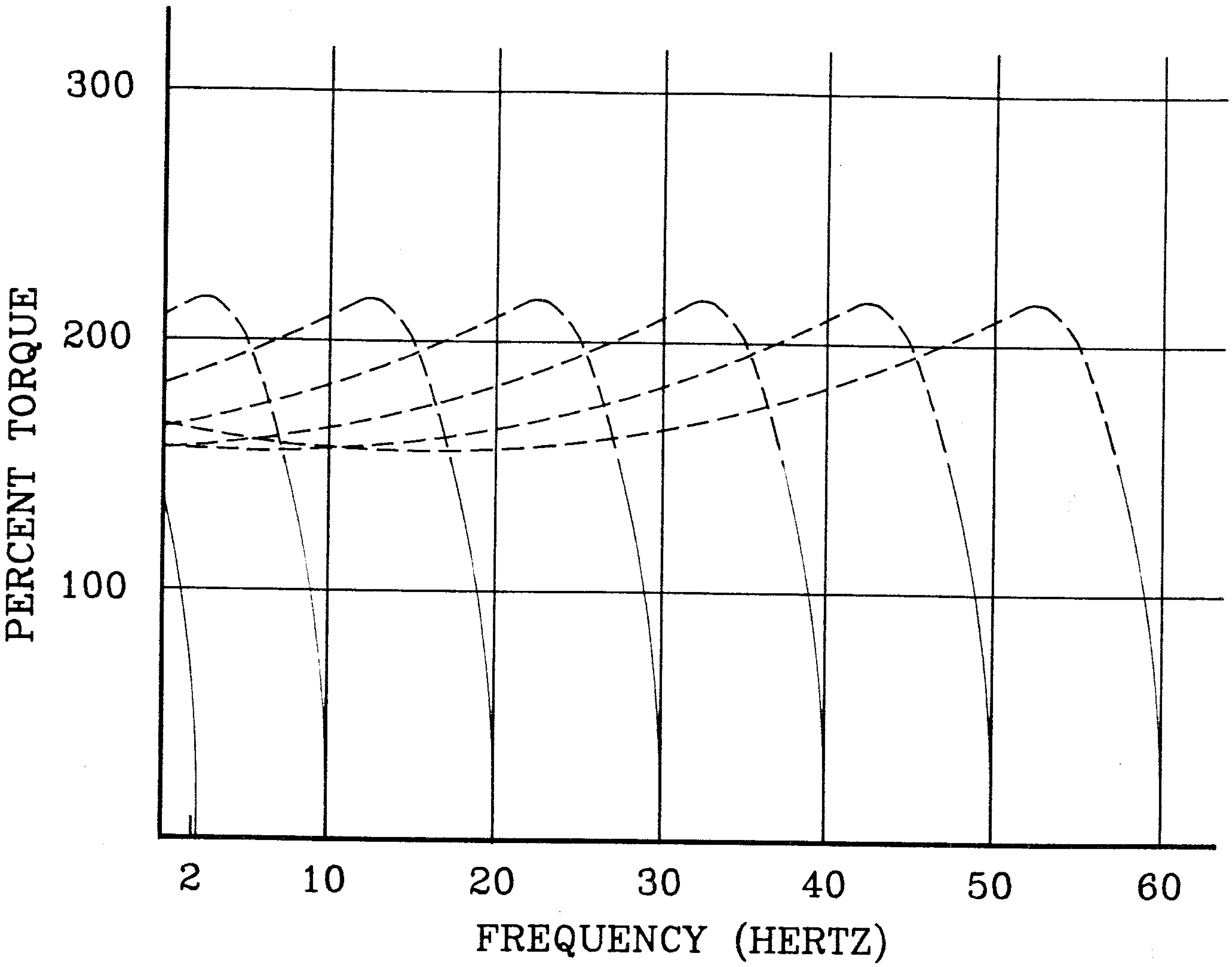


FIG. 2

TORQUE–SPEED CURVES

FOR CONSTANT VOLTS/HERTZ

* MOTORS OPERATED FROM AC DRIVE ARE NORMALLY NEVER OPERATED ON THE DOTTED PORTION OF THE CURVE.

The bi-polar transistor is currently the most popular switching devices in 600V, and up to 700 HP ASD technology. This is because of its higher gains and lower losses. In the lower drive rating, the IGBT is starting to enjoy market acceptance as its voltage and current ratings increase. The IGBT has much higher gains when compared with the standard bi-polar transistor. IGBT is a developing device and has very fast switching, in tenth of micro-second, and this results in almost sinusoidal current waveform and less audible noise. IGBT produces very steep voltage waveform and extra precaution should be taken if used with higher voltage motors for insulation protection. IGBT drives of up to 300 HP have been built.

The GTO switching devices enjoy a growing market share in the high rating ASD, because of its high voltage and current ratings.

The voltage and current ratings for the switching devices described here should only be used as a guideline since this technology is rapidly changing. The drive manufacturer must always be consulted for the most up-to-date drive current and voltage ratings.

4.0 BASIC TYPES OF ADJUSTABLE SPEED DRIVES

The basic components of an ASD are a line converter (rectifier) and load converter (inverter). The rectifier changes constant AC input to constant or variable DC output. The inverter alters the DC to variable voltage/frequency AC power fed to motors. The rectifier performs the power conversion using diods (uncontrolled DC voltage) or SCR (controlled DC voltage). The switching power devices typically used in an inverter circuit to achieve variable voltage/frequency are those described in the previous section..

The basic technology used to produce ASD are variable voltage inverter (VVI), current source inverter (CSI) and pulse width modulated (PWM).

4.1 VVI DRIVES

The VVI drives, Figure 3, utilizes a controlled rectifier to transform the incoming AC voltage to variable DC voltage. The frequency of the output is controlled by sequentially switching the transistors or thyristors in the inverter section in six discrete steps to produce the output voltage shown in Figure 3. The inverter output is controlled independent of load, so any squirrel cage induction motor, or even a group of motors, within the rating of the inverter may be driven by a VVI drive. Harmonic currents are proportional to the imposed harmonic voltages in the output wave and inversely proportional to motor leakage reactance. Motors designed with large leakage reactance reduce the harmonic currents, motor heating and pulsation torque. The main features of VVI drives are:

- Power rating 1- 1,000 HP
- Speed reduction 10:1
- Suitable for variable torque and constant torque load applications.
- Efficiency range 88-93%.
- Input power factor drops with speed.
- Inverter power and control circuit is reasonably simple.
- For retrofit application, motor derating is necessary to account for harmonics and reduced cooling.

4.2 CSI DRIVES

Current source inverter drives can be identified by the large reactor in the DC bus, see Figure 4. Most current source drives require that a motor be connected before the drive has the capability to commutate. Motor inductance characteristics, in addition to capacitors in the drive, are part of the commutation circuit. This makes it difficult to retrofit these drives to existing fixed speed motor. The most common designs of CSI drive

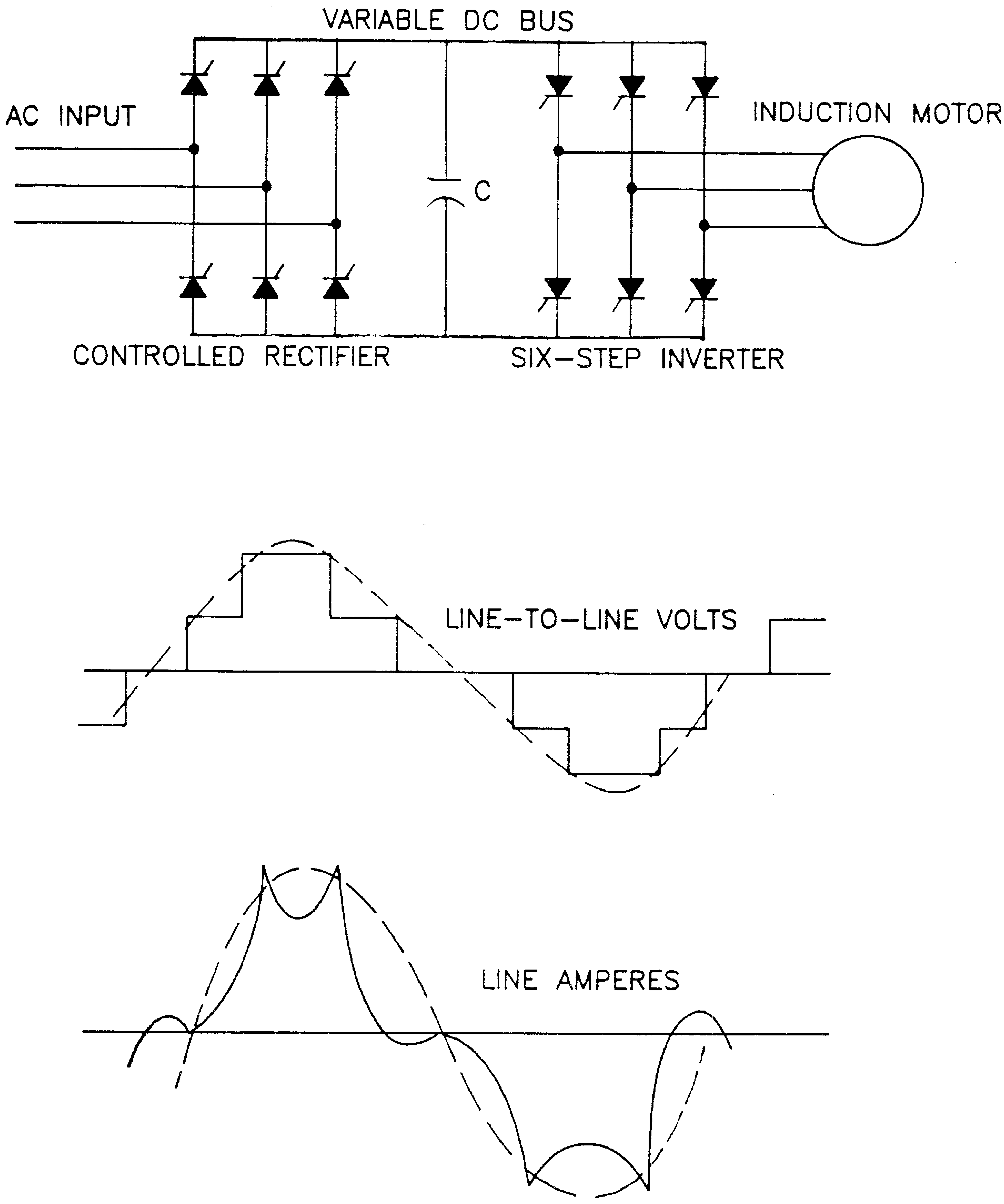


FIG. 3

VOLTAGE-SOURCE SIX-STEP INVERTER

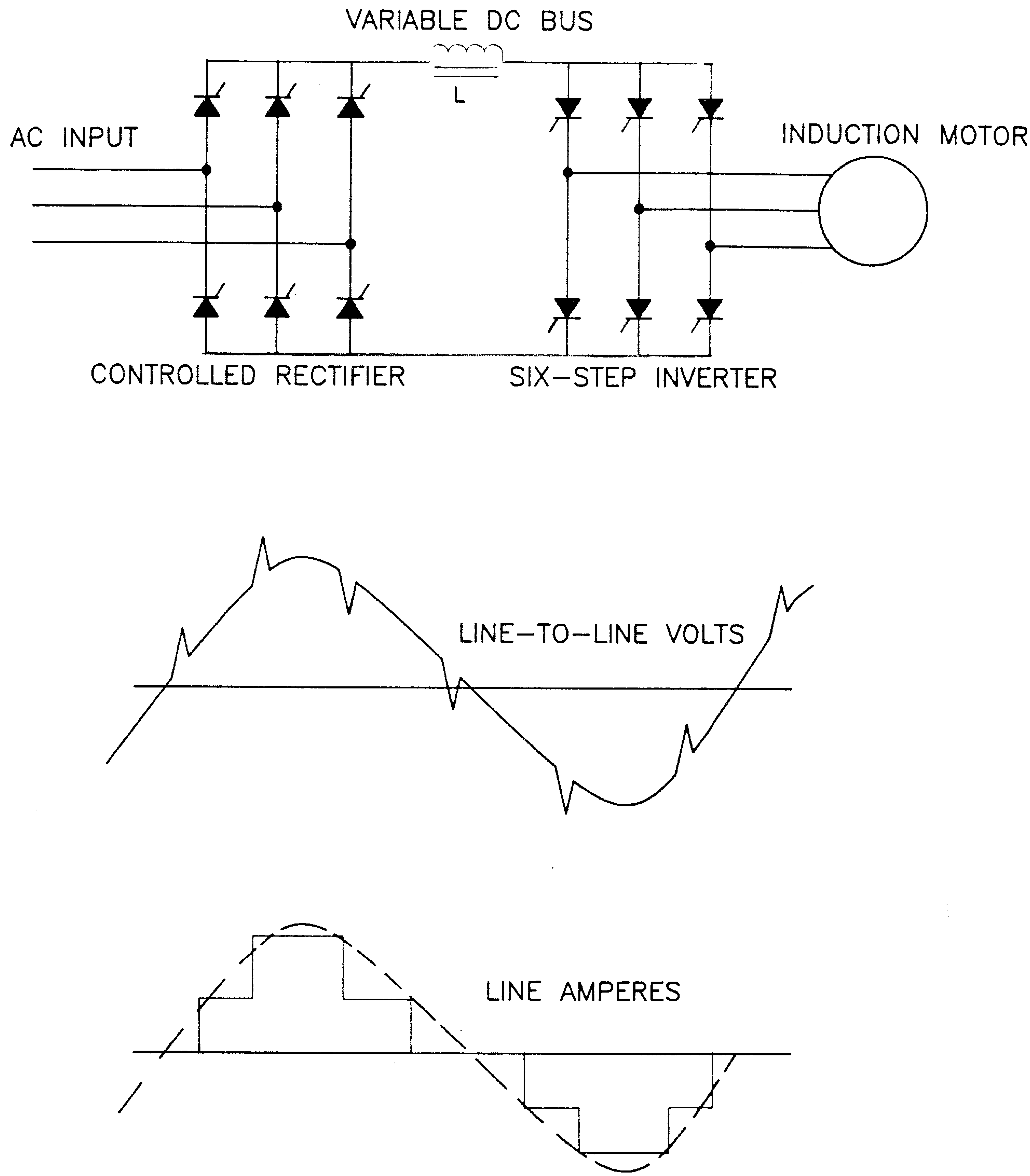


FIG. 4

<u>CURRENT–SOURCE INVERTER</u>

do create high voltage spikes during commutation. This could be a factor in selecting the drive in the higher voltage drives (2300 V and above) to assure that the insulation on the motor will not be damaged by the voltage spikes. An alternative design to this approach is one which includes capacitors on the output, which minimizes the voltage spikes.

The harmonic currents are determined by the harmonics in the output wave while the harmonic voltages generated in the motor are proportional to leakage reactance. Motor heating is less in motors with low leakage reactance. The main advantage of the CSI drive is its ability to have complete control of motor current which results in complete torque control. However, this current controlling characteristic necessitates a large filter inductor and a semi-complex regulator due to the difficulty of controlling the motor solely by current. The main features of these CSI drives are:

- Power rating 50 - 1,500 HP.
- Speed reduction 10:1.
- Suitable for variable torque, constant torque load applications.
- Efficiency range 88-93%.
- Input power factor drop with speed.
- Inverter power circuit is simple, but control circuit is semi-complex.
- Not suitable for retrofit applications.

Another type of current source drive is a load commutated inverter drive (LCI) which utilizes a separately excited synchronous motor which forces the commutation of the inverter section of the drive. This type of drive is common in the higher horsepower (1,500 and above). In most cases they use brushless exciters on the synchronous motor for excitation of the rotating fields. LCI drives, 12 pulse system connnected to synchronous motor and rated up to 25,000 HP, 6,000 rpm have been built, see Figure 11 for simplified single line diagram.

III. PWM DRIVES

These are the most popular drives used in the 600V range and is becoming almost the standard in the ASD industry. The PWM drive, see Figure 5, utilizes a diod rectifier to provide a constant DC voltage. The inverter section in this type of drive, therefore, controls both voltage and frequency. This is done by varying the width of the output pulses as well as the frequency in such a way that the effective voltage is approximately sinusoidal. Because a PWM drive presents a closer simulation of a sine wave power to the motor, less power filter components are required. However, the complex switching waveforms in the inverter require the most complex regulator of the drive types being discussed here and losses due to switching can be high. The main features of PWM drives are:

- Power rating 5 - 5,000 HP.
- Speed reduction 30:1.
- Suitable for variable torque and constant torque load applications.
- Efficiency range 85-95%.
- Input power factor is near unity.
- Inverter power circuit is simple, but control circuit is complex.
- Suitable for retrofit application and less motor derating is required, because harmonic currents are reduced.

