VARIABLE SPEED DRIVES USING THREE-PHASE CONTROLLED RECTIFIER AND INVERTER FED FROM A DC- LINK VOLTAGE SOURCE

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

January 2004

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Kehla Alfred Ngwenya

ABSTRACT

The purpose of this report is to design of variable speed drives using three-phase, half-wave controlled rectifier and inverter fed from a DC- link voltage source. These devices are used in industry to vary the speed of DC as well as AC motors according to the needs of a process.

The building blocks of Variable speed Drives are rectifier, DC link and the inverter. The rectifier is used to rectify the incoming AC power from the supply into a DC voltage. The DC link is used to smooth out the output of the rectifier. The output from the DC link is fed to the inverter stage. The inverter changes this DC power into AC power, to vary the speed of the AC motor.

For this project to be successful, there are a number of methods that were implemented. Firstly, the literature review of the variable speed drives was made. This was followed by the literature review of the firing circuit for the thyristor, the filter design and the inverter design. Lastly the software which was mainly used to simulate this design is Pspice.

The project is divided into to semesters, during the first semester of the project; the firing of the SCR was designed. This was followed by the design of the complete three-phase controlled rectifier, but this was only accomplished during the second semester of the project. The simulation results of SCR triggering and the rectifier shows that design was successful.

During the second semester DC Link as well as the inverter was to be designed. The DC link design was successful as shown in the simulation results. And up to this point, the rectifier can drive a DC motor. The design of the inverter is not yet completed.

ACKNOWLEDGEMENTS

First and foremost I would to thank the Almighty God for his grace and love that he has bestowed upon me to guide me through my final year of study.

Secondly, I would like to express my thanks to my final year project supervisor Mr. Taib B. Ibrahim for his support and exceptional guidance in the preparation of this project. Sir, your input this project has been very valuable.

In addition thanks are due to this individual, FYP coordinator, Mr. Mohd Zuki Yusoff, and Power systems technician Mr. Yassin.

Special thanks should be given to my fallow students colleagues who helped me in many ways.

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CHAPTER 1

INTRODUCTION

1.1 Background of the project

Variable speed drives or VSDs as the name implies are used in the industry to vary the speed of motors. These drives can be used to vary the speed of either AC or DC motors.

Most of the drives used in the industries today are electrical. Depending on the application, some of them are fixed speed and some of them variable speed. The variable speed drives, till a couple of decades back, had various limitations such poor efficiencies; they occupied larger space, and had lower speeds etc. However, the advent of power electronics transformed the scene completely and today we have variable speed drive systems which are not only smaller in size but also very efficient, higher degree of reliability and meeting all the stringent demands of various industries of modern era.

Modern technology offers various alternatives in selection of drive systems. Depending on the process requirements, environmental conditions and financial objectives of a company, choice of a drive system can be made. Primarily, the drive systems can be divided in two groups, DC variable speed drives and AC variable speed drives.

1.2 Problem Statement

The development in drive systems started with DC drive systems for most early variable speed requirements. This is because it was simple to construct and easy to control these drives systems. And this technology continued to be popular all over the world. But due to some of the disadvantages of DC motors, this technology has some draw backs. It is well known that DC motor need regular maintenance and they are not suitable for operation in hazardous areas like in petrochemical industries. Due to these limitations of DC drive systems, AC variable speed drives which use AC motors as the driven element where designed. Advantages of AC drive systems are that they require low maintenance and can operate in highly explosive environments like in petrochemical plants.

The problem with the conventional DC variable speed drive systems is that, they require regular maintenance and they cannot be used in explosive petrochemical plants.

1.3 Objective and Scope of Study

The main objective of this project is to design AC variable speed drive using controlled rectifier and self commutated inverter fed from a DC link source of voltage. Some of the project objectives are:

- Study the variable speed drives
- Design and Simulation using Pspice
- Building a prototype

Since this is a two semester project, during the first semester of the project only the rectifier section and a firing angle circuit of the project will be designed to control the speed of a DC motor. And during the second semester of the project an inverter will be designed and it will be interfaced to the rectifier by the DC link to control the speed of the AC motor, and this is what the project is trying to achieve.

CHAPTER 2

LITERATURE REVIEW AND THEORY

In AC variable speed drives the DC voltage is controlled, and the DC current is free to respond to motor needs. The AC variable speed drives uses a rectifier, a DC link, and an inverter to vary the frequency of the applied AC voltage.

In this system the three-phase AC supply is converted into variable DC supply with the help of phase control rectifier. The variable DC voltage is impressed at the input of a force-commutated bridge inverter and produces a variable-voltage, variable – frequency output to control the speed of an AC motor. The voltage-fed inverter produces a square-wave voltage at the machine input.

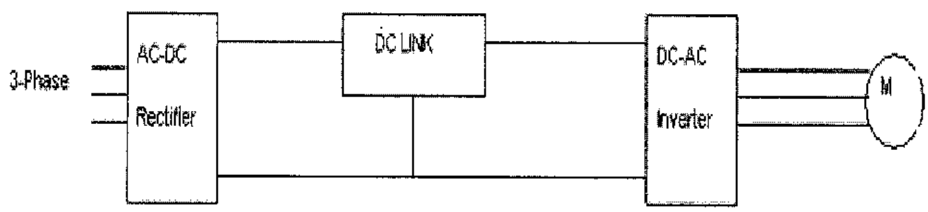


FIGURE 2

2.1 Controlled Rectifier

2.1.1 The Silicon Controlled Rectifier (SCR)

SCR also known as thyristor is a four layer, three electrode semiconductor device, can be thought of as a controlled diode that when off, blocks current of either polarity.

When forward biased and turned on, the SCR operates as an ordinary diode as long as the conducting current remains above the so called holding current level. In power electronic converters, an SCR is turned on by gate current supplied by an external source connected between the gate and cathode

The SCR is an electronic switch, with two main terminals, anode and cathode, and a "switch –on" terminal, the gate. Figure 2.1.1 shows a diagram of the SCR.

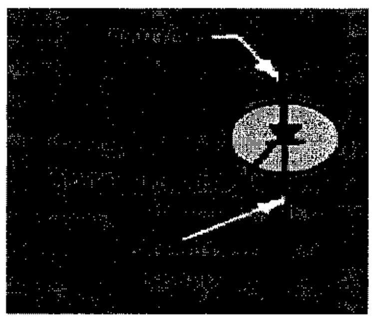


Figure 2.1.1

Like the diode current only flow in the forward- direction from anode to cathode. But unlike the diode which conducts in the forward direction as soon as forward current is available the SCR will continue blocking the forward current until a small voltage is applied to the gate in such a way that the gate terminal is positive with respect to the cathode. This will turn the SCR on. As soon as the anode-cathode current reaches the latching level, the gate current can be removed and the SCR will remain on. Once established, the anode-cathode current cannot be interrupted any gate signal. The SCR can only be turned off after the anode-cathode current is reduced to zero.

2.1.2 Three-phase, Half-wave controlled Rectifier

Three-phase half-wave controlled rectifier consists of three thyristors as shown in the figure below. This rectifier is also called a three-pulse circuit because the pulsation in DC voltage is three times the input frequency.

Each thyristor receives a firing pulse relative in time to its own phase voltage. The three gate pulses are displaced by 120° relative to each other, giving the same delay angle to each thyristor.

If each thyristor is triggered at the instant when source makes its anode voltage with respect to its cathode, that is 30° after the phase voltage crosses the zero axis, then the circuit behaves like half-wave uncontrolled diode rectifier.

However, if the firing of the thyristors is delayed from these crossing points, the output voltage waveform is altered.

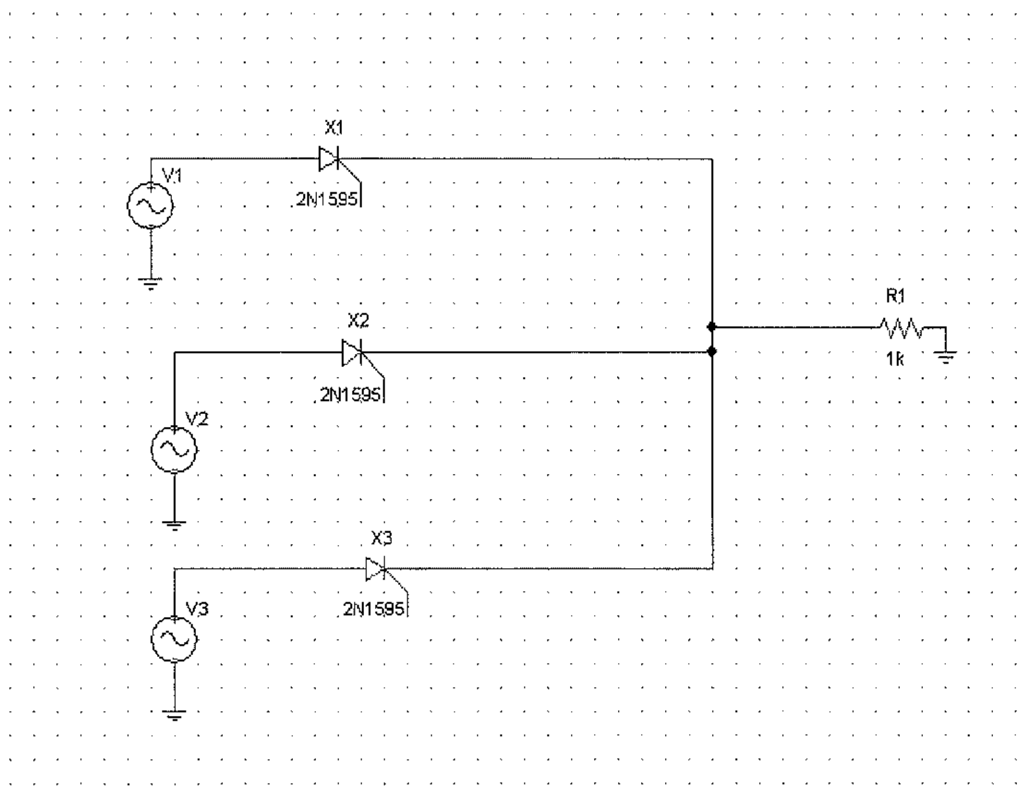


Figure 2.1

2.2 The DC Link or LC filter

Filters are indispensable circuit components of most practical power rectifiers. Depending on their placements, filters can be classified as input, output and immediate ones. Input filters screen the supply source from harmonic currents drawn by the rectifier and improve the input power factor of the rectifier. Output or load filters are employed to improve quality of the power supplied to the load. The immediate filters, usually called links, interface two converters forming a cascade such as that of a rectifier and inverter in the ac-to-dc-to-ac power conversion.

For the sake of this project, I will be looking at the immediate filter or DC link.

A filter at the DC side of a power converter is employed to reduce the voltage and current ripple. Depending on specific requirements, the filter consists of a capacitor connected in parallel with the converter terminal, inductor connected in series. If a DC current IC drawn from the capacitor C during a time interval Δt, then the voltage across the capacitor is given by $\Delta VC = 1/C\ (I\Delta t)$. It means that the higher the filter capacitance is, the more stable is the voltage across it. Analogously, if a DC voltage is applied to a inductor L over a interval Δt, the current in the inductor increases by $\Delta IL = 1/L\ (VL\Delta t)$ which implies a stabilizing impact of the inductance on the current.

Care should be taken for the resonant frequency of the filter to be significantly higher than the supply frequency. [Introduction to Power Electronics, page 114-115]

2.3 The Inverter

Inverters are static circuits that convert power from a Dc source to Ac power at a specified output voltage and frequency. Inverters are used in a wide of industrial applications including variable speed ac motor drives, induction heating, and aircraft power supplies.

In general there are two types of inverters, voltage source inverter (VSI) and current source inverters (CSI).

For the sake of this project we will look into voltage source inverter because according to project requirements, the inverter must be fed from a DC link source of voltage. [Principles of electric Machines and Power Electronics, P.C. Sen., page 541-542]

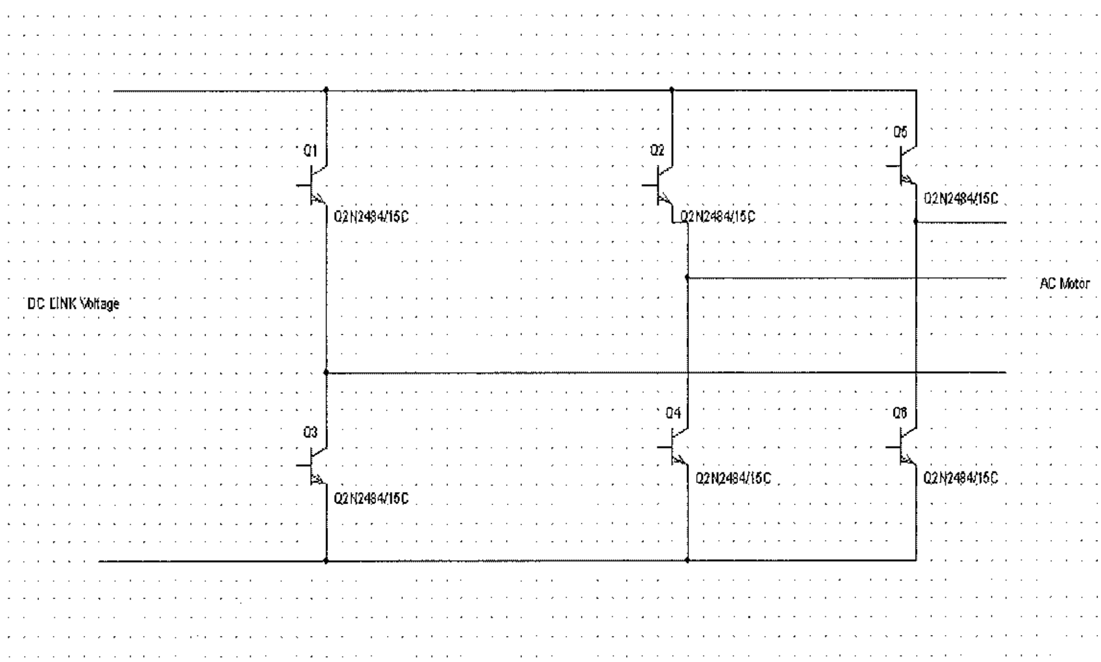
2.3.1 Voltage source inverter

The input of voltage source inverter is a stiff DC voltage supplier, which can be a battery or the output of a controlled rectifier. The switching device can be a conventional thyristor, a GTO thyristor or a power transistor.