In certain applications where high starting torque (above 150%) is required at 150% starting current, conventional PWM drive could be modified to include flux vector control. In this case, the magnetizing current component and torque producing component of the stator current are both independently controlled. This type of drive controller requires an encoder mounted on motor shaft to measure the slip frequency. The flux vector controllers are also used when automatic reacceleration (after a momentary loss of power) is specified for high inertia load such as induced

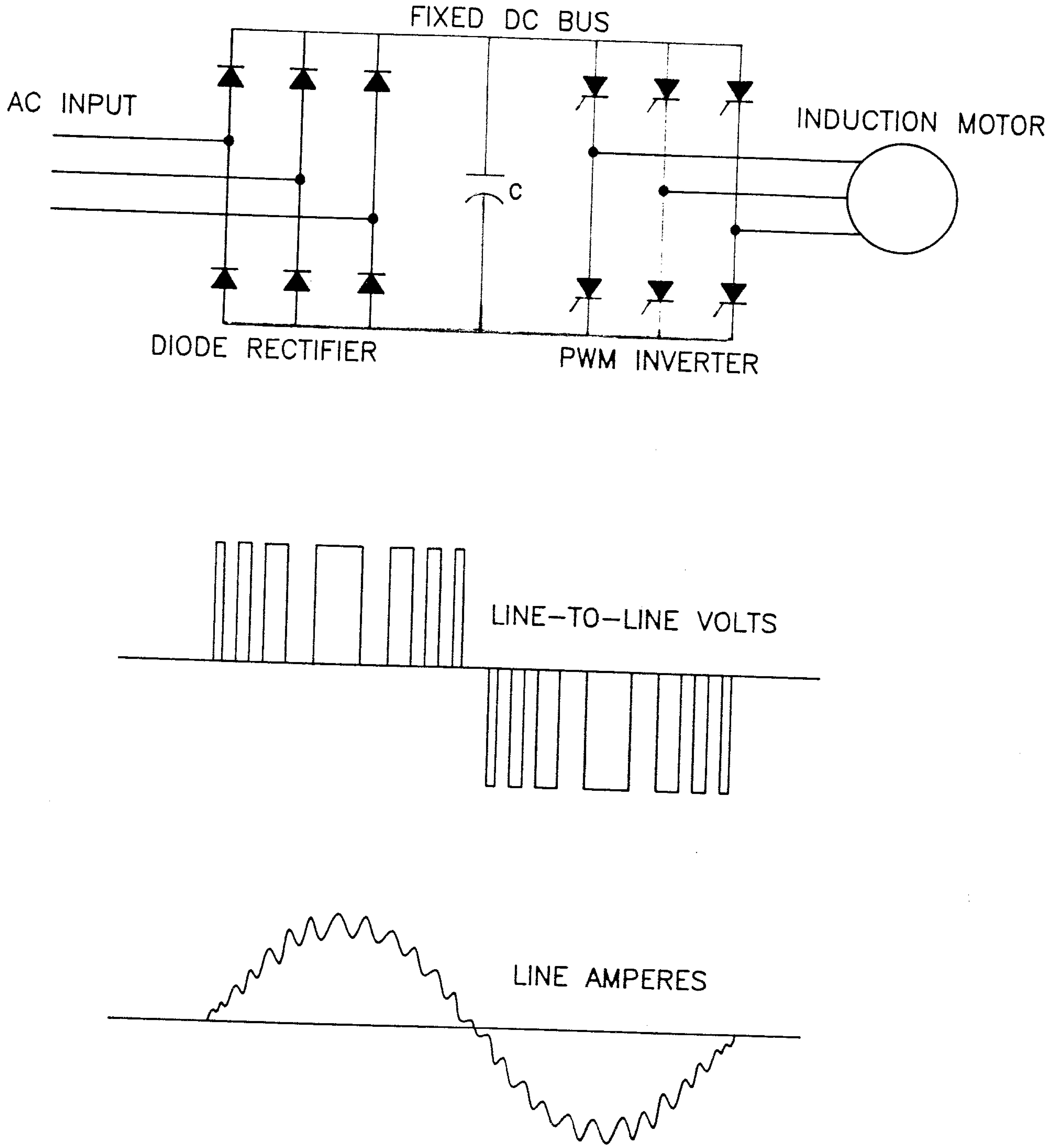


FIG. 5

PULSE-WIDTH MODULATED INVERTER

draft fan. The controller is capable to almost instantaneously acquire synchronism with motor (catch on fly) upon power restoration thus avoiding process upset. It is feasible to retrofit flux vector control on existing PWM drives. Flux vector control drives up to 1,000 HP have been built.

5.0 APPLICATION CONSIDERATION OF ASD

ASD are extensively used in industry for various applications. They are normally divided into three categories depending on their torque requirement:

1 - constant torque
2 - variable torque
3 - constant horsepower.

5.1 CONSTANT TORQUE APPLICATION

A constant torque load is characterized as one in which the horsepower requirement is directly proportional to the operating speed. The horsepower torque relationship is defined by the following formula:

$$\text{Torque (lb. ft)} = \frac{\text{HP x 5250}}{\text{RPM}}$$

Thus the torque remains a constant value of the horsepower and speed vary proportionally. This characteristic is shown graphically in Figure 6. Constant torque is achieved by maintaining the motor current constant at all specified operating speed range. Horsepower requirements is linearly proportional to speed and hence energy saving is less when compared with variable torque application. Therefore, it is difficult to justify the use of these drives on energy basis alone without considering the other process requirements.

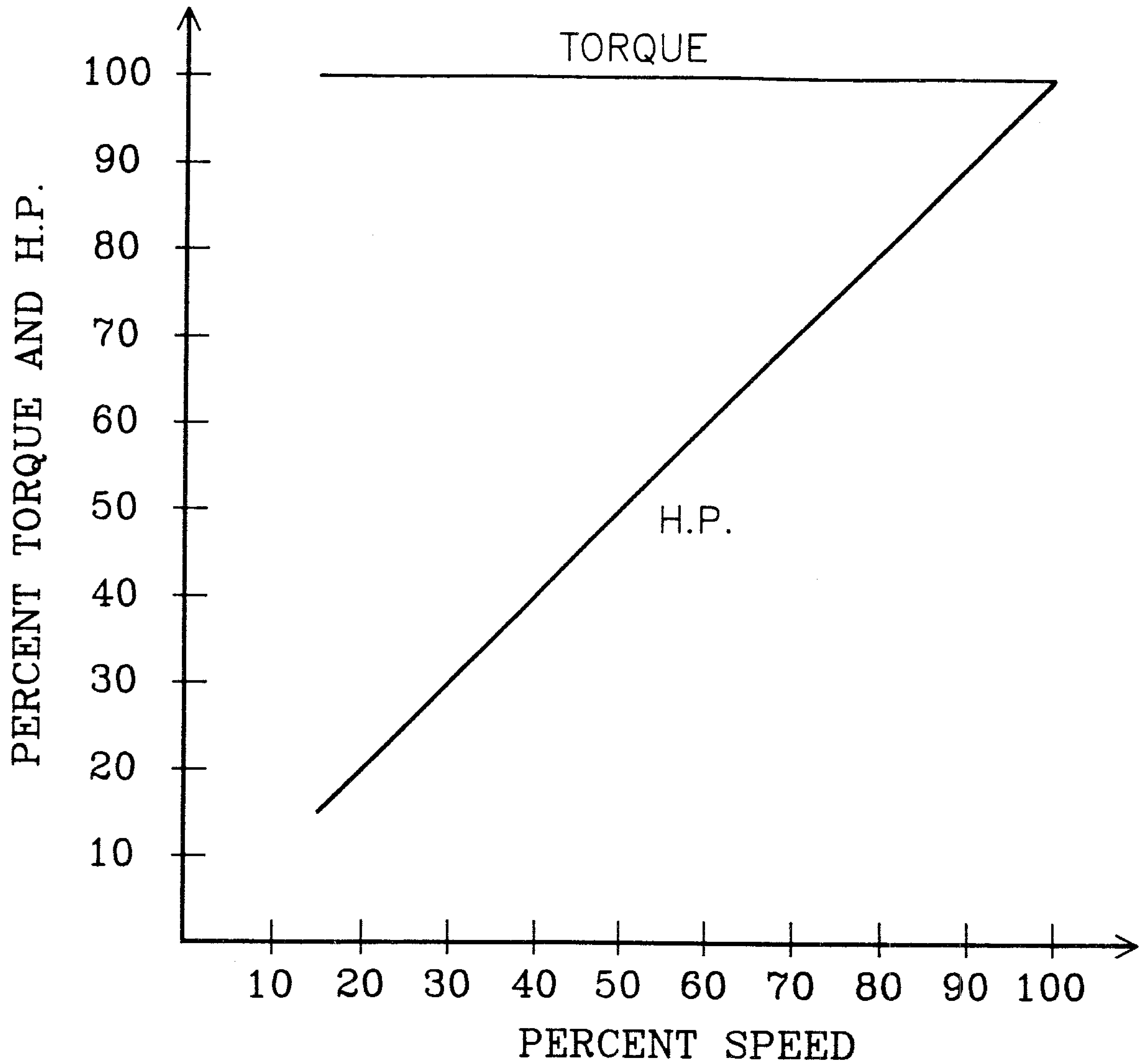


FIG. 6

CONSTANT TORQUE LOAD

$$HP \propto N$$

For constant torque application, the motor experiences considerable temperature rise when operating at minimum specified speed, because of reduced ventilation and constant current requirement. It is expected that the motor temperature could rise by up to 30°C above its sine wave rating when running at 50% speed and using self ventilation. Figure 7 shows continuous torque capability versus speed for self ventilated motor. The motor is capable to safely operate at rated torque and current between 100% to 50% speed provided motor design allows for additional temperature rise. Below 50% speed operation, constant torque application is not recommended without using a separately forced ventilated motor. For retrofit application, Class F insulation motor should be used, and it is not recommended to use Class B insulation.

Typical examples of constant torque applications are reciprocating compressors, reciprocating pumps, conveyors, screw type mixers, etc. Figure 8 shows the current waveform of PWM drive connected to 500 HP motor and driving positive displacement pump via a 15/1 gear ratio. This field measurement was conducted with motor running at 70% rated speed and 50% load, and with two out of three valves badly leaking. The PWM drive was unstable, producing very loud pulsating noise and repeatedly tripping upon load increasing. This problem was corrected by repairing the leaky pump valves.

Positive displacement pumps and compressors must be started on bypass (no load) and therefore, automatic re-acceleration after momentary loss of power is not recommended. The pump must always manually be unloaded before starting the drives.

It is recommended to carry out tortional analysis in large drive constant torque applications especially for two poles motor to ensure that the natural resonance of the mechanical components are not excited by the drive harmonics within the operating speed range.

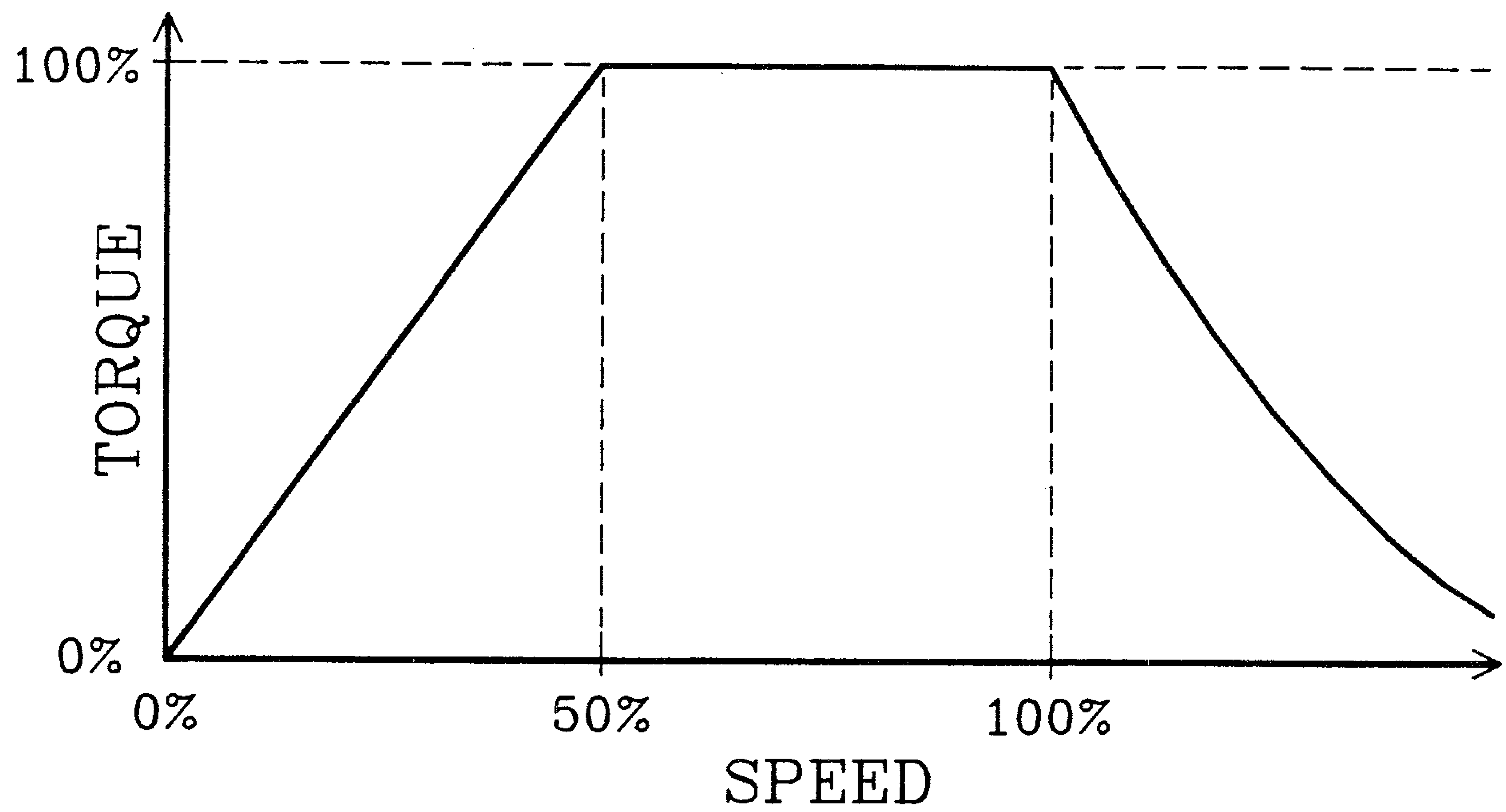


FIG. 7

MOTOR TORQUE CAPABILITY

FOR SELF-VENTILATED

TORQUE CAPABILITY IS LIMITED BY

COMBINATION OF LOSSES AND VENTILATION

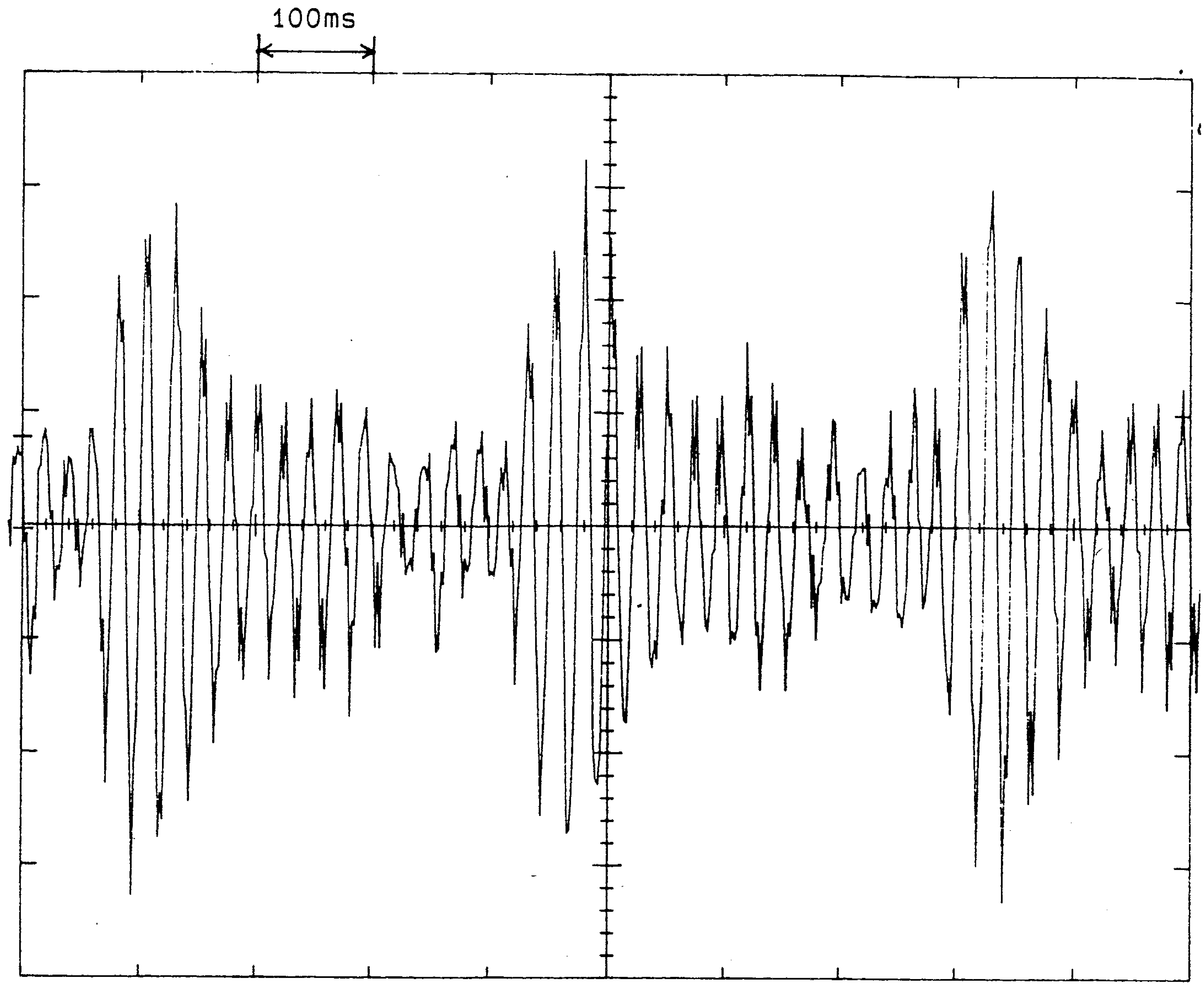


FIG. 8

500 H.P. MOTOR CURRENT PULSATION IN PWM DRIVE OPERATING WITH FAULTY PUMP VALVES

5.2 VARIABLE TORQUE APPLICATION

For variable torque load, the torque varies directly with speed squared, and horsepower varies directly with speed cube, see Figure 9. Harmonic losses are maximum at rated speed. Considerable energy saving is achieved with this application even at slightly reduced speed. For example, at 80% speed the horsepower requirement is almost 50% rating. Typical applications are centrifugal pumps, fans and compressors.

Motor should be specified with 80°C rise above 40°C ambient when connected to ASD and at rated speed to properly allow for harmonic losses. Class F insulation is recommended. Motor derating is minimal for retrofit variable torque application. Continuous torque capability without motor overheating is from 25% to 100% speed for self ventilated machine.

5.3 CONSTANT HORSEPOWER APPLICATION

In this application the torque requirement varies inversely with speed as shown in Figure 10. Typical application of constant horsepower are drill machine, laths, milling machine, etc. The applied rated voltage across the motor is kept constant above rated speed to avoid saturation.

6.0 HARMONICS IN ADJUSTABLE SPEED DRIVES

Harmonics is a subject of increased interest, because of proliferation of harmonic producing devices. For example, the use of ASD's has been increasing and this trend is expected to continue, because of good economical incentives. Harmonics currents and voltages are produced whenever ASD are used. Their operation, as described earlier, require converting AC to DC and DC to AC and this results in generating harmonics both into ~~board~~ load and power supply.