Both single-phase and three-phase voltage source inverters are used in industry but, for the sake of this project we only look at the three phase inverter. [Principles of electric Machines and Power Electronics Sen., page 542]

2.3.2 Three-phase bridge Inverter

The three-phase bridge inverter circuit changes the incoming DC voltage to a three-phase variable-frequency variable-voltage output. The input DC voltage can be from DC source or a rectified AC voltage. The circuit for three-phase inverter is shown in figure 2.3.2. The circuit consists of six power switches with associated power diodes. The switches are opened and closed periodically in the proper sequence to produce the desired output waveform. The rate of switching determines the output frequency of the inverter. [Power Electronics Technology, Ashfaq, page 329-330]



Q1
Q2N2484/15C
Q2
Q2N2484/15C
Q5
Q2N2484/15C
AC Motor
DC LINK Voltage
Q3
Q2N2484/15C
Q4
Q2N2484/15C
Q6
Q2N2484/15C

Figure 3.2.2

CHAPTER 3

METHODOLOGY

3.1 SCR triggering

A thyristor or SCR is like an ordinary diode; the difference is that it has a third terminal called gate. For the thyristor to be energized its anode terminal must be positive with respect to its cathode terminal, and its gate terminal must be positive with respect to cathode terminal, this is called SCR triggering. SCR triggering is achieved by supplying a voltage pulse to the gate terminal. When this two conditions have been met it's when the thyristor can be in the ON mode.

3.1.1 SCR triggering design

The following calculations are based on triggering of the SCR in figure 3.1.1.In this design the maximum value of the variable resistor R is chosen as 50k. To find the value of the capacitor, the following equation applies.

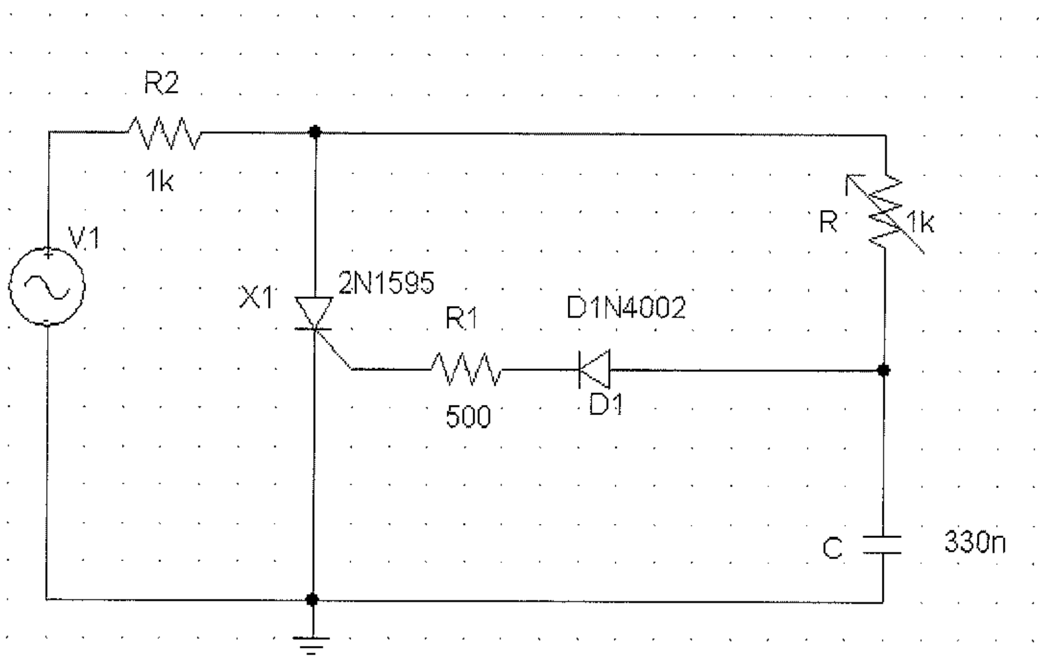


Figure 3.1.1

$RC \geq 0.65T$, T is the time in seconds.

Therefore, $RC \geq 0.65\frac{1}{F}$ and F= 1/T.

$C \geq \frac{0.65}{RF}$, R = 50k and F=50Hz

Therefore, C $\geq$ 260nF

The maximum value of the limiting resistor between the diode and the gate terminal of the thyristor is calculated using the following equation.

$$R_{1max} = \frac{\sqrt{2}V}{I_{GT}}$$

V is the supply voltage = 240V and I_{GT} which is the current needed to trigger the thyristor is equal to 30mA; this is according to the appended data sheet.

Therefore, R_{1max} =11,313 Ω

The limiting resistor of 500 Ω is chosen in this design.

3.2 Three –phase half-wave controlled rectifier design

Since the project requirements did not specify whether to use a three-phase full-wave controlled rectifier or a three-phase half-wave controlled rectifier, I have decided to use the three-phase half-wave controlled rectifier for this design. The three-phase controlled rectifier consists of three thyristors as shown from figure 3.2. In this circuit, the pulsation in DC voltage is three times the input frequency, 150Hz for this design since the supply voltage is 50Hz.

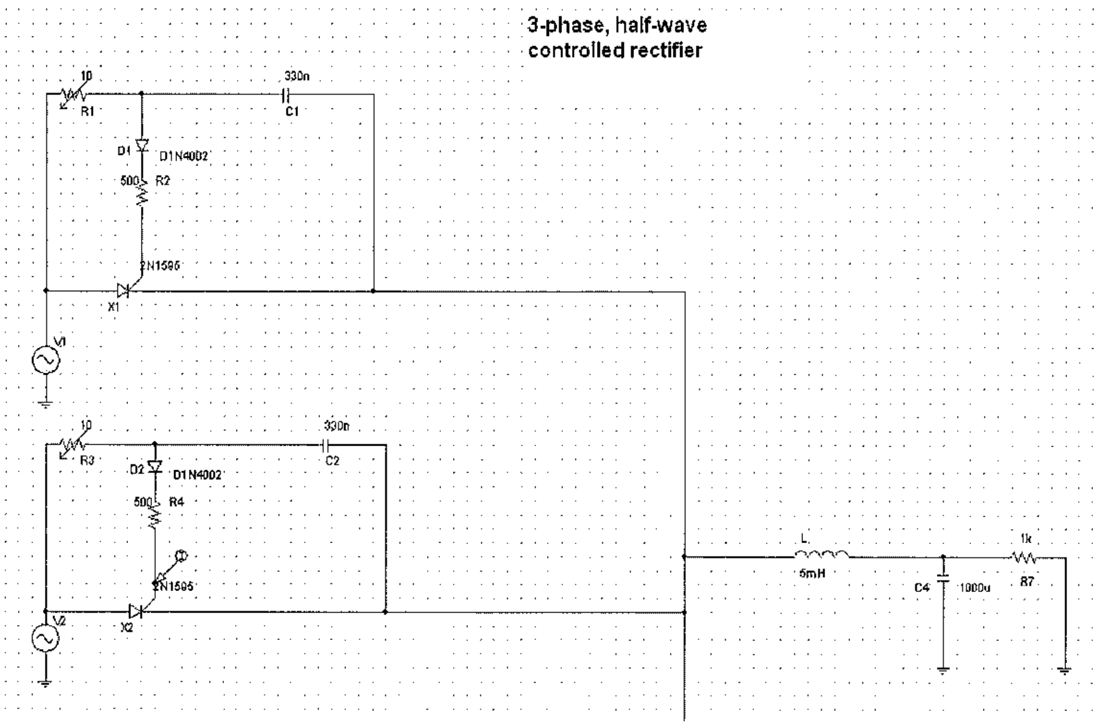


Figure 3.2

Each thyristor must receive a firing signal relative in time to its own phase voltage. The firing of these three thyristors is derived from the single-phase firing of one thyristor from section 4.4.1. The circuit consists of a variable resistor, a capacitor a diode and a current limiting resistor between diode and the gate terminal of the thyristor The very same circuit can be used to implement a three-phase controlled rectifier. The difference in this case is that for three-phase half –wave controlled rectifier I use three thyristors, meaning that my circuit will require three firing circuits to trigger the three thyristors.