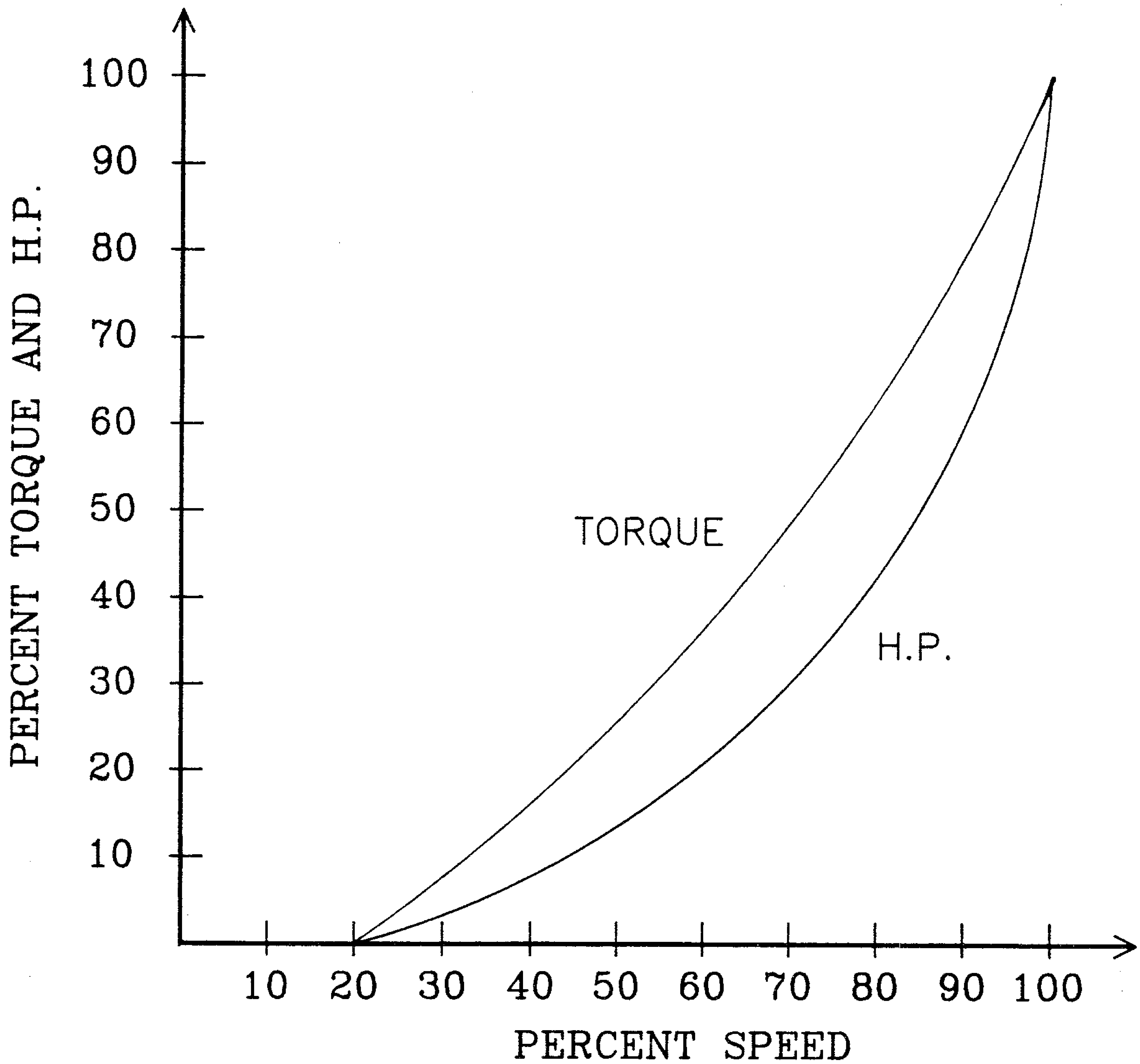


FIG. 9

VARIABLE TORQUE LOAD

$$T \propto N^2$$

$$HP \propto N^3$$

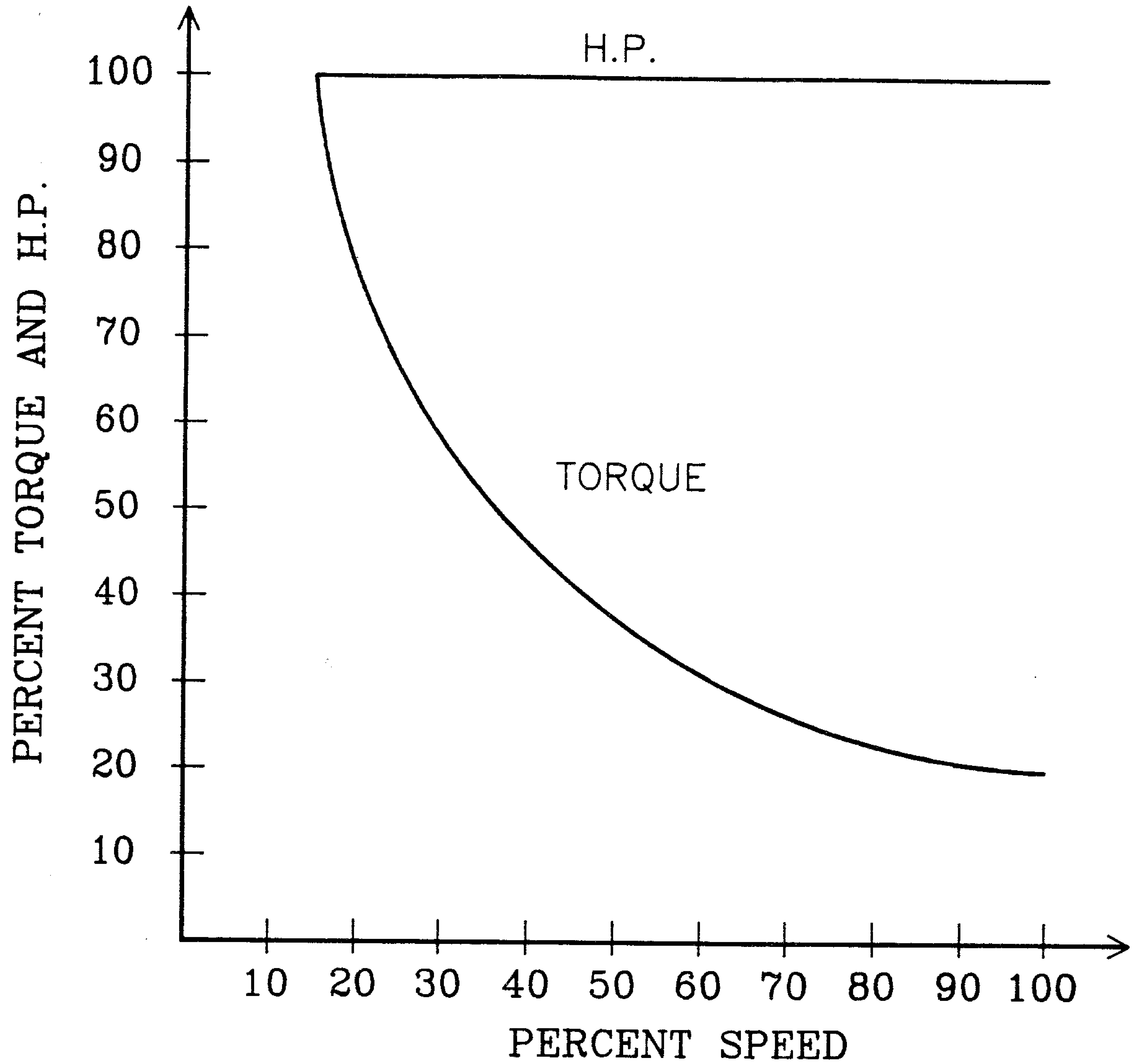


FIG. 10

CONSTANT H.P. LOAD

$$T \propto \frac{1}{N}$$

In addition to ASD there are other devices which are considered as sources of harmonics and these are:

Rectifier
DC Motor Drives
UPS
Arc Furnace
Static Var Generator
Cyclo Converter
Static Motor Starter

The presence of these devices in a plant does not necessarily indicate that there is a harmonic problem. At one extreme, these harmonics may be of low magnitude and, therefore, harmless, or they may be high enough to cause problems such as motor overheating, capacitor's failure and telephone interference. It has been suggested that when 20% or more of the plant load consists of harmonic producing equipment, then a harmonic study should be considered. Another guide is when harmonic producing load exceeds 1.5% short circuit level at point of application, then harmonic problem is expected.

Harmonics are currents or voltages which have frequencies that are integer multiples of the fundamental power frequency. For example, for 60 HZ supply the fifth harmonic is 300 HZ. A 3-phase power converter generates harmonic current the order and magnitude of which are given the following equations:

$$h = KP \pm 1$$

$$I_h = \frac{I_1}{h}$$

h : order of harmonic
P : number of pulses of the converter system
K : any integer 1,2,3,---
I_h: harmonic current
I_1: fundamental current

It can be seen that the magnitude of harmonic current is inversely proportional to its harmonic order, and therefore, the magnitude of high order harmonics diminish rapidly. A six pulse converter system (P = 6), see Figure 11, would produce harmonic currents of the order 5th, 7th, 11th, 13th, 17th, 19th, 23rd, 25th, etc. For a 12 pulse system converter configuration, as shown in Figure 12, the harmonics generated are 11th, 13th, 23rd, 25th, etc. Therefore, a 12 pulse converter system provides a significant reduction in the voltage distortion and, equally important, it eliminates assuming balanced conditions the lowest order harmonics of 5th and 7th which are typically of most concern. The 12 pulse system is normally used to large drives, 2,000 Hp and above.

7.0 HARMONIC GUIDELINES

In order to compare levels of harmonic distortion in a power system, the Total Harmonic Distortion factor is used, and is defined in IEEE Standard 519-1981 as:

$$\text{THD} = \left(\frac{\text{sum of squares of amplitudes of all harmonics}}{\text{square of amplitude of fundamental}} \right)^{1/2} \times 100\%$$

The revised IEEE 519 (to be published soon) specify two criteria to evaluate harmonic distortion:

1 - A limitation in the harmonic current that a user can transmit into the utility system.

2 - The quality of the voltage that the utility must furnish the user.

The first criteria puts the responsibility on the user to limit harmonic current injected back into power system and these limits are given in Table 1. These harmonic current limits are based on the size of the user with respect to the size of the power system to which the user is connected. The smaller the ratio of ASD load to available short circuit level, the larger is the harmonic current allowed to inject back into utility.

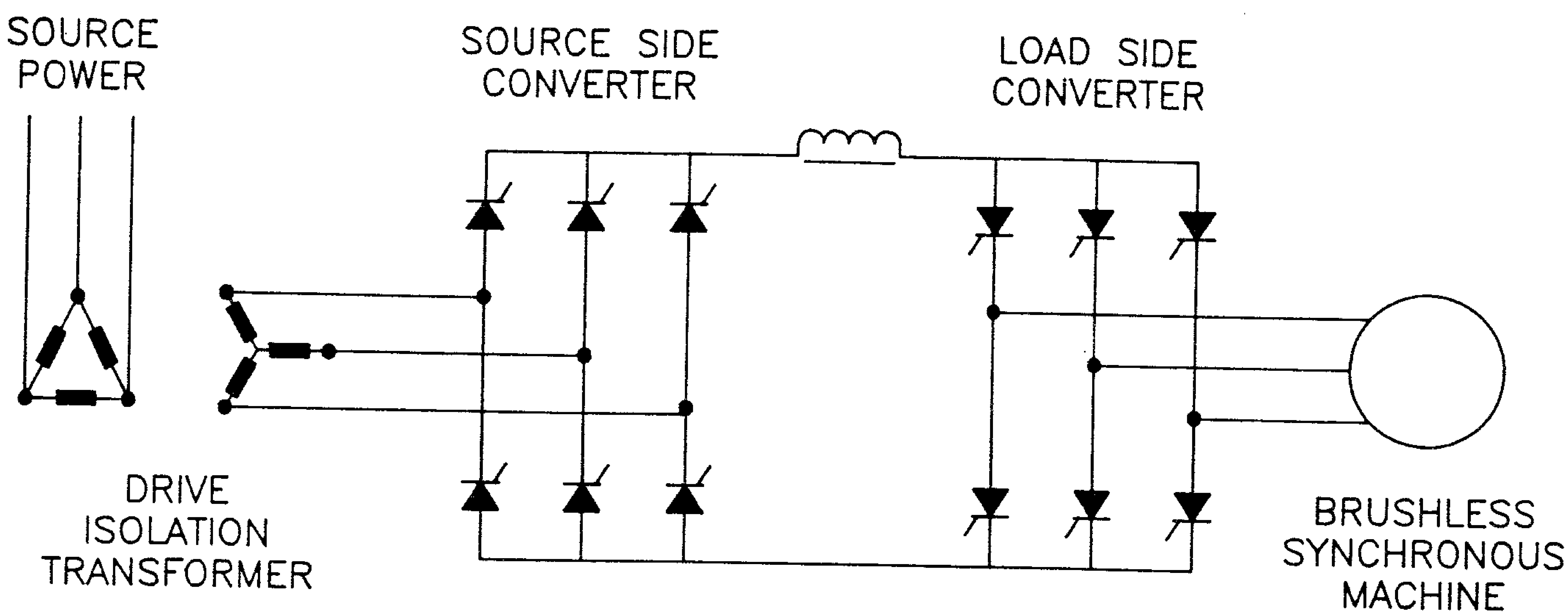


FIG. 11

BASIC CIRCUIT FOR 6-PULSE LCI DRIVE CONNECTED TO 3-PHASE MACHINE

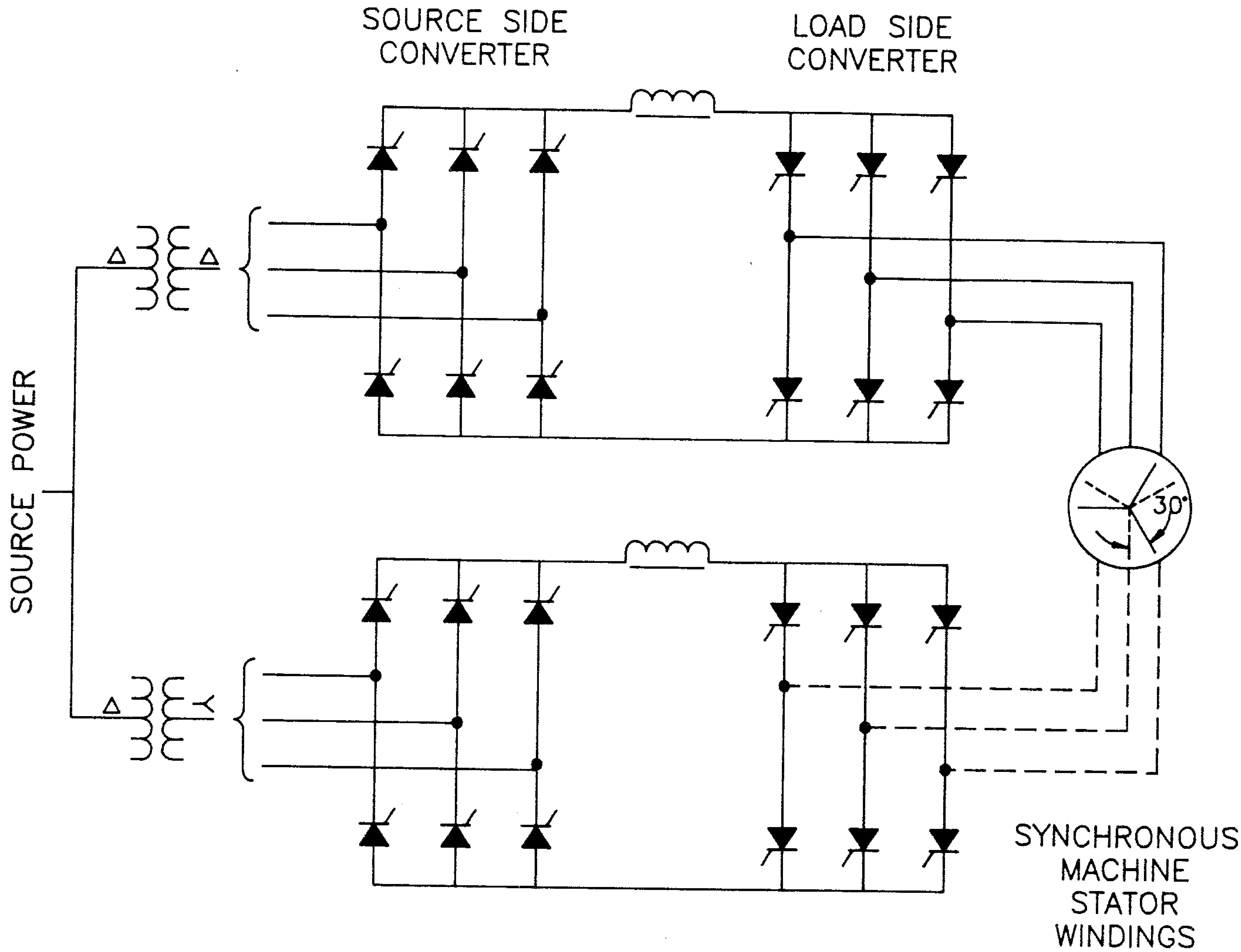


FIG. 12

BASIC CIRCUIT FOR 12–PULSE LCI DRIVE CONNECTED TO 6–PHASE MACHINE

TABLE 1

CURRENT DISTORTION LIMITS FOR
GENERAL DISTRIBUTION SYSTEMS
(120 VOLTS TO 69,000 VOLTS)

MAXIMUM HARMONIC CURRENT DISTORTION IN % OF FUNDAMENTAL						
HARMONIC ORDER (ODD HARMONICS)						
I_{SC}/I_L	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	THD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20–50	7.0	3.5	2.5	1.0	0.5	8.0
50–100	10.0	4.5	4.0	1.5	0.7	12.0
100–1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Where I_{SC} = MAXIMUM SHORT CIRCUIT CURRENT AT PCC.
And I_L = MAXIMUM DEMAND LOAD CURRENT (FUNDAMENTAL FREQUENCY) AT PCC.

The second criteria puts the responsibility on the utility to furnish the user with a good quality voltage. Table 2 shows the permissible harmonic voltage level at the incoming power supply. Ontario Hydro voltage THD requirements are, in general, more stringent than those given in Table 2. For example at 27.6 KV level Ontario Hydro voltage THD requirement is 3%, whereas IEEE recommends 5%.

Another harmonic limitation which is normally very difficult to meet and is sometimes overlooks is the IT products. This represents the harmonics interference with telephone lines when running in the proximity of power lines. Table 3 shows the IT limits as specified by IEEE 519. Ontario Hydro IT products limits are more stringent than IEEE guidelines and it is 5,000A at 27.6 KV voltage level. It is extremely important to consult the local utility as to their harmonic guidelines as this may be more stringent or relaxed when compared to IEEE 519.

8.0 INSTALLATION EXAMPLES

In order to better understand the presence of harmonics in an ASD, harmonics measurements for a new installation are presented and analyzed. It covers 6-pulse system for constant torque application.

Figure 13 shows a simplified power schematic for 500 HP PWM drive. It consists of the following:

1. Input line filters (optional), but provided in this application to reduce line notching.

2. 6 pulse rectifier to convert 575V AC incoming voltage to constant DC voltage.

3. Filter reactor to smooth the DC nipples and hence minimize harmonic line. Filter capacitor to smooth the DC voltage which is applied to the inverter.

TABLE 2

VOLTAGE DISTORTION LIMITS

BUS VOLTAGE AT PCC	INDIVIDUAL VOLTAGE DISTORTION (%)	TOTAL VOLTAGE DISTORTION THD (%)
BELOW 69kV	3.0	5.0
69kV TO 138kV	1.5	2.5
138 kV AND ABOVE	1.0	1.5

TABLE 3

BALANCED *I•T* GUIDELINES FOR CONVERTER INSTALLATIONS, TIE (SUPPLY) LINES

CATEGORY	DESCRIPTION	*I•T*
I	LEVELS MOST UNLIKELY TO CAUSE INTERFERENCE	UP TO 10,000
II	LEVELS THAT MIGHT CAUSE INTERFERENCE	10,000 TO 25,000
III	LEVELS THAT PROBABLY WILL CAUSE INTERFERENCE	GREATER THAN 50,000

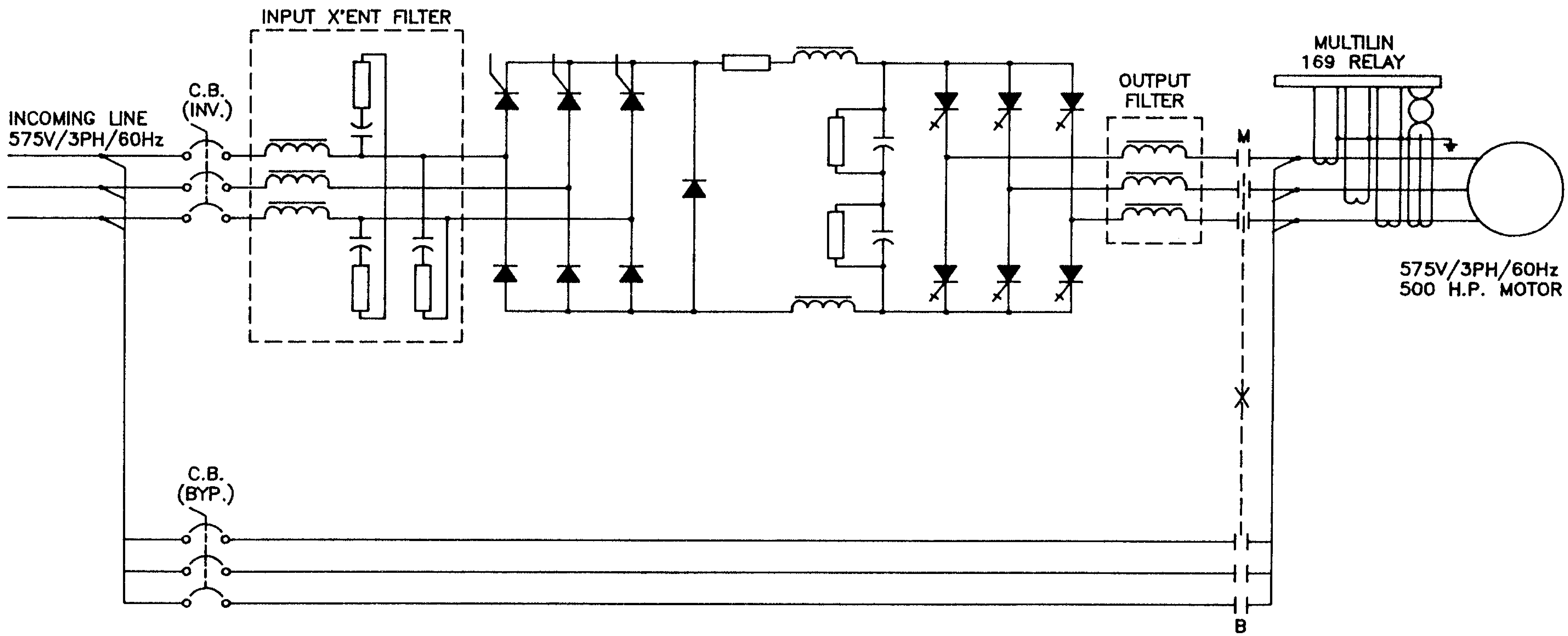


FIG. 13

POWER SCHEMATIC FOR 500 H.P. PWM DRIVE USING GTO IN INVERTER CIRCUIT

4. 6 pulse inverter using GTO's to provide variable voltage/frequency output.

5. Electrical bypass to run the motor at fixed speed directly on line in the event of drive unavailability.

6. 500 HP, 575 induction motor driving positive displacement pump via a gear box (15:1 ratio). The motor has RTD's sensors in stator and bearings and is protected using Multilin 169 plus.

Figure 14 represents the input line current to PWM drive running at rated load and speed (3,550 rpm). The total current THD is 25.3%. The dominant harmonic components are the 5th, 7th, 11th and 13th. Figure 15 is for motor current with 4.2% current THD, and dominant harmonics are 11th and 13th.

Figure 15 shows that for PWM drive operating at rated speed the current waveform is close to sine wave. Typically this current waveform (THD = 4.2%) would cause a temperature rise by 10°C above the sinusoidal waveform.

Figure 16 and 17 represent the line current and motor current respectively with motor running at rated torque and 50% speed. It can be seen that the motor current THD is 17% which is much higher than that measured at 100% speed. The dominant harmonics are those at carrier frequency ± 1, namely 29th is 12.4% and 31st is 10.9% of fundamental. The increase in harmonic current components coupled with the reduction in ventilation (50% speed) result in considerable temperature rise. In this case, the motor was specified to meet 80°C temperature rise above 40°C ambient when connected to PWM drive and running at 50% speed and delivering rated torque. Heat run tests with sine wave 60 HZ supply and with PWM drive were specified to ensure meeting temperature rise requirement. Motor temperature rise by resistance method was measured to be 67.3°C when connected to 60 HZ sinusoidal supply. The temperature increased to 79°C when the motor was tested with PWM drive and running at 100% speed and torque.

Date- 05-26-1991

vertical scale= .25 volts/cm   horizontal scale= .002 sec/cm

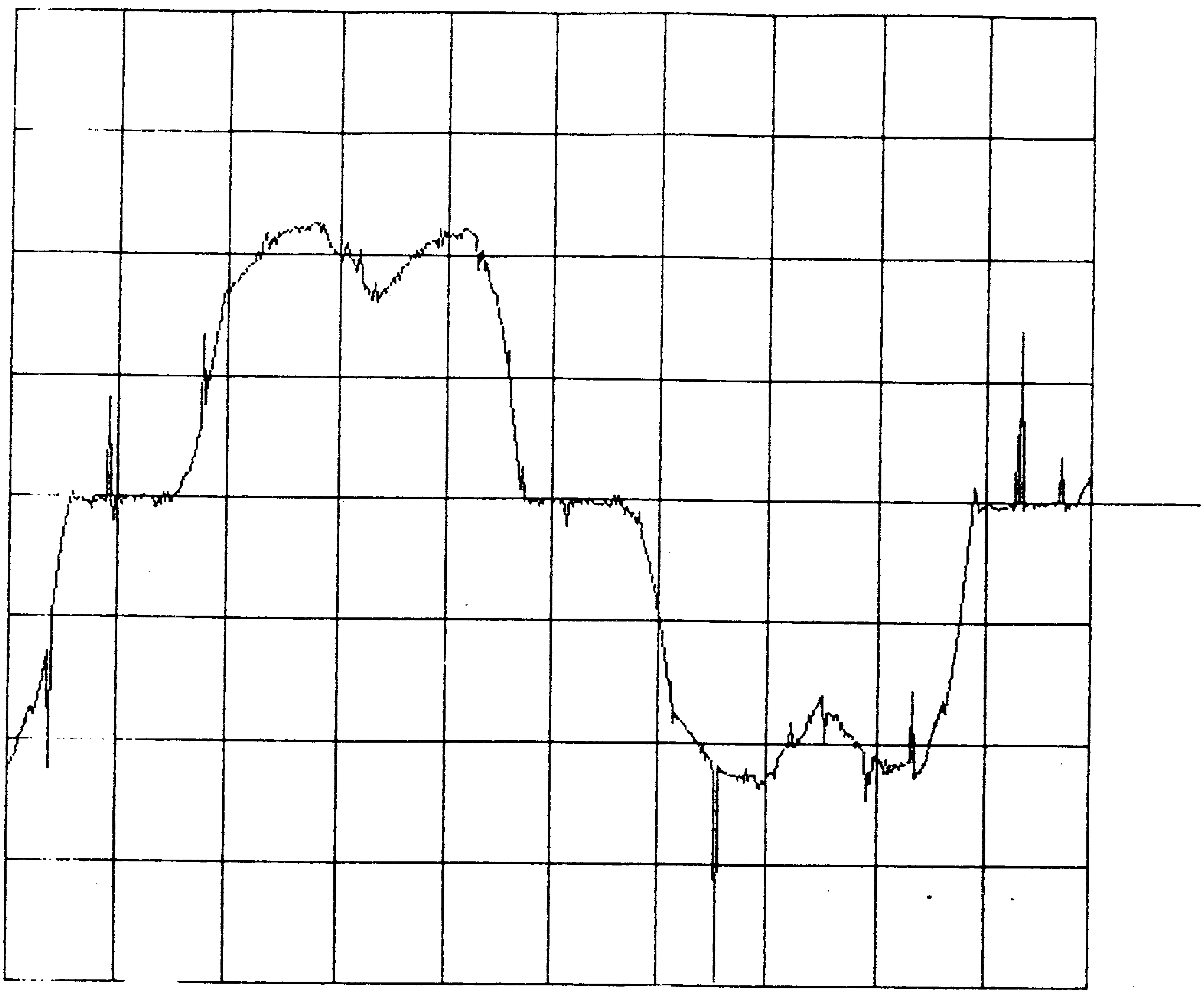


FIG. 14

INPUT CURRENT WAVEFORM TO PWM DRIVE WITH 500 HP MOTOR RUNNING AT RATED LOAD AND <u>FULL</u> SPEED (3600 RPM).

THD (CURRENT) = 25.3%

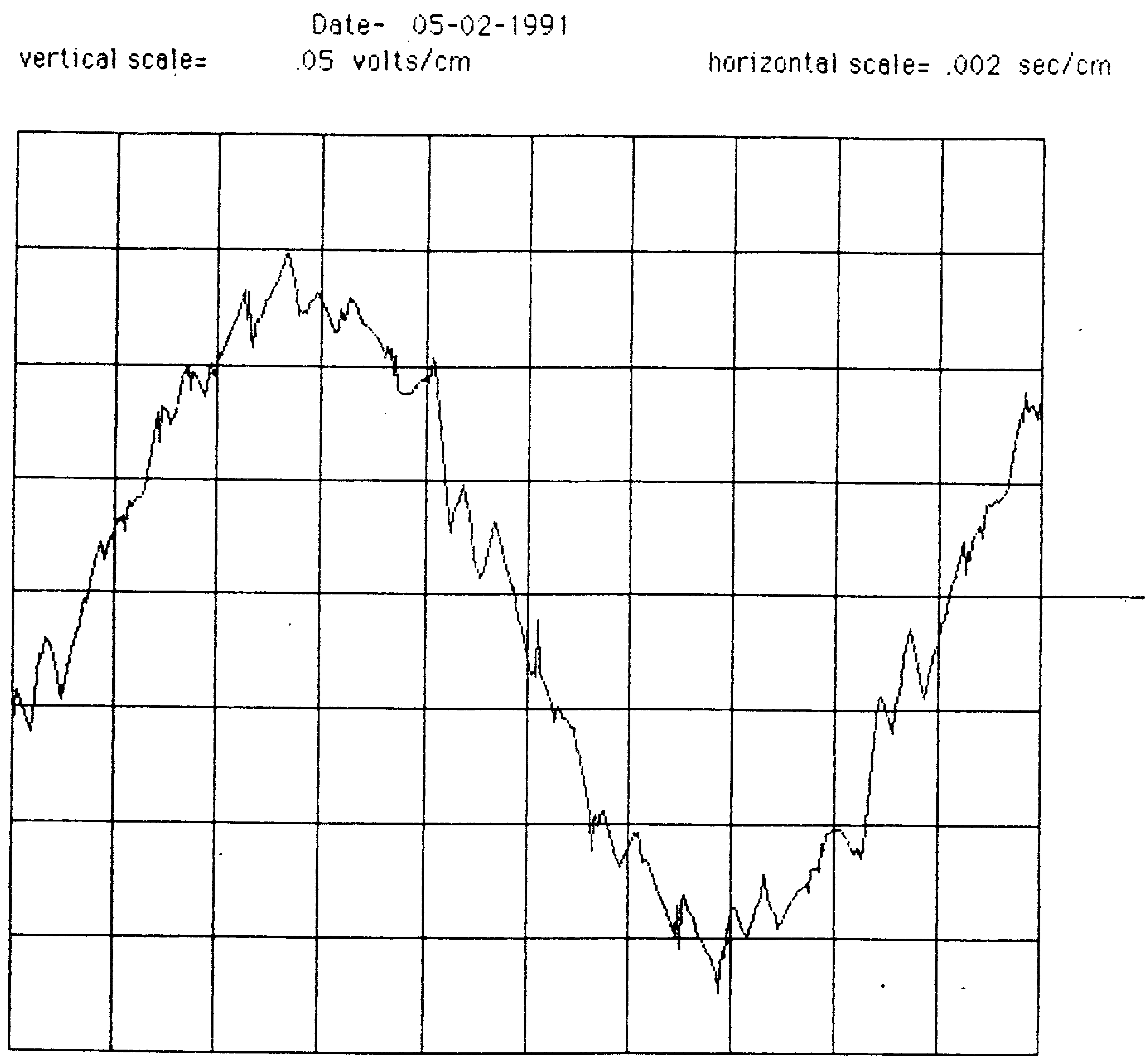


FIG. 15 **500 HP MOTOR CURRENT WAVEFORM WHEN CONNECTED TO PWM DRIVE AND RUNNING AT RATED LOAD AND FULL SPEED (3600 RPM) THD (CURRENT) = 4.2%**

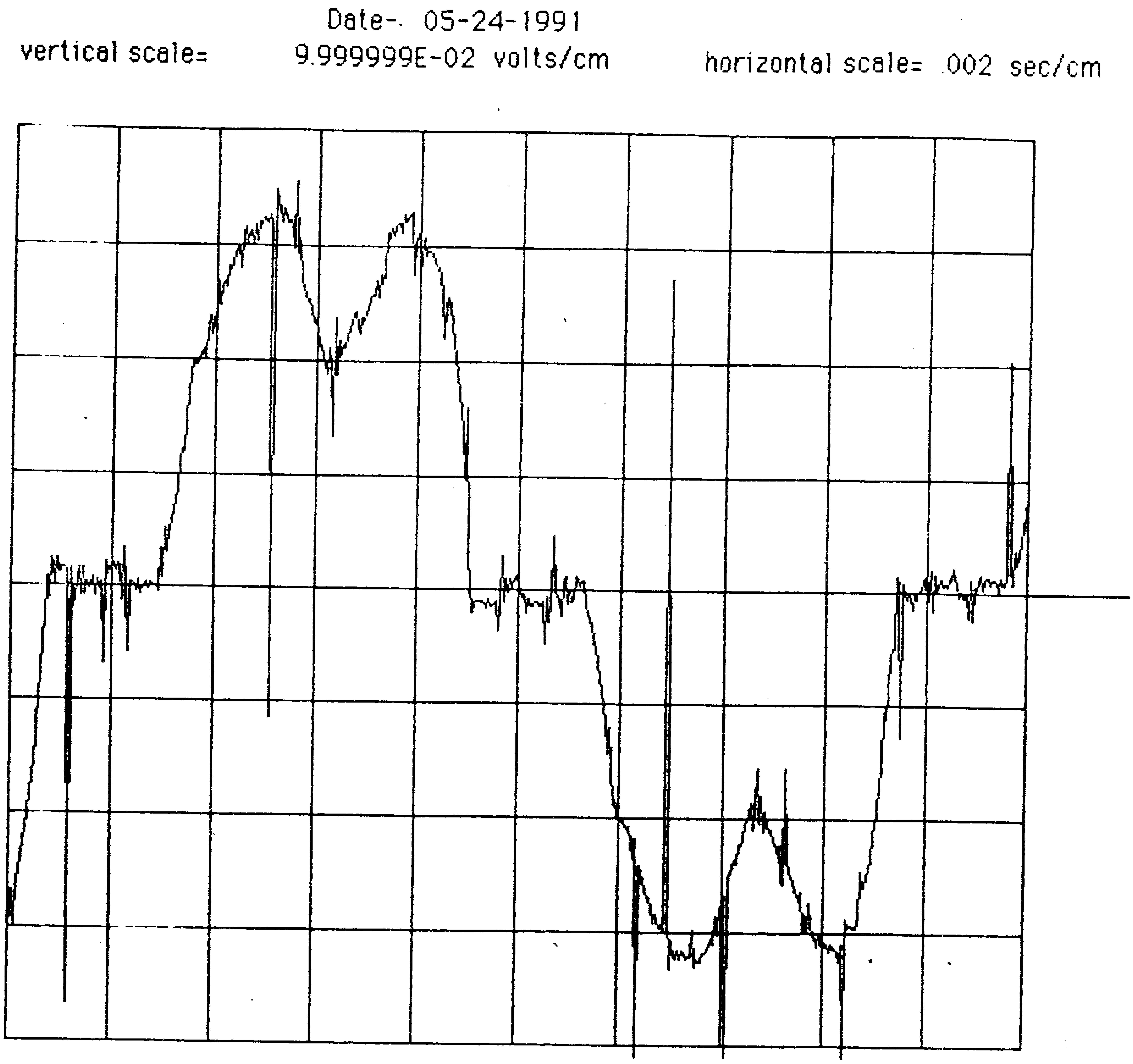


FIG. 16

INPUT CURRENT WAVEFORM TO PWM DRIVE WITH 500 HP MOTOR RUNNING AT RATED LOAD AND 50% SPEED (1800 RPM).