3.3 DC Link or LC filter design

Inductors and capacitors are used to build a DC Link that filters the voltage and current ripples and improve the input power factor.

Capacitors as well as inductors are designed in such a way to optimize the overall filter performance.

The design sequence for the filter consists of the following steps:

- Calculate the capacitance needed to manage a certain amount of ripple voltage.
- Size the inductor
- Calculate the resonant frequency of the filter.

3.3.1 Calculation of the ripple suppression Capacitor and Inductor

The following information is available:

Motor specifications: $V_{nominal} = 220\text{-}240V$

$I_a = 1.6$ A

$I_{exc} = 0.2$ A

Speed = 3000 rpm

Rectifier: Ripple frequency, $F_r = 150Hz$

Main power= 20V (Amplitude), 50Hz, 3- phase

Ripple voltage, $V_r = 13V$

The ripple suppression capacitor is calculated from this formula: $Q = CV_r$

And therefore, $\frac{I}{f} = CV_r$

I = the load current

F = ripple frequency and,

V_r is the ripple voltage (peak-to-peak); please refer to the output voltage from the rectifier graph in the appendix. From the figure, the $V_r = 13V$ and the ripple frequency is 150Hz. The load current is 1.6 A. This is the armature current of the DC motor to be driven by the rectifier.

Therefore the capacitance value, $C = \dfrac{I}{FV_r}$

$$C \approx 820\text{uF}$$

A 1000uF capacitor is used.

To find the value of the inductor, X_L must be larger than X_C. Since $X_C = 1/(2\pi fC)$

$X_C = 1.06\Omega$

Let X_L be 5 Ω

$X_L = 2\pi fL$

Therefore, L= 5mH

Resonant frequency: $f_o = 1/(2\pi\sqrt{LC}) = 71.1\text{Hz}$

3.4 Thyristor selection for the rectifier

3.4.1 Voltage Rating

The voltage of the thyristor or semiconductor power device, V_{rate} in the rectifiers should exceed the highest instantaneous voltage possible to appear between any two points of the power circuit. So in rectifier this voltage is the peak voltage of supply, Vs.

Semiconductor devices are vulnerable to over voltage, even those of a very short duration, substantial safety margins should therefore be assumed in the design.

The safety margins depend on the voltage level, the higher ones used in low-voltage converters.

Thus denoting a voltage safety margin by S_v, the condition to be met is:

$V_{rate} = (1+S_v)\, V_s$

3.4.2 Voltage Rating Calculation

Let S_v be 0.8 and the for V_s a 20V amplitude from the supply is used.

Therefore, $V_{rate} = (1+0.8)\ 20$

$V_{rate} = (1+0.8)\ 20 = 36V$

The thyristors with a voltage rating of 100V are used in this project. Refer to the appended datasheet (2N6396).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

4.1.1 SCR gate triggering

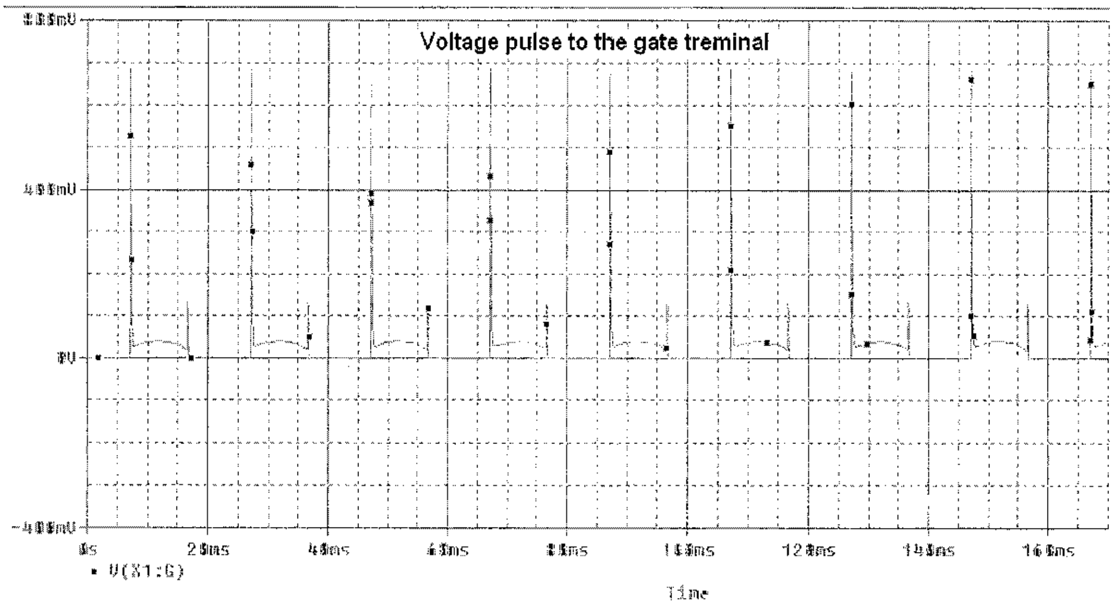


Figure 4.1.1

4.1.2 Three –phase half-wave controlled rectifier

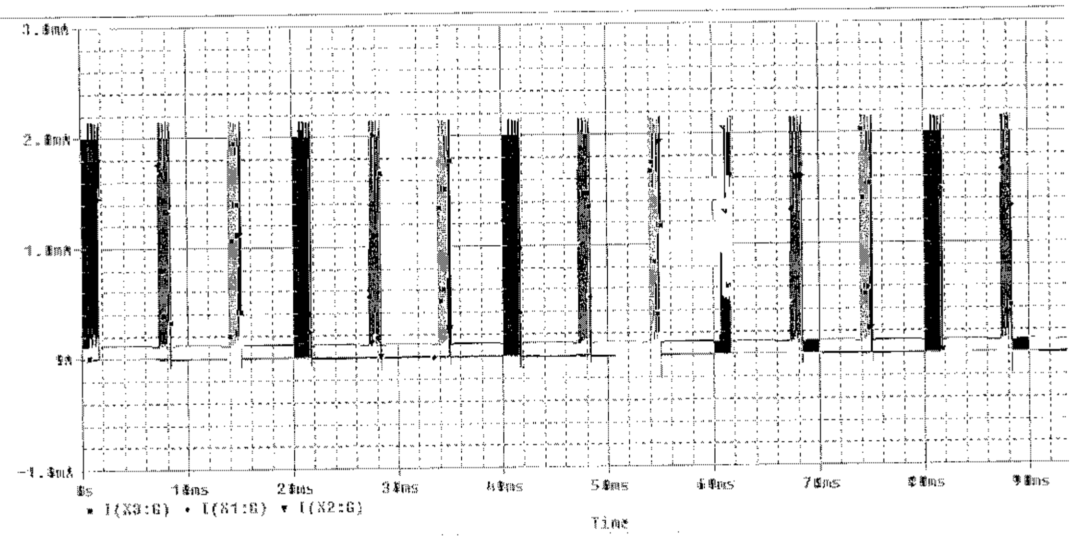


Figure 4.1.2 a

Figure 4.1.2 a shows the triggering of the SCRs when the value of he variable resistor is 100ohm.

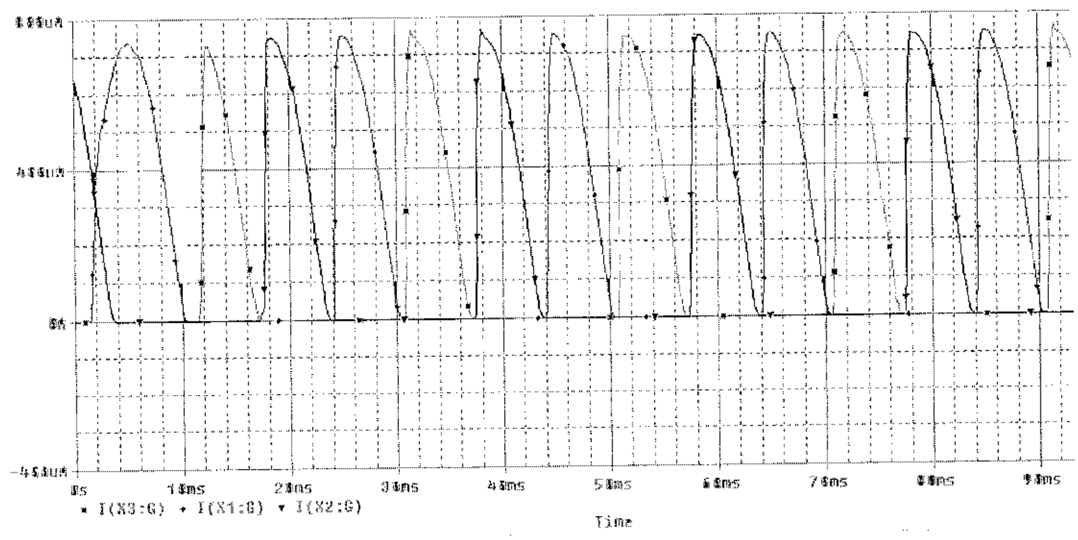


Figure 4.1.2 b

Figure 4.1.2 b shows the triggering of the SCRs when the value of the variable resistor is 50k

4.1.3 Output Voltage of the Rectifier

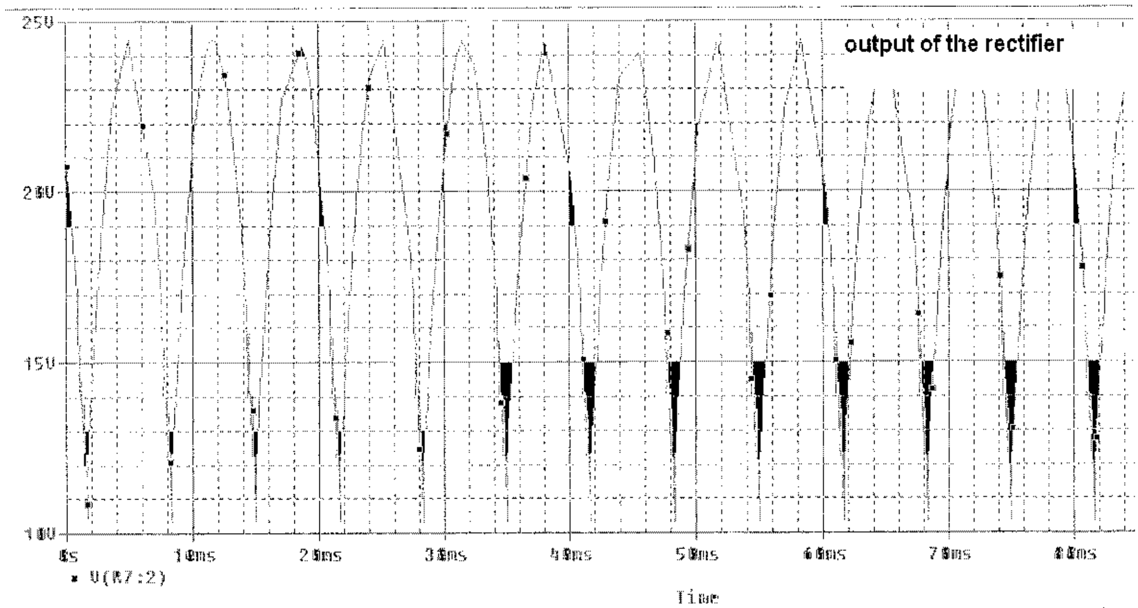


Figure 4.1.3 a

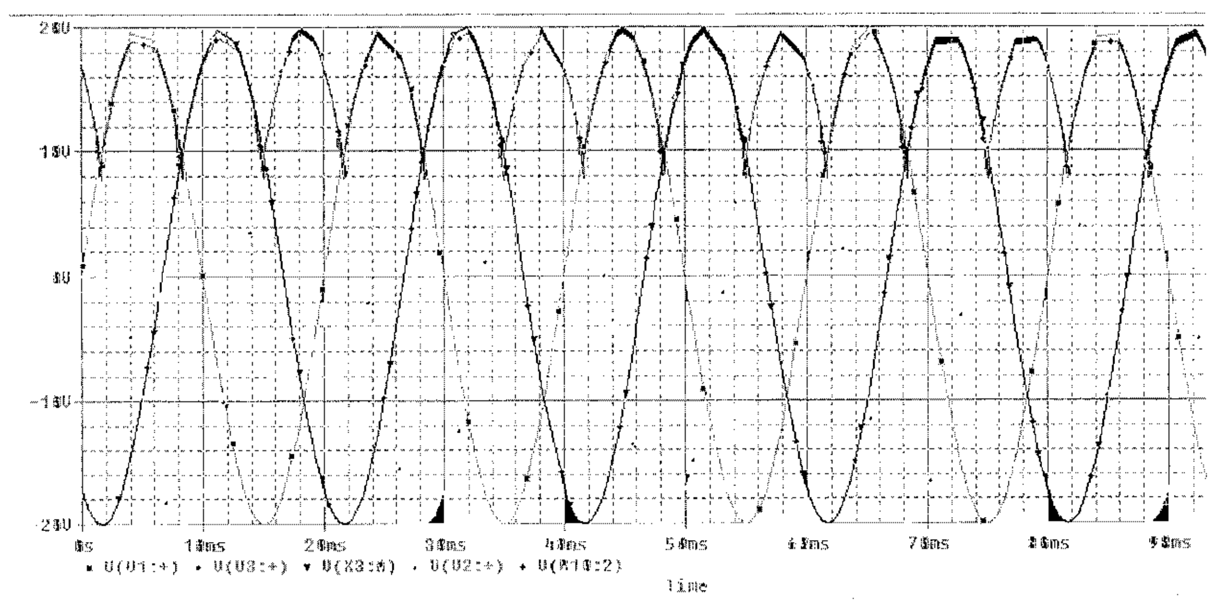
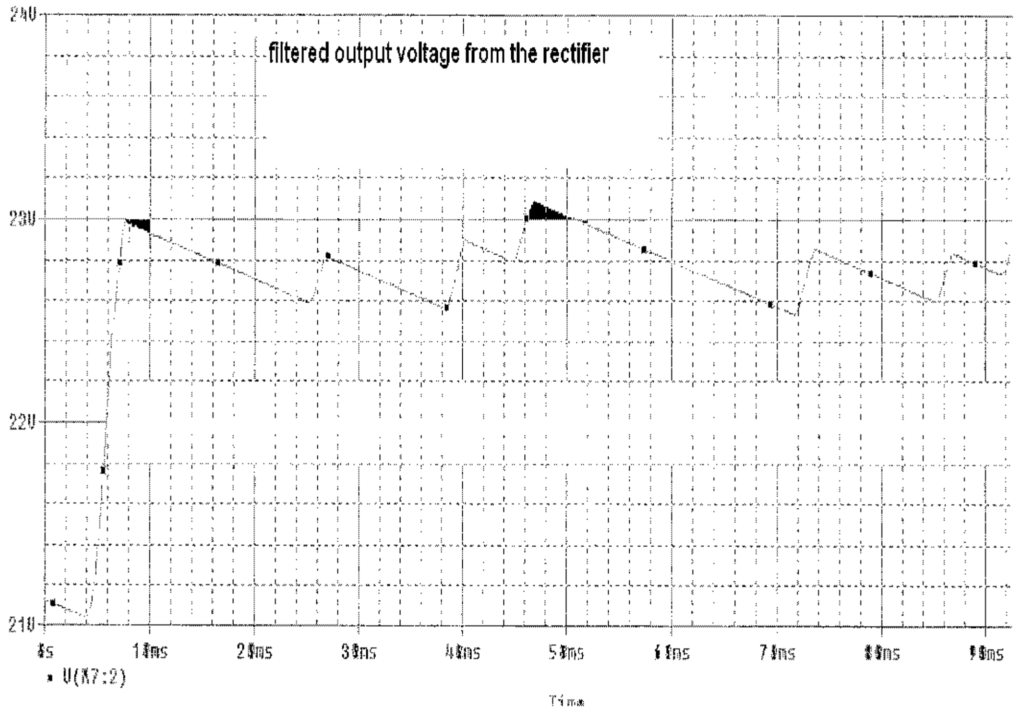