THD (CURRENT) = 30.5%

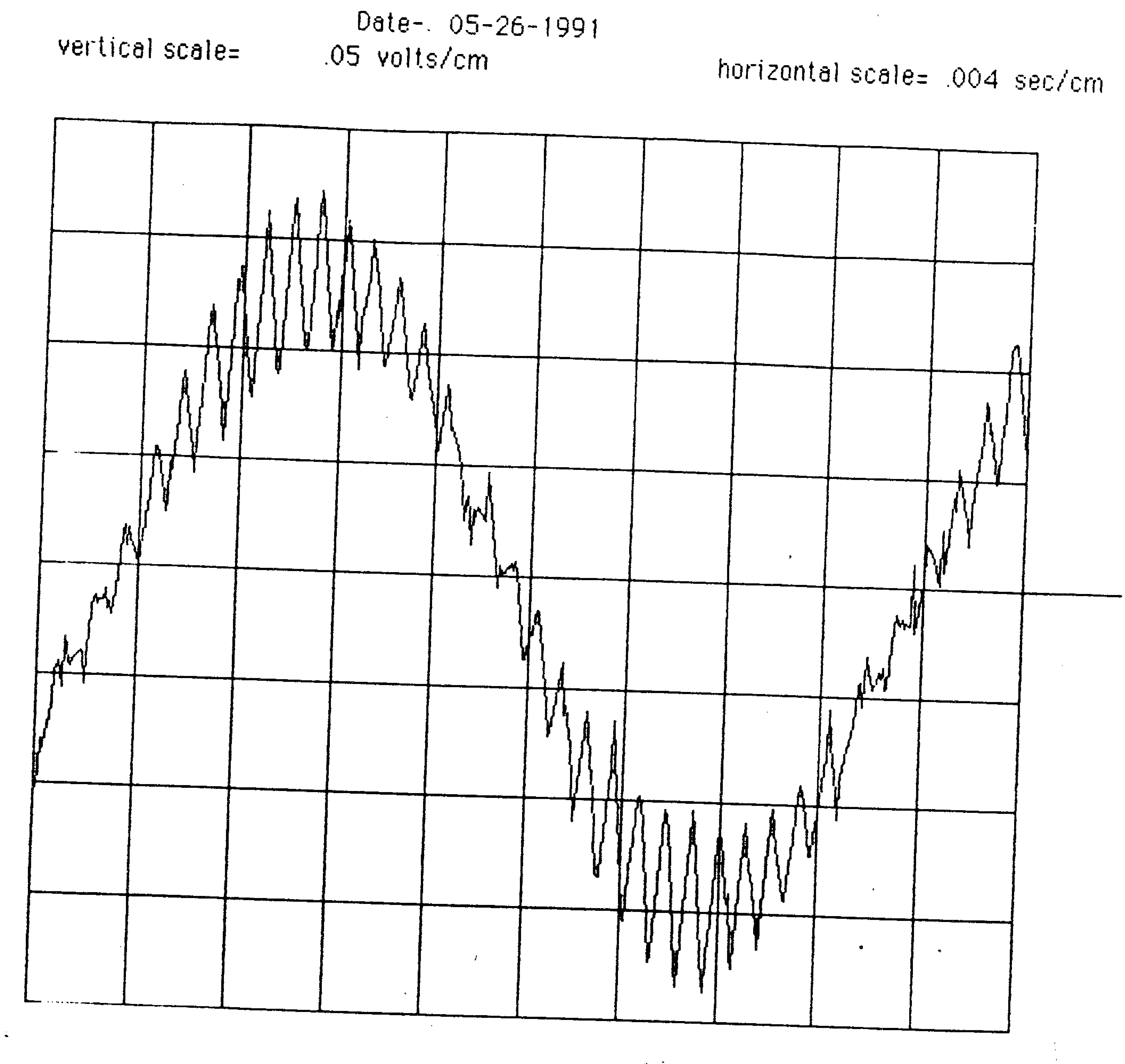


FIG. 17

500 HP MOTOR CURRENT WAVEFORM WHEN CONNECTED TO PWM DRIVE AND RUNNING AT RATED LOAD AND 50% SPEED (1800 RPM)

THD (CURRENT) = 17%

Table 4 shows the various measured temperature rise comparison. The temperature rise was measured at 90°C when connected to PWM drive and running at 50% speed and rated torque. This clearly does not meet the specified temperature rise of 80°C and the motor was rejected. A new motor had to be built and tested and it met the specified temperature rise.

It can be seen that when operating with PWM drive at constant torque and 50% speed, the temperature rise is expected to be 30°C higher when compared to sine wave test. It is extremely critical that the motor is designed to properly accommodate additional heating resulting from both harmonics and reduced ventilation. This motor has WPII enclosure, and it is noted that the replaceable air filter performs better than the washable filters, because the former is less sensitive to change in air flow at reduced operating speed. Washable air filters need a constant air flow of about 300 to 500 ft. per minute to give a reasonable performance.

9.0 TRAINING REQUIREMENTS

It is strongly recommended to conduct an in-house training for Operations and Maintenance personnel to familiarize them with main features of ASD. This will ensure good utilization of ASD. Proper operating and maintenance instruction manuals should be provided. All associated alarms, emergency shutdown devices and selector switches should be clearly described. Permissible operating speed range should be tagged at the operator station. It is import to carry some spare parts.

10.0 CONCLUSIONS

Almost all ASD save energy. For variable torque application, the ASD is very energy conscious, because the horsepower varies proportionally to the cube of the speed.

TABLE 4

HEAT RUN TEST RESULTS FOR 500 H.P., 600V INDUCTION MOTOR TESTED WITH SINE WAVE AND WITH PWM DRIVE

CONSTANT TORQUE APPLICATION

FREQUENCY	POWER	TEMP. RISE BY RESISTANCE	ΔT
60Hz	SINE	67.3°C	--
60Hz	PWM	79°C	10.4°C
30Hz	PWM	96°C	28.1°C

MOTOR DID NOT MEET SPECIFICATION OF 80°C RISE WHEN CONNECTED TO PWM AND RUNNING AT 50% SPEED.

When selecting an ASD for a particular application, there are many items that need to be considered at the initial stages. These include type of ASD, torque requirements at all operating speed range including standstill, drive cost, power factor, maintenance, reliability, temperature rise due to harmonics and reduced ventilation.

It is inevitable that harmonics will be generated whenever an ASD is used. The order and magnitude of these harmonics greatly depend on the drive configuration and system impedance. The principle effect of harmonics in motors is overheating and this might require motor derating from 5 to 15 percent depending on type of insulation class and load characteristic.

For constant torque application it is recommended to specify a motor with 80°C temperature rise at rated torque and minimum operating speed. For variable torque application 80°C rise is recommended at rated load and speed, because harmonic losses are maximum. Class F insulation should always be specified for constant or variable torque application.

For large ASD installation, harmonic study should be conducted to ensure meeting Ontario Hydro harmonic requirements, and that there is no resonance available with power factor correction capacitors.

Heat run test is recommended, whenever feasible, to ensure drive performance is satisfactory.

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ADJUSTABLE SPEED DRIVES APPLICATION CONSIDERATIONS

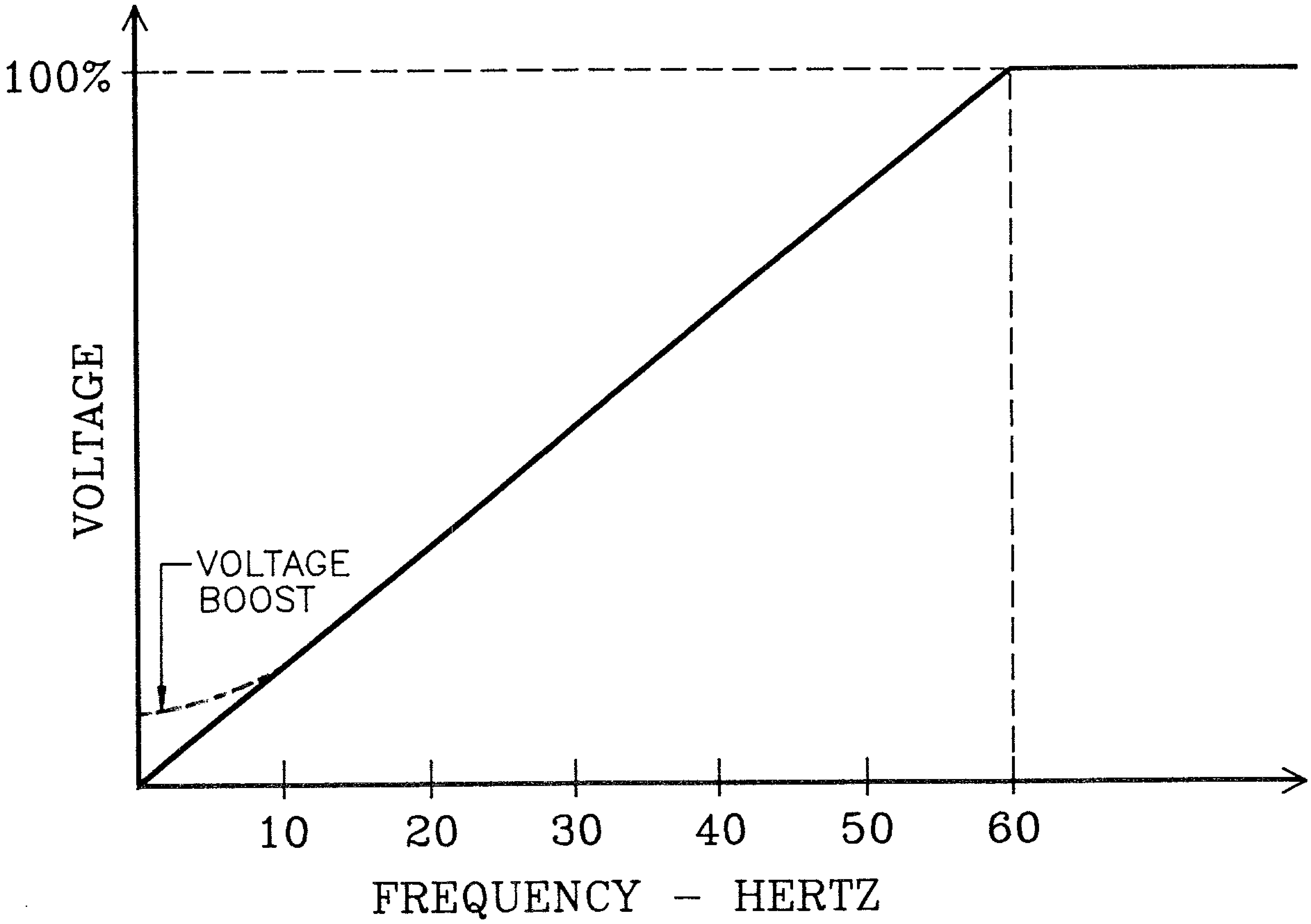
DUPONT CANADA WORKSHOP
MAY 14, 1992

ROBERT A. HANNA
P.ENG., Ph.D.

PRESENTATION OVERVIEW

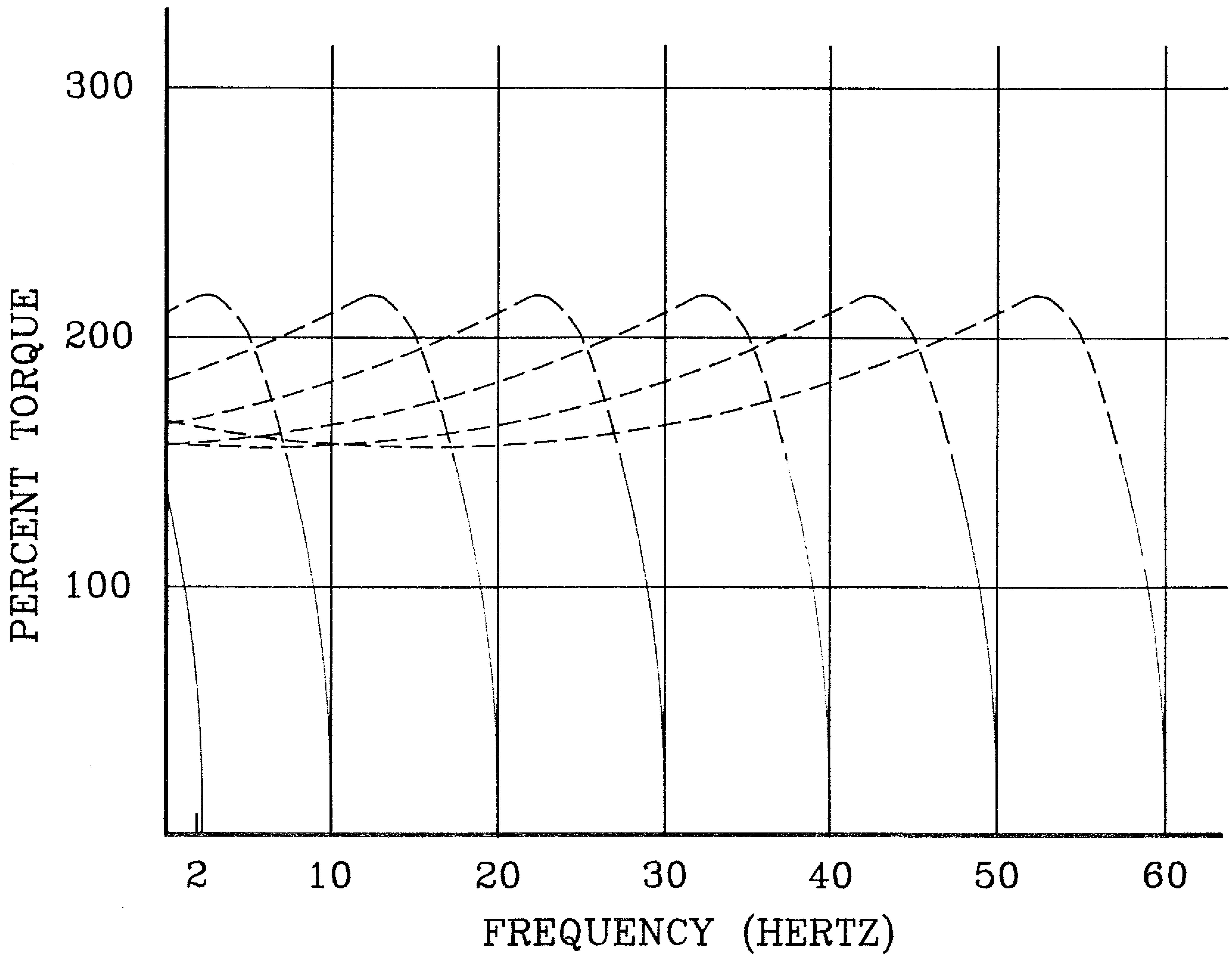
* PRINCIPLES OF ASD
* SEMICONDUCTOR DEVICES
* BASIC TYPES OF ASD
* APPLICATIONS : CONSTANT TORQUE; VARIABLE TORQUE AND CONSTANT H.P.
* HARMONICS IN ASD AND THEIR GUIDELINES
* CASE STUDIES

VOLTS / HERTZ REQUIREMENT FOR ASD



* REQUIREMENTS OF CONSTANT VOLTS / HERTZ APPLIES TO ALL TYPES OF ASD TO PRODUCE CONSTANT TORQUE CAPABILITY

* MOTOR SPEED = $\frac{120 \times \text{FREQUENCY}}{\text{NUMBER OF POLES}}$



TORQUE–SPEED CURVES FOR CONSTANT VOLTS/HERTZ

* MOTORS OPERATED FROM AC DRIVE ARE NORMALLY NEVER OPERATED ON THE DOTTED PORTION OF THE CURVE.

POWER SWITCHING DEVICES USED IN INVERTER CIRCUIT OF ASD

* BI-POLAR TRANSISTOR
  - MOST POPULAR DEVICE IN LOW VOLTAGE RANGE (UP TO 700 H.P., 600V)

* INSULATED GATE BI-POLAR TRANSISTOR (IGBT)
  - RECENTLY DEVELOPED DEVICE FOR LOW H.P. APPLICATIONS (UP TO 300 H.P., 600V)

* THYRISTOR
  - ORIGINAL DEVICE STILL USED FOR LARGE H.P. RATING (ABOVE 2500 H.P., 4kV)

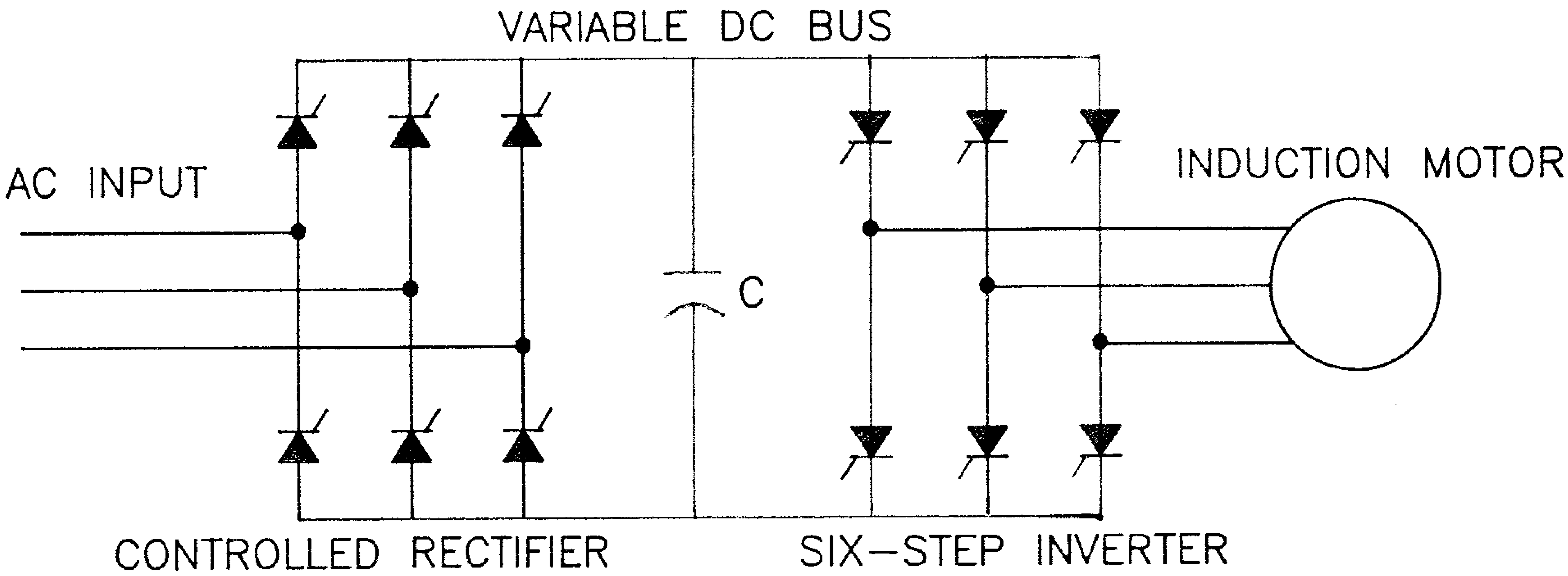
* GATE TURN-OFF THYRISTOR (GTO)
  - GRADUALLY REPLACING THE TRADITIONAL THYRISTOR FOR MEDIUM H.P. RATINGS (UP TO 2500 H.P., 4kV)