Figure 4.1.3 b

Figure 4.1.3a and b shows the output voltage waveform of the rectifier. The waveform only consists of the positive component of the input voltage.

4.1.4 DC Link or LC filter design

To smooth out the output from the rectifier Dc link or LC filter is used. This consists of a series inductor and a shunt capacitance. A combination of L and C produces a lower ripple with normal component than is possible with either L or C alone.



4.2 Discussions

The SCR triggering is achieved by applying a pulse signal to the gate terminal of the SCR, and also it must be ensured that this pulse signal is positive with respect to the cathode terminal, and lastly the anode terminal must also be positive with respect to the cathode terminal. These conditions will cause the SCR to be triggered. Figure 4.1.1 shows the pulse signals that are applied to the gate terminal of the SCR. Once this SCR is energized the pulse signal can be removed from the gate terminal and the SCR will remain n the ON mode until the anode to cathode current is interrupted.

Figure 4.1.2a shows the pulse signals that are applied to the gate terminals of the three SCRs, of the three-phase, half-wave controlled rectifier. These SCRs are denoted by X1, X2 and X3. The magnitude of the pulse signals are above 2mA. For these types of SCRs to be triggered, the maximum gate current required is 30mA. From the results of simulation, a 2mA current end to be sufficient.

The pulse signals of figure 4.1.2a are obtained when the value of the variable resistor at 100ohm. From this waveform we can see that the voltage that will be supplied to the output of the rectifier will be higher, hence the speed of the motor will be high.

Figure 4.1.2b shows the pulse signals when the value of the variable resistor is at maximum, 50k. From the waveform we can see that the output voltage of the rectifier will be small, hence the speed of the motor will be low.

Figure 4.1.3 shows the output waveform of the rectifier, it is clear from the figure that the waveform consists of only the positive component of the input voltage. This is the rectified input voltage from the supply voltage.

Figure 4.1.4 shows the filtered voltage. This voltage has fewer ripples than the output voltage from figure 4.1.3.

CHAPTER 5

CONCLUSION AND RECOMMEDATIONS

5.1 Conclusions

The aim of the project was to design a variable speed drive using three-phase controlled rectifier and the inverter fed from a DC link source of voltage.

The project was divided into two semesters. During the first semester, the firing circuit and the rectifier were to be designed. And during the second semester of the project, the DC link and the inverter were to be designed.

The project was completed until to the design of the DC link, the inverter was not designed.

The results of the project up to the DC link shows that the design can work. The design of the SCR firing circuit as successfully designed. The required pulse signals that are needed to be fed to the gate terminals of the SCRs were obtained from the firing circuit.

The design of the rectifier was implemented using three SCR firing circuits, since for the three-phase rectifier we need three SCRs. The output voltage waveform from the rectifier consists only of the positive component of the input voltage. This is the desired output voltage waveform from the rectifier. This output voltage waveform was fed to the filter, and the output voltage from the filter consisted fo fewer ripples that the output waveform of the rectifier.

So the design up to the DC link can work successfully because the anticipated results tend to be true.

5.2 Recommendations

The objective of this project was to design a variable speed drive using three-phase controlled rectifier and the inverter fed from a DC link source of voltage. The project was completed until to the design of the DC link, meaning that the inverter was not completed. So this design can only be used to control the speed of the DC motor.

The recommendations I can make is that some work needs to be done on the design of the DC link to ensure that it works satisfactorily. Although this design can work the resonance frequency of the filter is not way very large than the supply frequency. So redesigning the filter will be one of the recommendations.

Lastly further project work that needs to be carried out will be the design of the inverter, so that the design can be used to control the speed of AC motor.

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APPENDIX A
PROJECT GANTT CHART

Suggested Milestones for First Semester of 2 Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Selection of Project Topic															
	-Propose Topic															
	-Topic assigned to students															
2	Preliminary Research Work															
	-Introduction															
	-Objective															
	- literature															
	-Project planning															
3	Submission of Preliminary Report				X											
4	Project Work															
	Literature- Rectifiers															
	Literature- DC Link															
	Literature- Inverter															
5	Submission of Progress Report								X							
6	Project work continue															
	Designing of Rectifier															
	Designing of Firing Circuit															
	Simulation And Prototype															
7	Submission of Interim Report Final Draft													X		
8	Oral Presentation															X
9	Submission of Interim Report														X	

X Suggested milestone

Process

APPENDIX B
2N6395 SCR DATASHEET

2N6394 Series

Preferred Device

Silicon Controlled Rectifiers

Reverse Blocking Thyristors

Designed primarily for half-wave ac control applications, such as motor controls, heating controls and power supplies.

- Glass Passivated Junctions with Center Gate Geometry for Greater Parameter Uniformity and Stability
- Small, Rugged, Thermowatt Construction for Low Thermal Resistance, High Heat Dissipation and Durability
- Blocking Voltage to 800 Volts
- Device Marking: Logo, Device Type, e.g., 2N6394, Date Code

***MAXIMUM RATINGS** (T_J = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Peak Repetitive Off–State Voltage(1) (T_J = −40 to 125°C, Sine Wave, 50 to 60 Hz, Gate Open) 2N6394 / 2N6395 / 2N6397 / 2N6399	V_{DRM}, V_{RRM}	50 / 100 / 400 / 800	Volts
On-State RMS Current (180° Conduction Angles; T_C = 90°C)	$I_{T(RMS)}$	12	A
Peak Non-Repetitive Surge Current (1/2 Cycle, Sine Wave, 60 Hz, T_J = 125°C)	I_{TSM}	100	A
Circuit Fusing (t = 8.3 ms)	I^2t	40	A^2s
Forward Peak Gate Power (Pulse Width ≤ 1.0 μs, T_C = 90°C)	P_{GM}	20	Watts
Forward Average Gate Power (t = 8.3 ms, T_C = 90°C)	$P_{G(AV)}$	0.5	Watts
Forward Peak Gate Current (Pulse Width ≤ 1.0 μs, T_C = 90°C)	I_{GM}	2.0	A
Operating Junction Temperature Range	T_J	−40 to +125	°C
Storage Temperature Range	T_{stg}	−40 to +150	°C

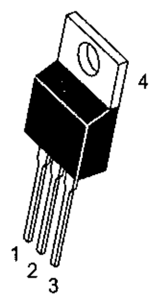
*Indicates JEDEC Registered Data

(1) V_{DRM} and V_{RRM} for all types can be applied on a continuous basis. Ratings apply for zero or negative gate voltage; however, positive gate voltage shall not be applied concurrent with negative potential on the anode. Blocking voltages shall not be tested with a constant current source such that the voltage ratings of the devices are exceeded.

ON Semiconductor

http://onsemi.com

SCRs
12 AMPERES RMS
50 thru 800 VOLTS



TO–220AB
CASE 221A
STYLE 3

PIN ASSIGNMENT	
1	Cathode
2	Anode
3	Gate
4	Anode

ORDERING INFORMATION

Device	Package	Shipping
2N6394	TO220AB	500/Box
2N6395	TO220AB	500/Box
2N6397	TO220AB	500/Box
2N6399	TO220AB	500/Box

Preferred devices are recommended choices for future use and best overall value.

February, 2000 – Rev. 2

Publication Order Number:
2N6394/D

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	2.0	°C/W
Maximum Lead Temperature for Soldering Purposes 1/8″ from Case for 10 Seconds	T_L	260	°C

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted.)

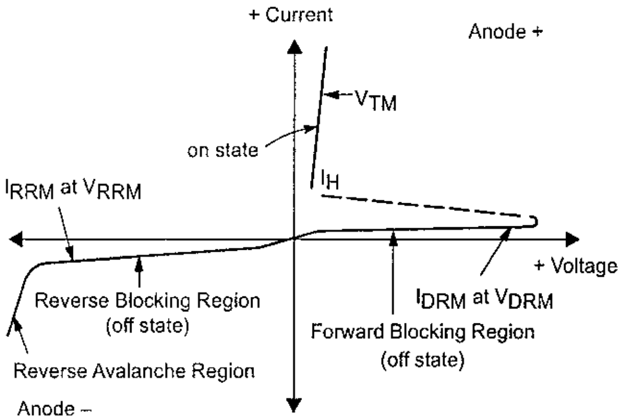
Characteristic	Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS					
*Peak Repetitive Forward or Reverse Blocking Current (V_{AK} = Rated V_{DRM} or V_{RRM}, Gate Open) T_J = 25°C T_J = 125°C	I_{DRM}, I_{RRM}	— —	— —	10 2.0	μA mA
ON CHARACTERISTICS					
*Peak Forward On–State Voltage(1) (I_{TM} = 24 A Peak)	V_{TM}	—	1.7	2.2	Volts
*Gate Trigger Current (Continuous dc) (V_D = 12 Vdc, R_L = 100 Ohms)	I_{GT}	—	5.0	30	mA
*Gate Trigger Voltage (Continuous dc) (V_D = 12 Vdc, R_L = 100 Ohms)	V_{GT}	—	0.7	1.5	Volts
Gate Non–Trigger Voltage (V_D = 12 Vdc, R_L = 100 Ohms, T_J = 125°C)	V_{GD}	0.2	—	—	Volts
*Holding Current (V_D = 12 Vdc, Initiating Current = 200 mA, Gate Open)	I_H	—	6.0	50	mA
Turn-On Time (I_{TM} = 12 A, I_{GT} = 40 mAdc, V_D = Rated V_{DRM})	t_{gt}	—	1.0	2.0	μs
Turn-Off Time (V_D = Rated V_{DRM}) (I_{TM} = 12 A, I_R = 12 A) (I_{TM} = 12 A, I_R = 12 A, T_J = 125°C)	t_q	 — —	 15 35	 — —	μs
DYNAMIC CHARACTERISTICS					
Critical Rate–of–Rise of Off-State Voltage Exponential (V_D = Rated V_{DRM}, T_J = 125°C)	dv/dt	—	50	—	V/μs

*Indicates JEDEC Registered Data

(1) Pulse Test: Pulse Width ≤ 300 μsec, Duty Cycle ≤ 2%.

Voltage Current Characteristic of SCR

Symbol	Parameter
V_{DRM}	Peak Repetitive Off State Forward Voltage
I_{DRM}	Peak Forward Blocking Current
V_{RRM}	Peak Repetitive Off State Reverse Voltage
I_{RRM}	Peak Reverse Blocking Current
V_{TM}	Peak On State Voltage
I_H	Holding Current