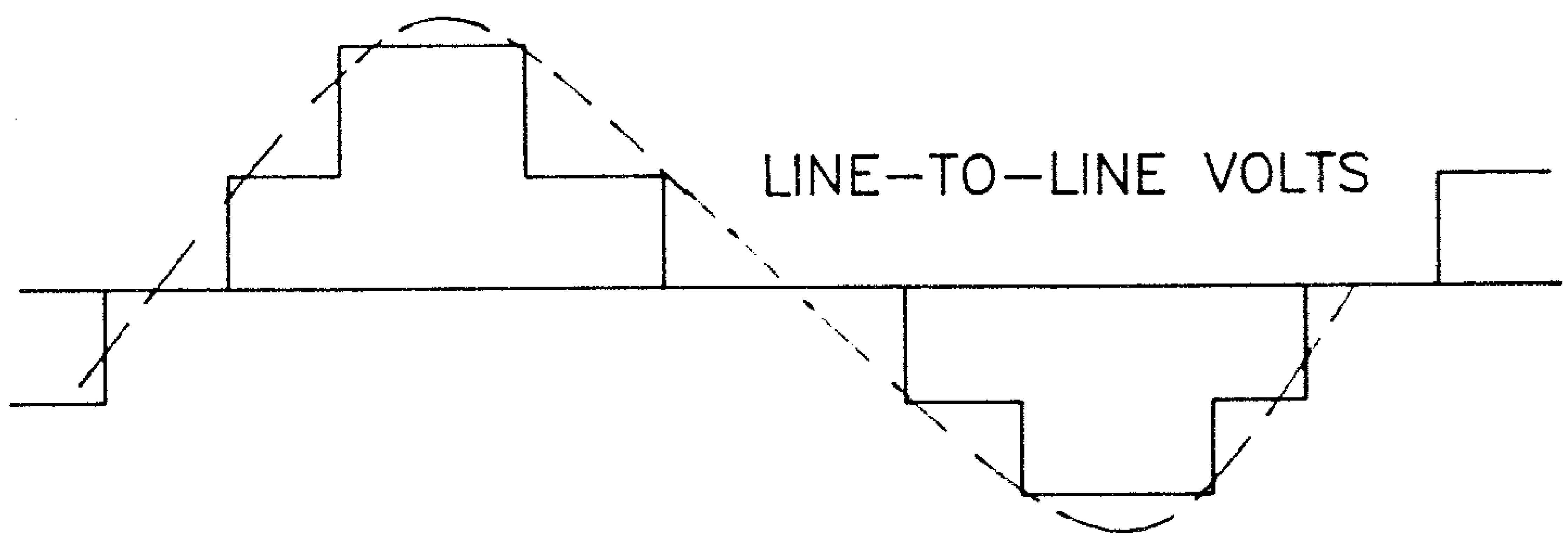
BASIC TYPES OF ASD

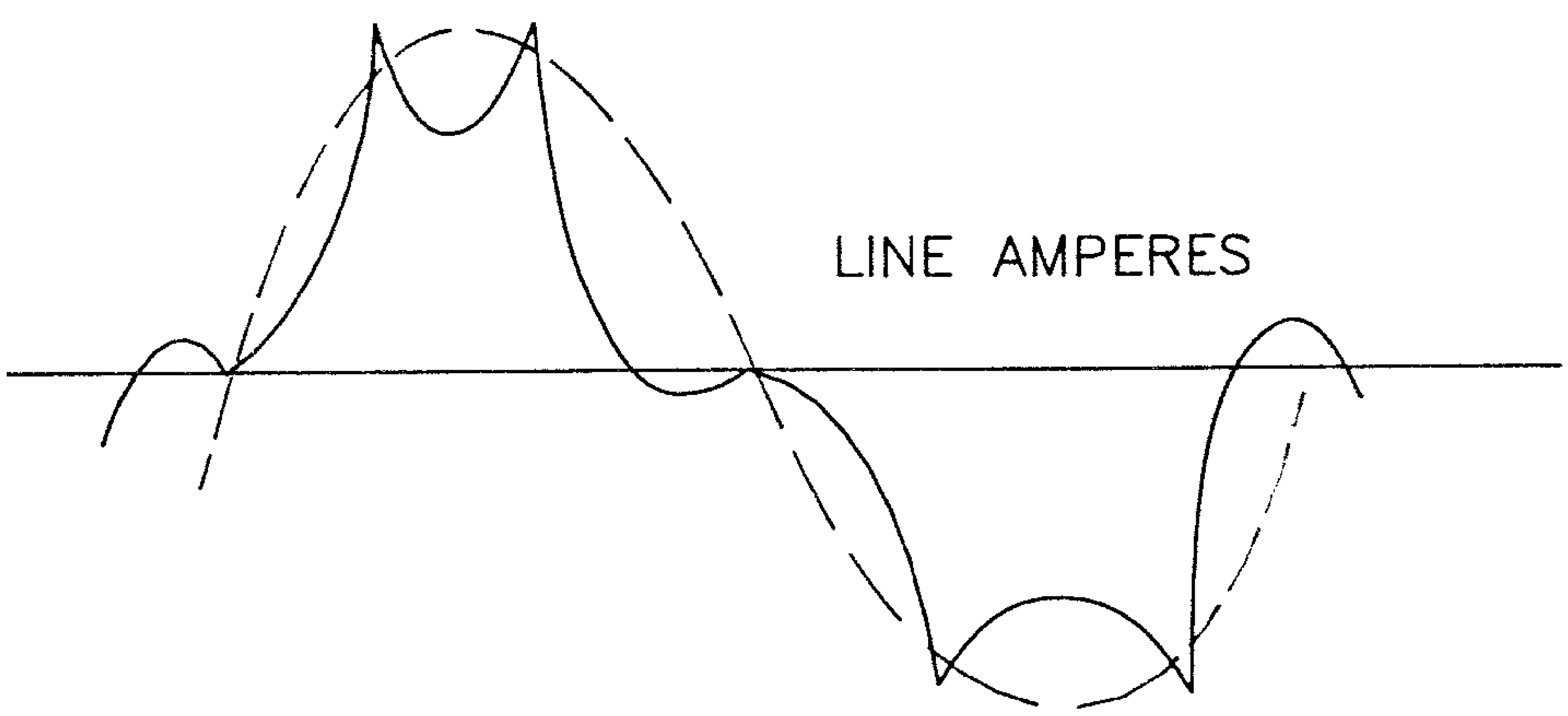
I – VARIABLE VOLTAGE INVERTER – VVI

II – CURRENT SOURCE INVERTER – CSI

III – PULSE WIDTH MODULATED – PWM







VOLTAGE-SOURCE SIX-STEP INVERTER

VVI DRIVES MAIN FEATURES

* POWER RATING : 1–1000 H.P.

* POWER REDUCTION : 10:1

* USED WITH CONSTANT TORQUE AND VARIABLE TORQUE APPLICATIONS

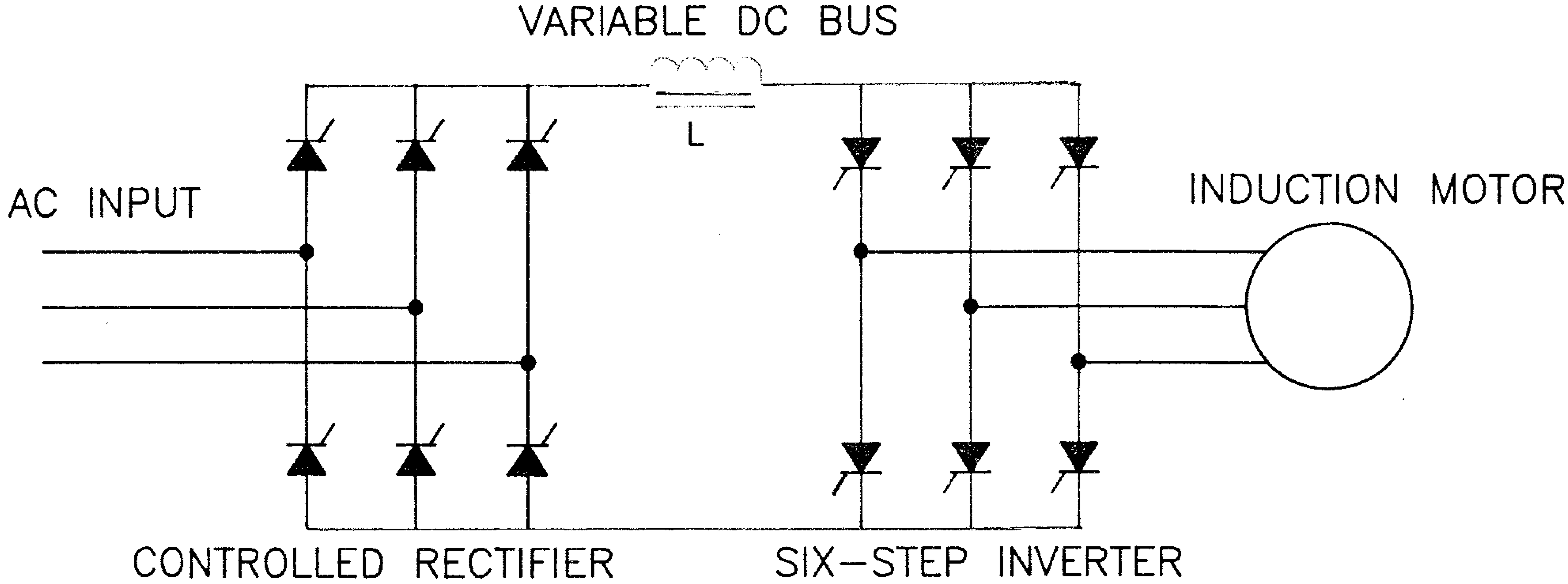
* INPUT POWER FACTOR REDUCES WITH SPEED

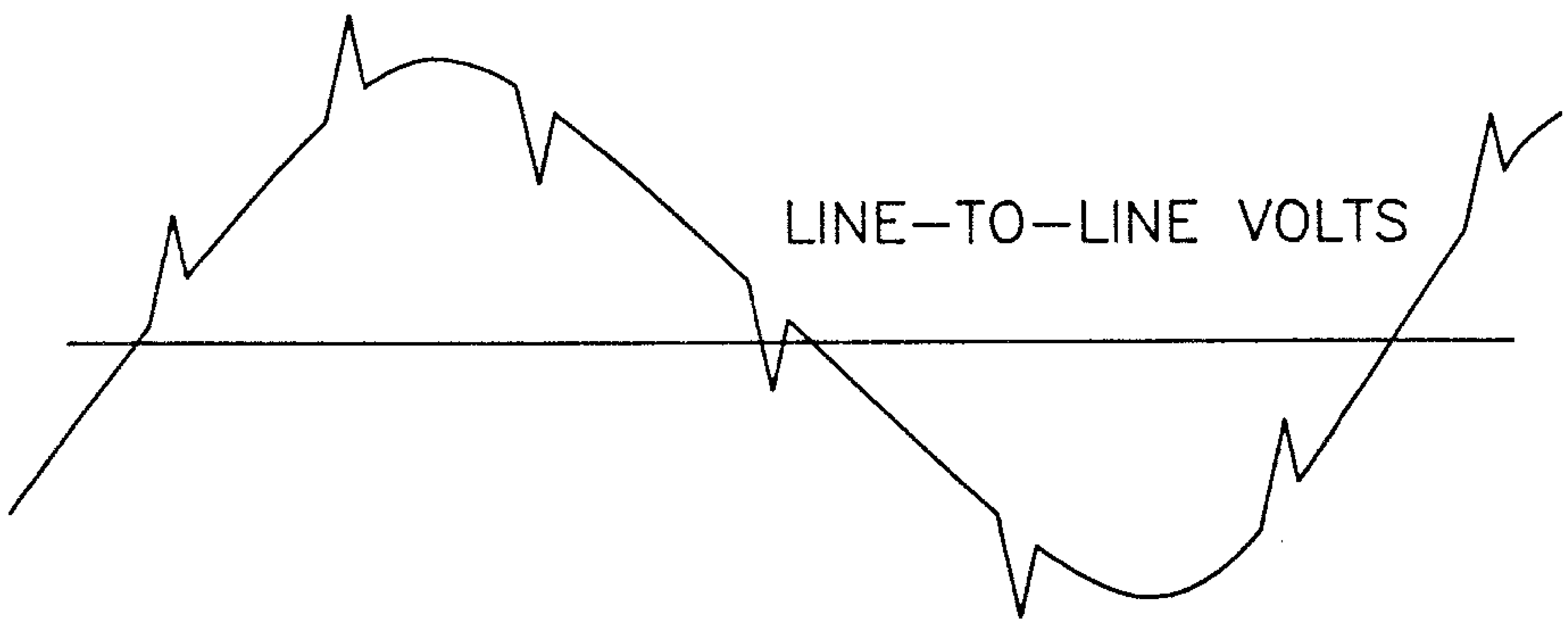
* SUITABLE FOR RETROFIT OF SINGLE OR GROUP OF MOTORS

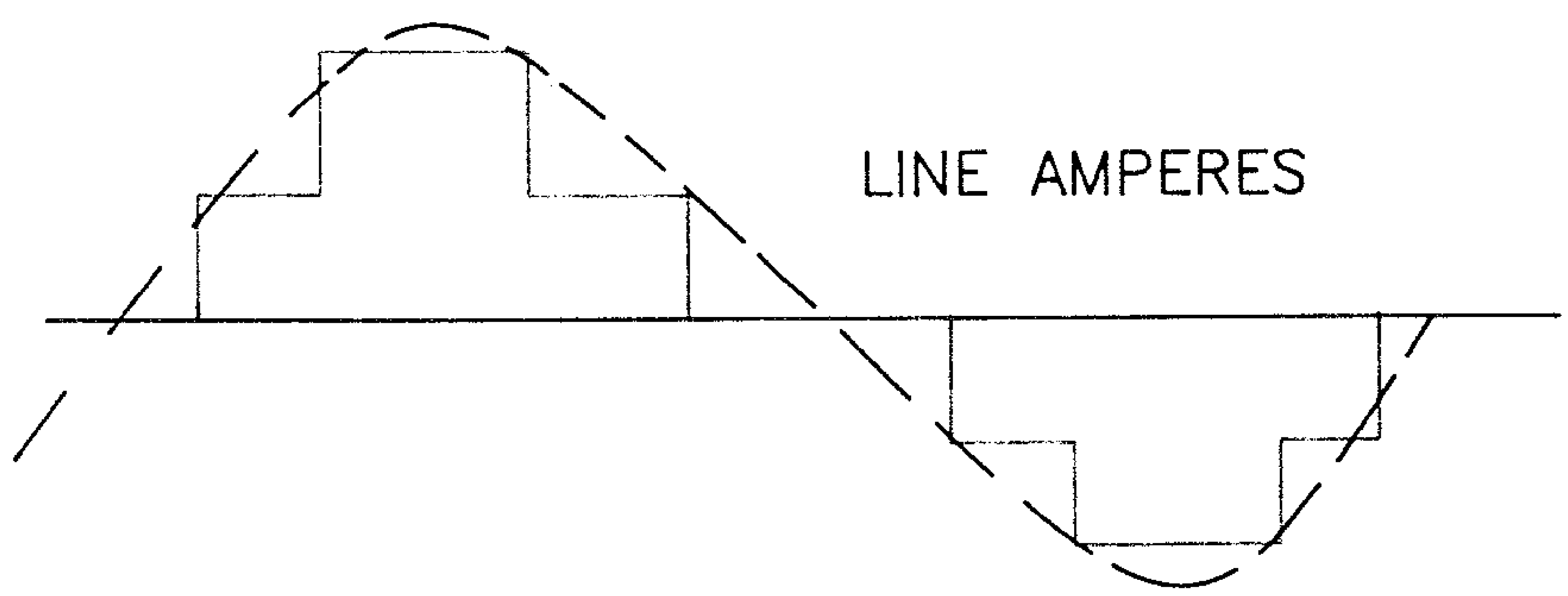
* MOTOR DERATING IS REQUIRED TO ACCOUNT FOR HARMONICS LOSSES

* INVERTER POWER AND CONTROL CIRCUITS ARE RESONABLY SIMPLE

* STANDARD INVERTER CANNOT OPERATE IN A REGENERATIVE MODE







CURRENT-SOURCE INVERTER

CSI DRIVES MAIN FEATURES

* POWER RATING : 1–1000 H.P.
  (INDUCTION MOTOR)
  : UP TO 25000 H.P.
  (SYNCHRONOUS MOTOR, LCI DRIVE)

* SPEED REDUCTION : 10:1

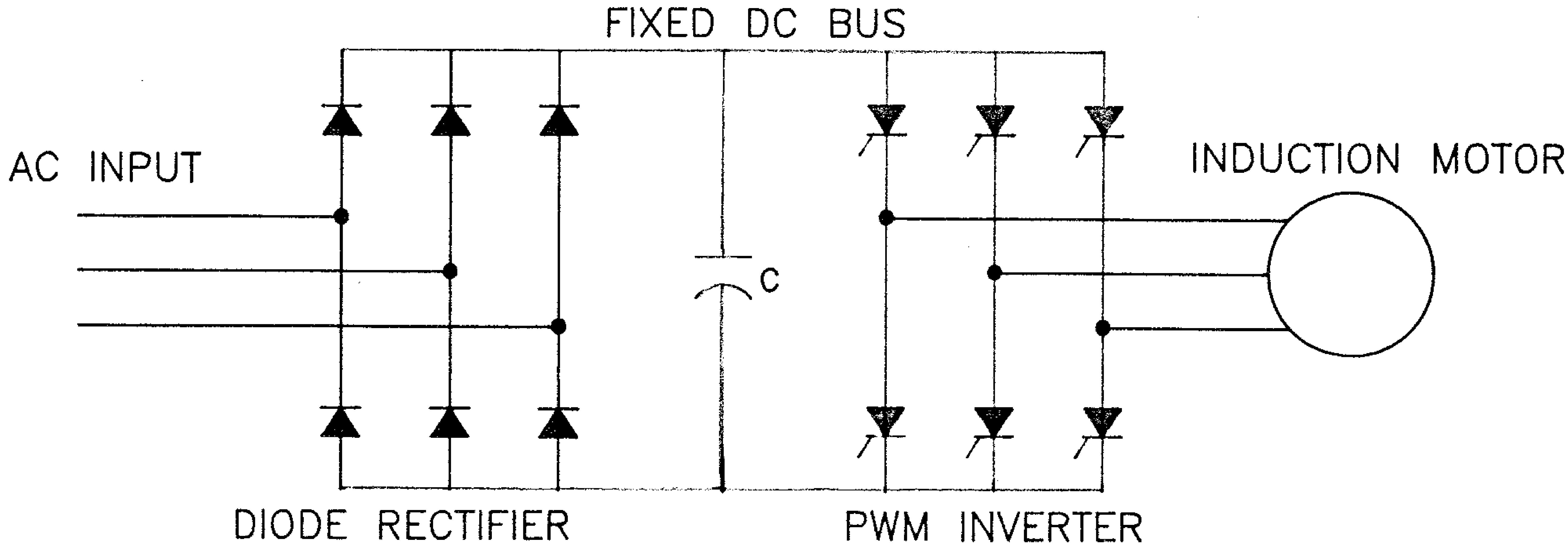
* USED WITH CONSTANT TORQUE AND VARIABLE TORQUE APPLICATIONS

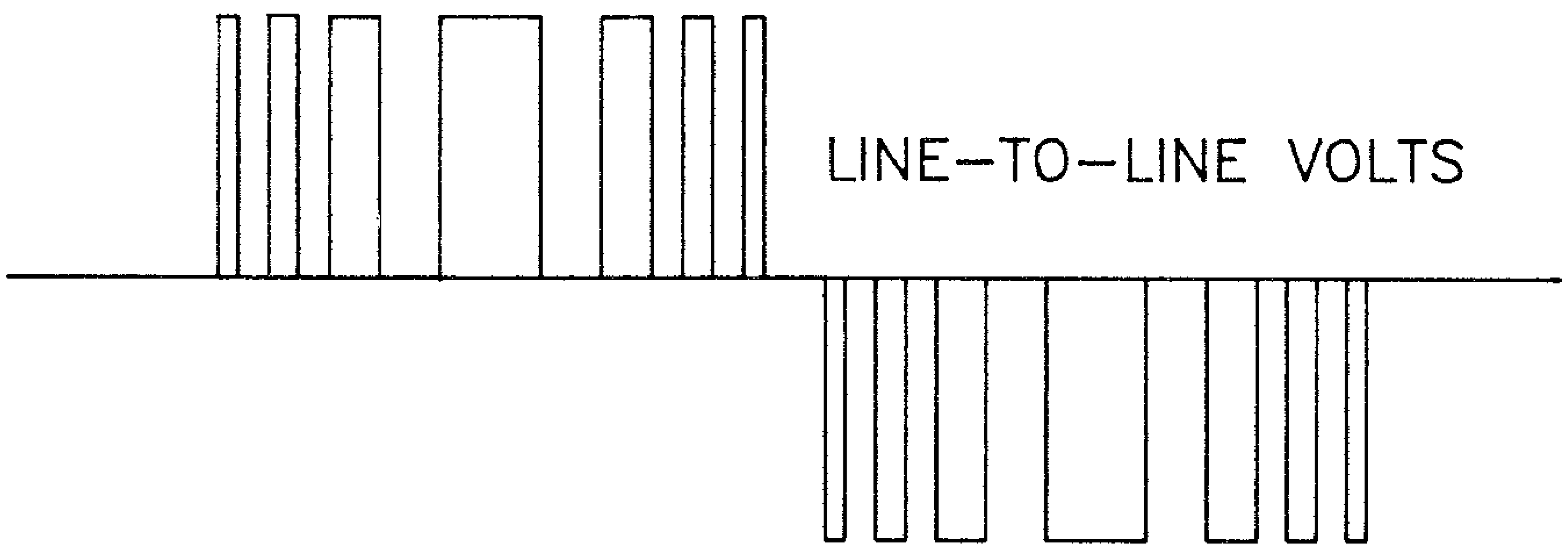
* INPUT POWER FACTOR REDUCES WITH SPEED

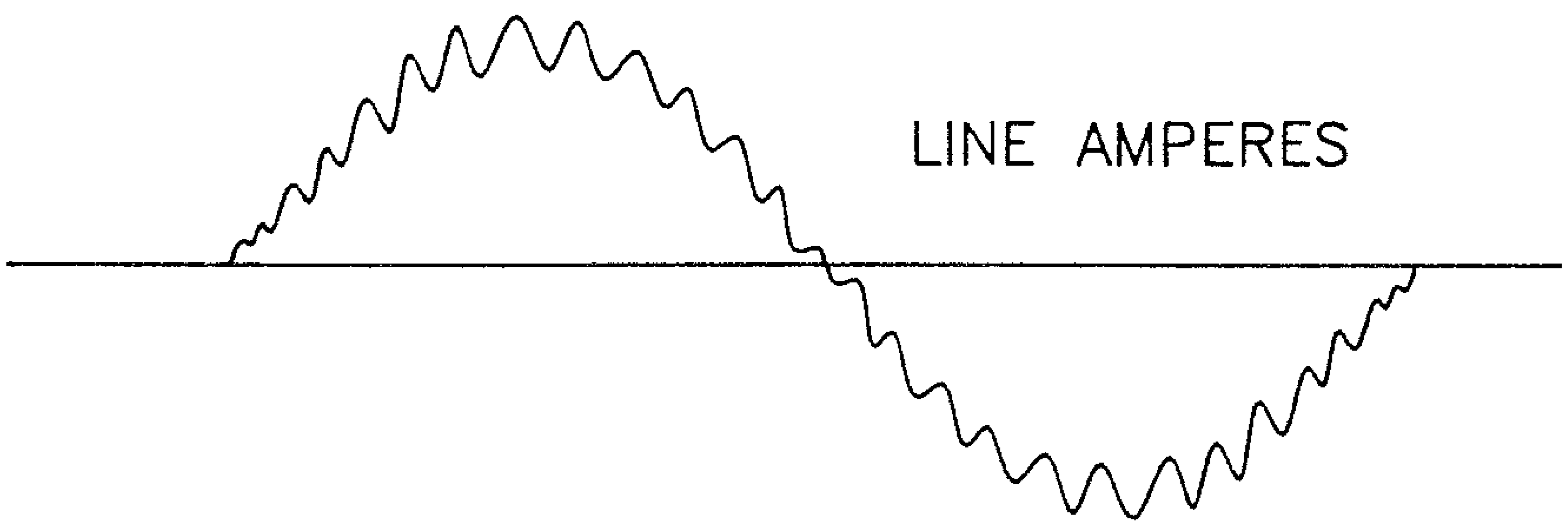
* NOT SUITABLE FOR RETROFIT APPLICATIONS

* MOTOR LOSSES ARE INCREASED DUE TO HARMONICS

* INVERTER POWER CIRCUIT IS SIMPLE BUT CONTROL CIRCUIT IS SEMI–COMPLEX







PULSE-WIDTH MODULATED INVERTER

PWM DRIVES MAIN FEATURES

* MOST POPULAR DRIVES IN LOW AND MEDIUM SIZE H.P.
* POWER RATING : 50–5000 H.P.
* SPEED REDUCTION : 30:1
* USED WITH CONSTANT TORQUE AND VARIABLE TORQUE APPLICATIONS
* INPUT POWER FACTOR IS NEAR UNITY
* SUITABLE FOR RETROFIT APPLICATIONS
* HARMONIC LOSSES, IN GENERAL, ARE LESS BUT MOTOR IS SUBJECTED TO VOLTAGE STRESSES
* INVERTER POWER CIRCUIT IS SIMPLE BUT CONTROL CIRCUIT IS COMPLEX

FLUX VECTOR CONTROL DRIVE

* MODIFIED PWM DRIVE

* CONTROL BOTH MAGNETIZING AND TORQUE PRODUCING COMPONENTS OF STATOR CURRENT INDEPENDENTLY

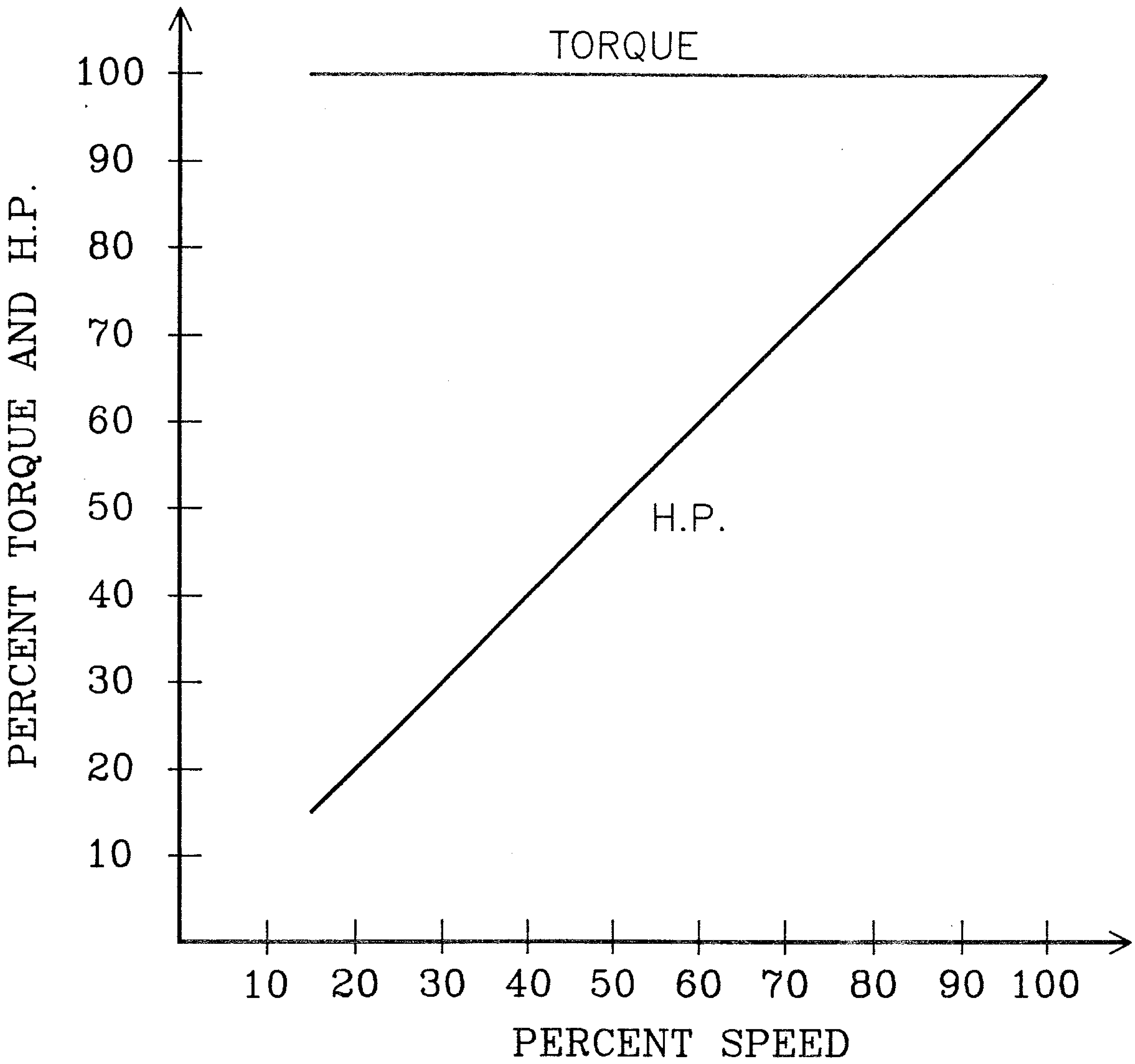
* REQUIRE AN ENCODER ON MOTOR SHAFT

* APPLICATIONS : HIGH STARTING TORQUE ABOVE 150%
  : AUTOMATIC REACCELERATION FOR HIGH INERTIA LOAD, I.D. FAN

* RATING : UP TO 1000 H.P.

VSD APPLICATIONS

* CONSTANT TORQUE
* VARIABLE TORQUE
* CONSTANT H.P.



CONSTANT TORQUE LOAD

$$HP \propto N$$

CONSTANT TORQUE APPLICATION

* EXAMPLES : RECIPROCATING COMPRESSORS AND PUMPS, SCREW TYPE MIXER, CONVEYORS, etc.

* INCREASED TEMPERATURE RISE DUE TO HARMONICS AND REDUCED VENTILATION

* SELF-VENTILATED MOTOR FOR 50-100% SPEED RANGE

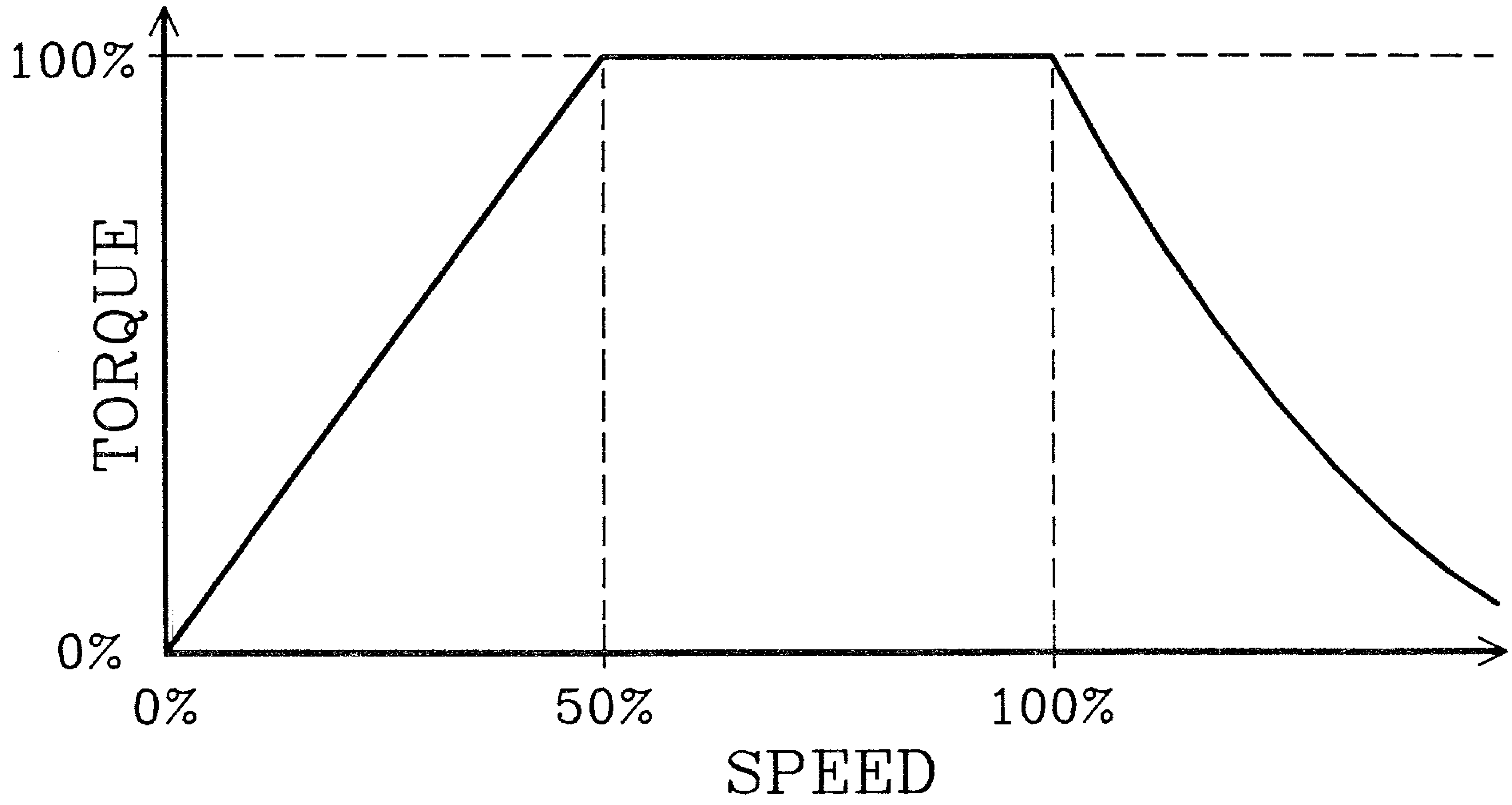
* FORCED VENTILATED MOTOR BELOW 50% SPEED

* FOR RETROFIT APPLICATION, USE CLASS F INSULATION MOTOR ONLY

* TORTIONAL ANALYSIS IS RECOMMENDED SPECIALLY FOR TWO POLE MOTORS

* H.P. IS LINEARLY PROPORTIONAL TO SPEED

* DIFFICULT TO JUSTIFY THEIR USE ON ENERGY SAVINGS ALONE



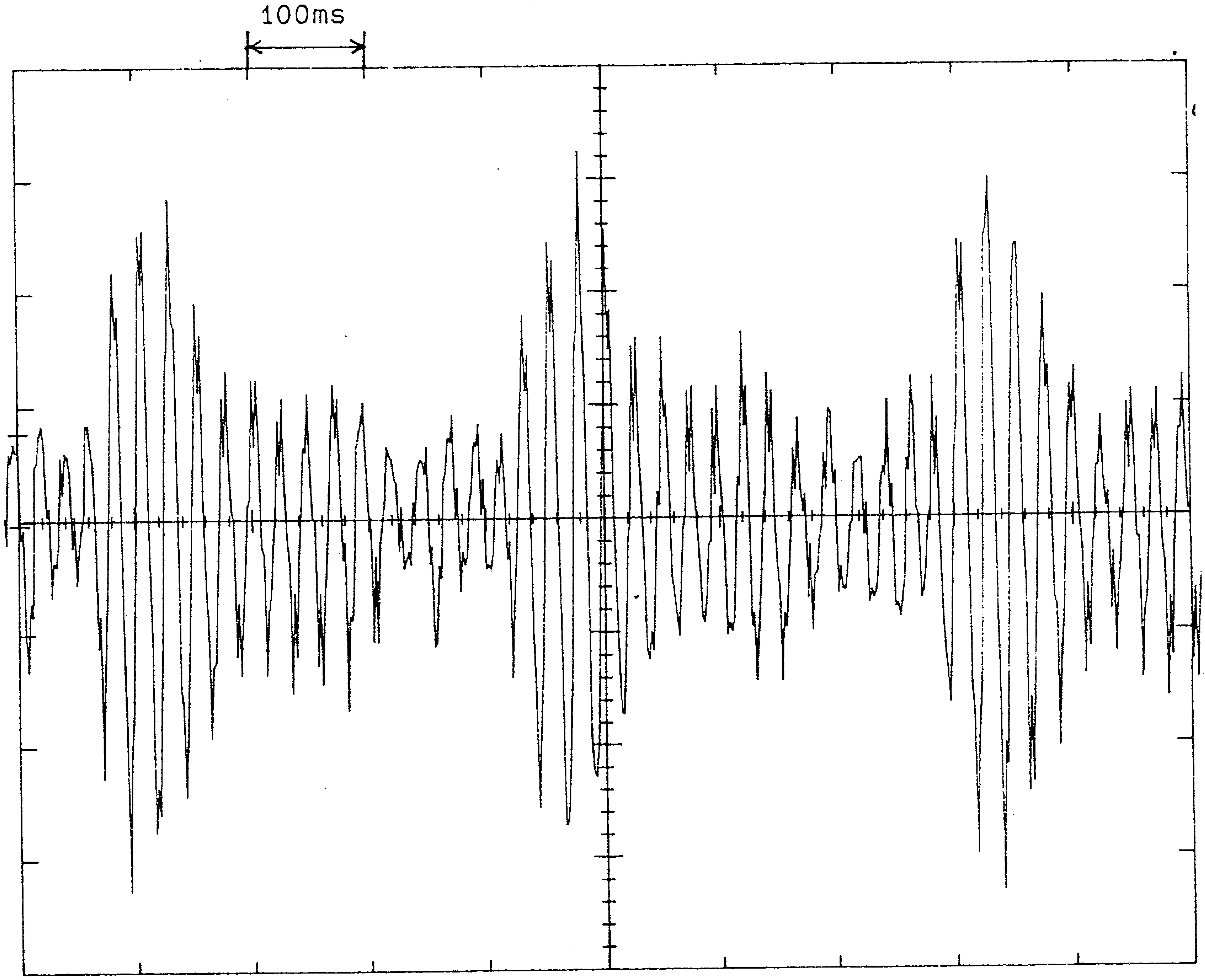
MOTOR TORQUE CAPABILITY

FOR SELF-VENTILATED

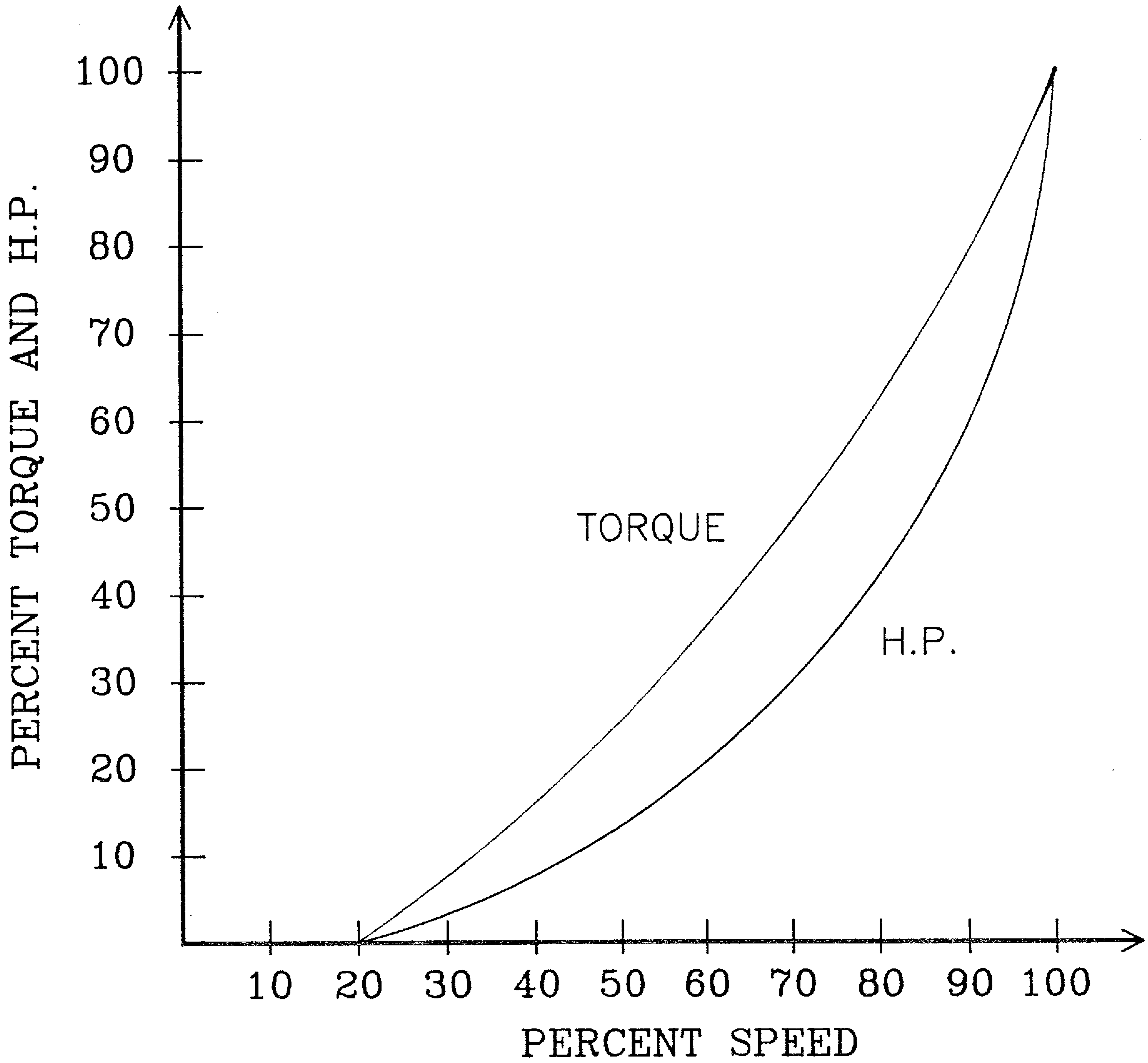
TORQUE CAPABILITY IS LIMITED BY

COMBINATION OF LOSSES AND VENTILATION

additional reduced



500 H.P. MOTOR CURRENT PULSATION
IN PWM DRIVE OPERATING WITH
FAULTY PUMP VALVES



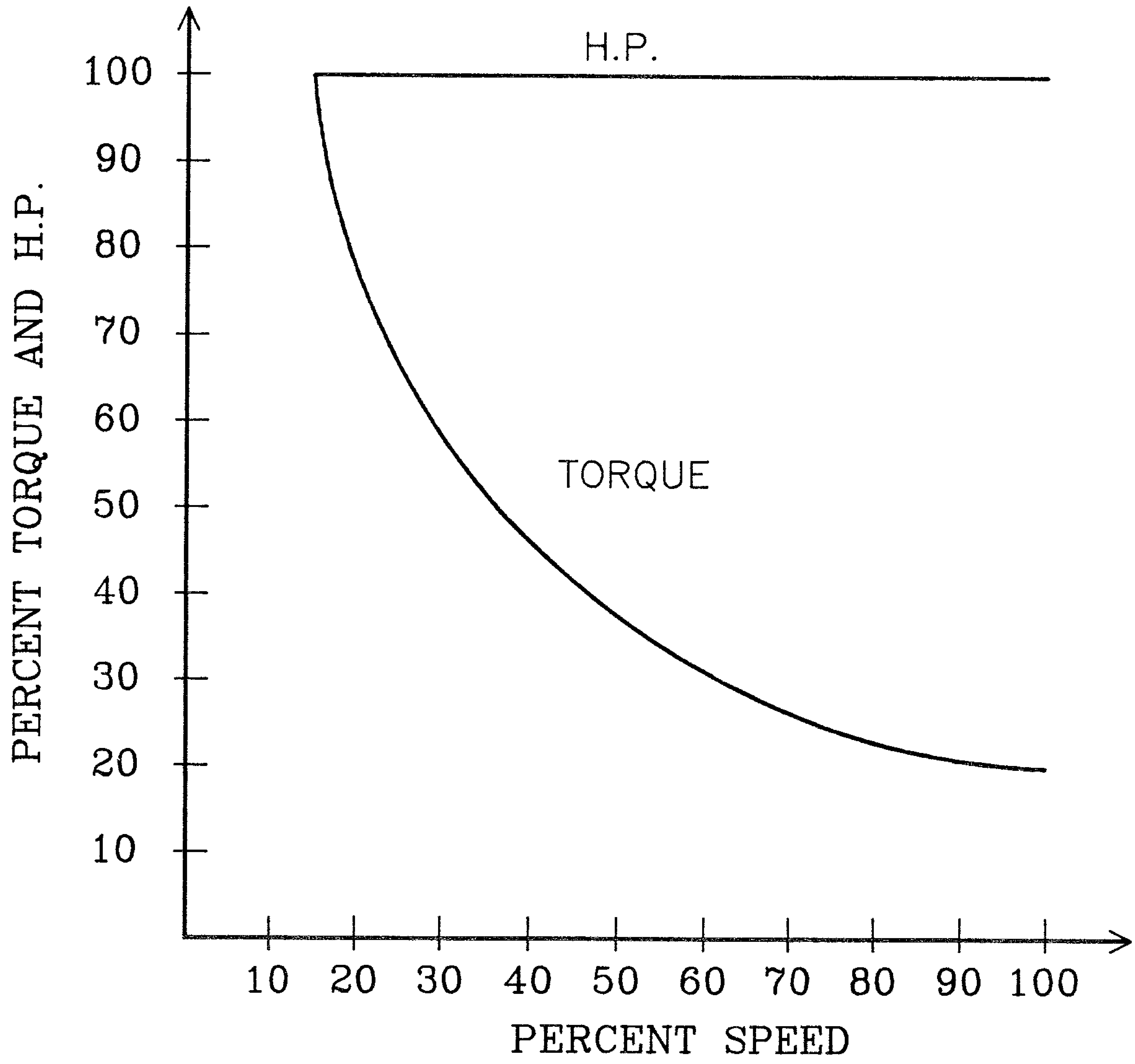
VARIABLE TORQUE LOAD

$$T \propto N^2$$

$$HP \propto N^3$$

VARIABLE TORQUE APPLICATION

* EXAMPLES : CENTRIFUGAL PUMPS, FANS, AND COMPRESSORS
* HARMONIC LOSSES ARE GREATEST AT RATED SPEED
* SELF-VENTILATED MOTOR FOR 25-100% SPEED RANGE
* CLASS F INSULATION IS RECOMMENDED
* TORQUE VARIES DIRECTLY WITH SPEED SQUARED
* H.P. VARIES DIRECTLY WITH SPEED CUBED
* CONSIDERABLE ENERGY SAVING EVEN AT SLIGHTLY REDUCED SPEED



CONSTANT H.P. LOAD

$$T \propto \frac{1}{N}$$

HARMONIC PRODUCING EQUIPMENT

* RECTIFIER
* DC MOTOR DRIVES
* UPS
* ARC FURNACE
* STATIC VAR GENERATOR
* CYCLO CONVERTER
* STATIC MOTOR STARTER

$$h = KP \pm 1$$

$$I_h = \frac{I_1}{h}$$

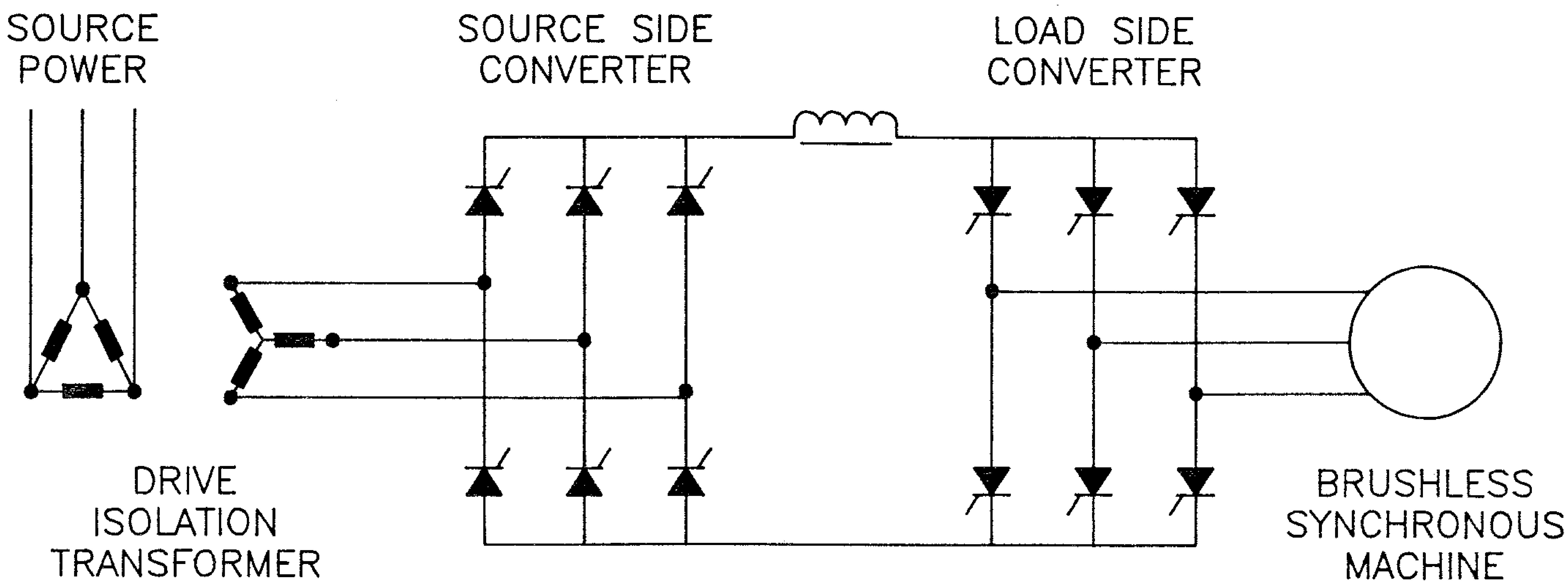
HARMONIC ORDER AND MAGNITUDE PRODUCED BY POWER CONVERTER

* FOR SIX PULSE :

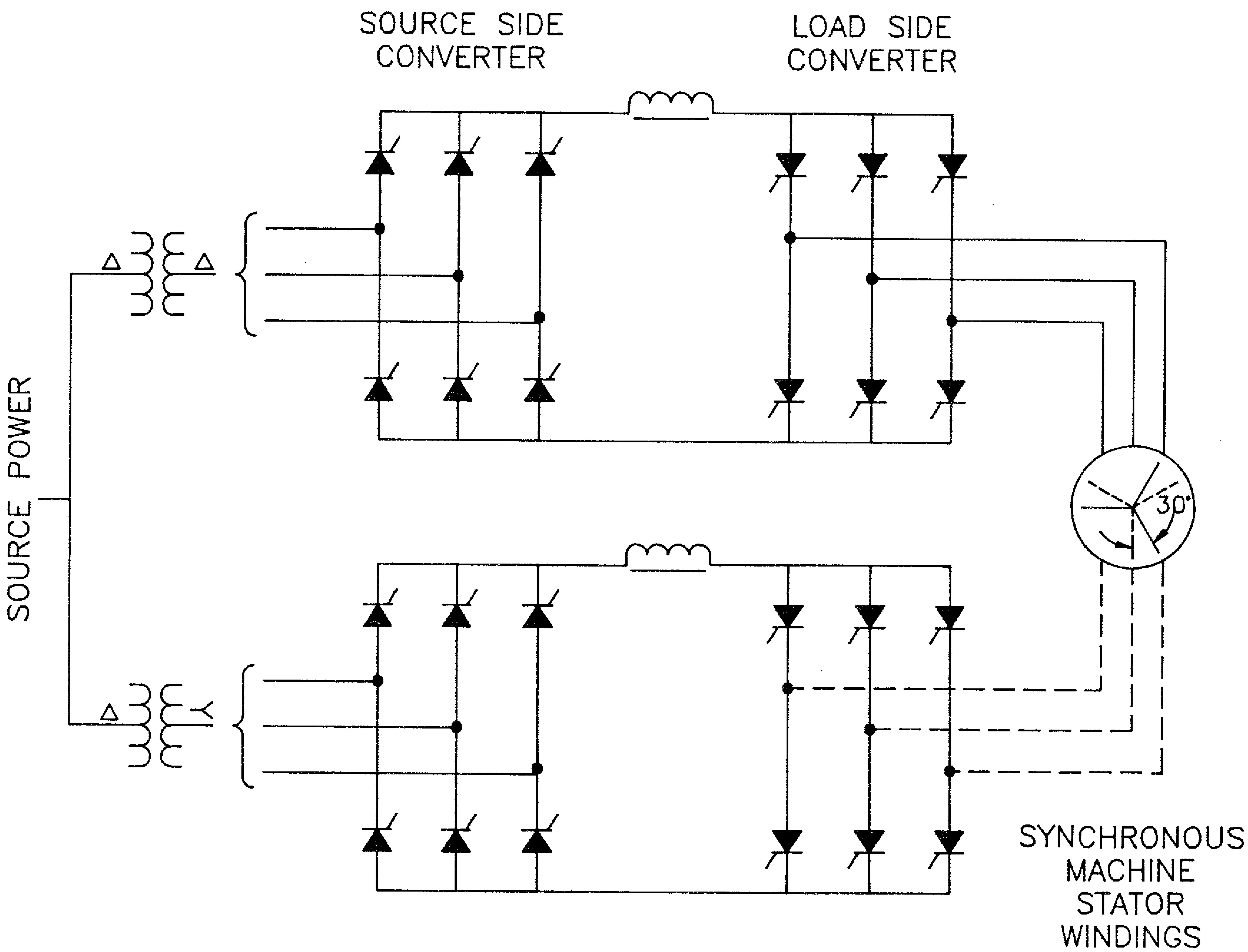
  h = 5, 7, 11, 13, 17, 19, . . .

* FOR TWELVE PULSE :

  h = 11, 13, 23, 25, . . .



BASIC CIRCUIT FOR 6-PULSE LCI DRIVE CONNECTED TO 3-PHASE MACHINE



BASIC CIRCUIT FOR 12-PULSE LCI DRIVE CONNECTED TO 6-PHASE MACHINE

REVISED IEEE 519

RECOMMENDED PRACTICES AND REQUIREMENTS FOR HARMONIC CONTROL IN ELECTRICAL POWER SYSTEM

TWO CRITERIA TO EVALUATE HARMONIC DISTORTION :

1. A LIMITATION IN THE HARMONIC CURRENT THAT A USER CAN TRANSMIT INTO THE UTILITY SYSTEM.

2. THE QUALITY OF THE VOLTAGE THAT THE UTILITY MUST FURNISH THE USER.

HARMONIC PROBLEM IS A <u>SYSTEM</u> PROBLEM.

CURRENT DISTORTION LIMITS FOR GENERAL DISTRIBUTION SYSTEMS (120 VOLTS TO 69,000 VOLTS)

MAXIMUM HARMONIC CURRENT DISTORTION IN % OF FUNDAMENTAL						
HARMONIC ORDER (ODD HARMONICS)						
I_{SC}/I_L	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	THD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20–50	7.0	3.5	2.5	1.0	0.5	8.0
50–100	10.0	4.5	4.0	1.5	0.7	12.0
100–1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Where I_{SC} = MAXIMUM SHORT CIRCUIT CURRENT AT PCC.
And I_L = MAXIMUM DEMAND LOAD CURRENT (FUNDAMENTAL FREQUENCY) AT PCC.