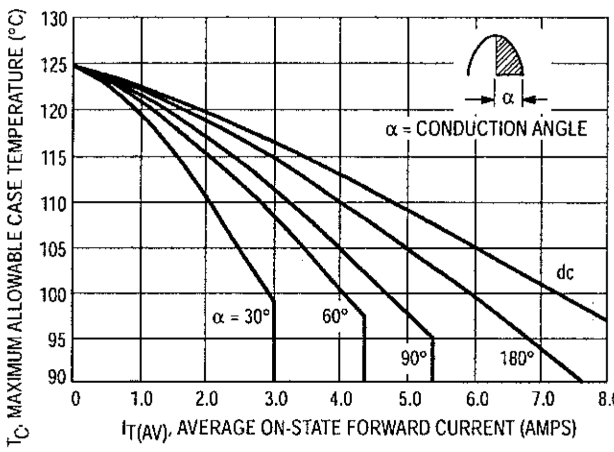


Figure 1. Current Derating

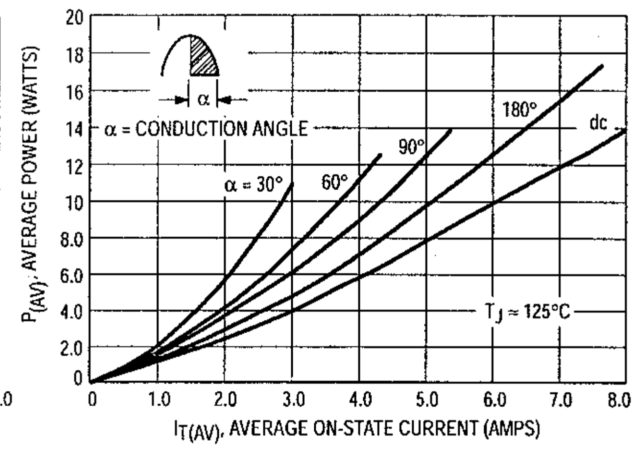


Figure 2. Maximum On–State Power Dissipation

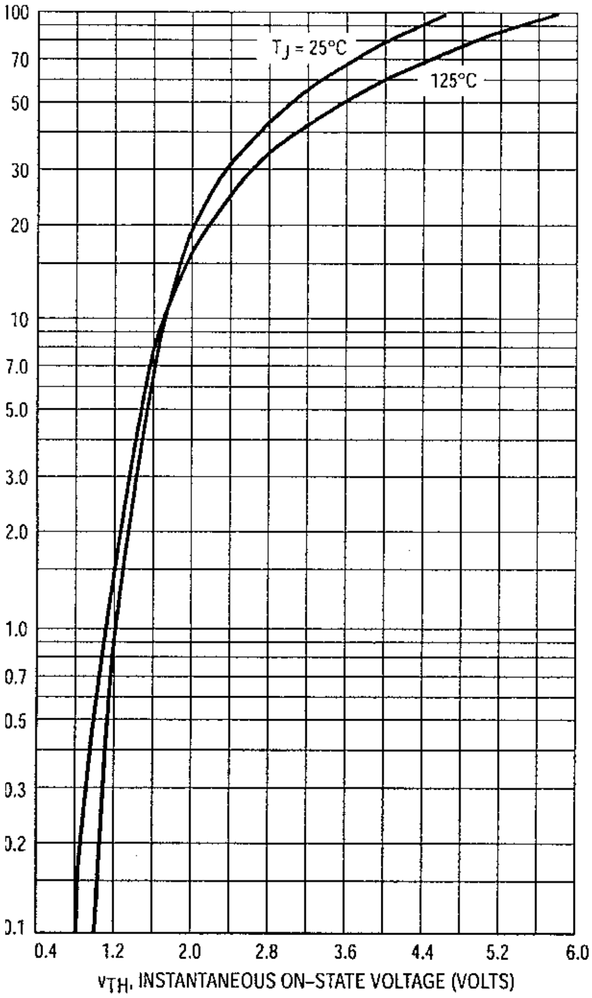


Figure 3. On–State Characteristics

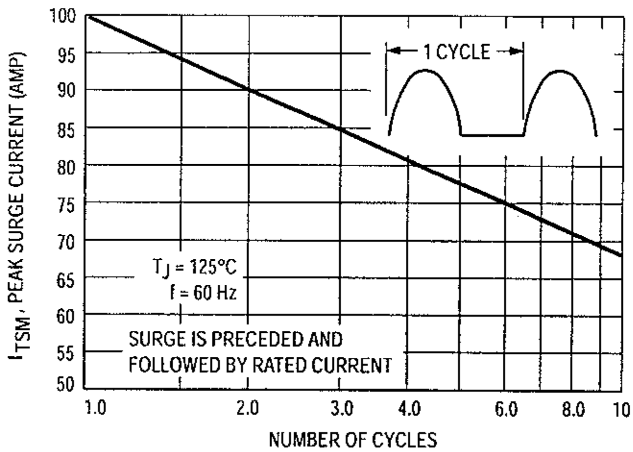


Figure 4. Maximum Non–Repetitive Surge Current

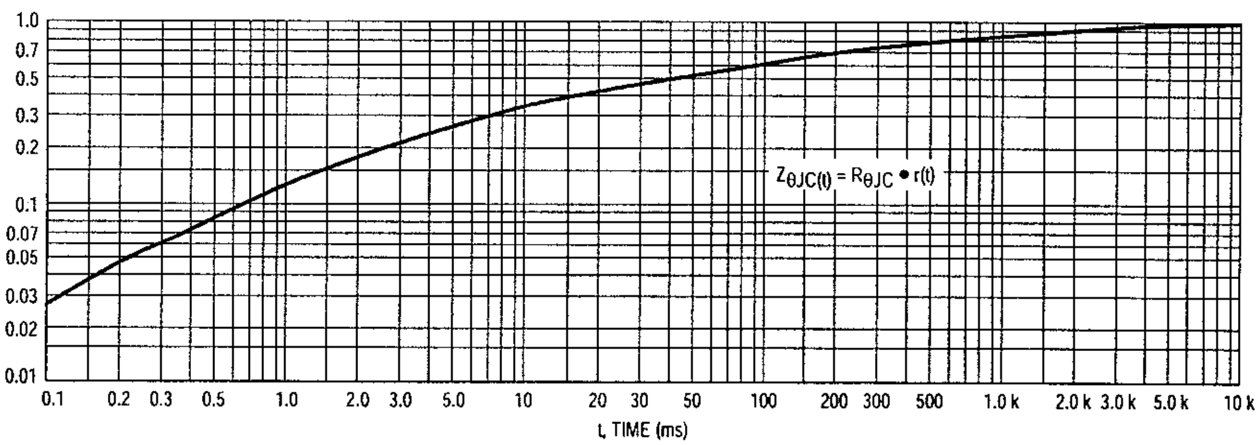


Figure 5. Thermal Response

TYPICAL CHARACTERISTICS

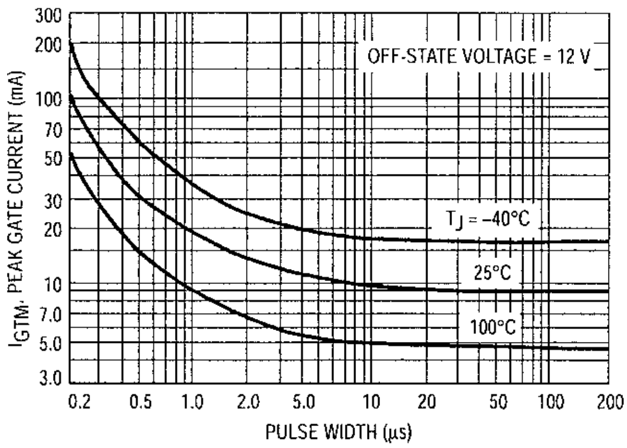


Figure 6. Typical Gate Trigger Current versus Pulse Width

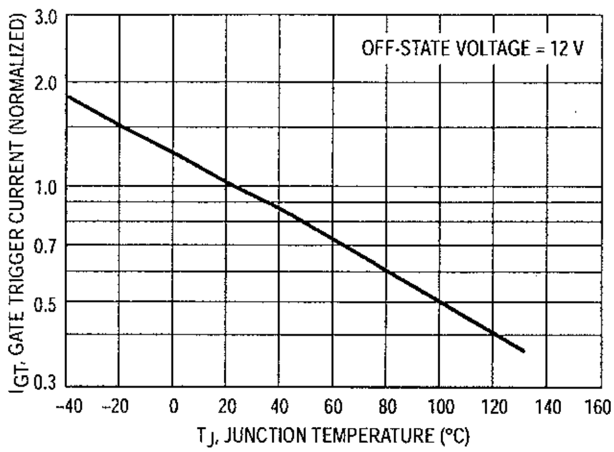


Figure 7. Typical Gate Trigger Current versus Temperature

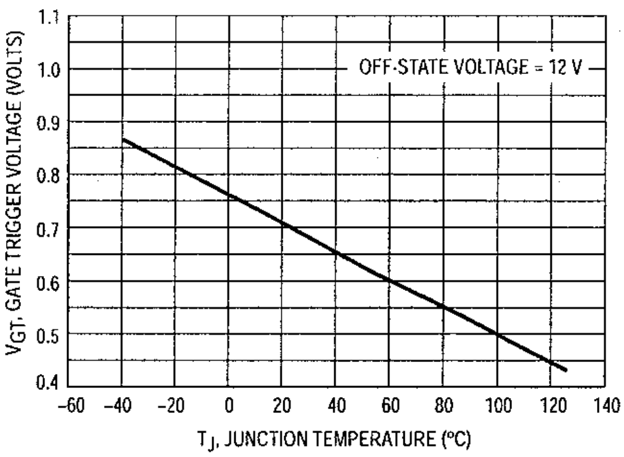


Figure 8. Typical Gate Trigger Voltage versus Temperature

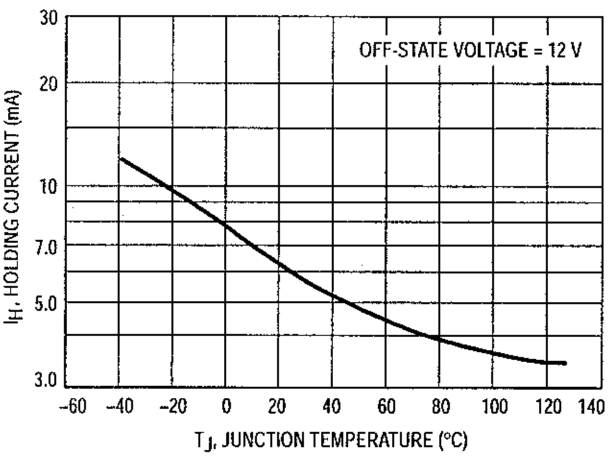
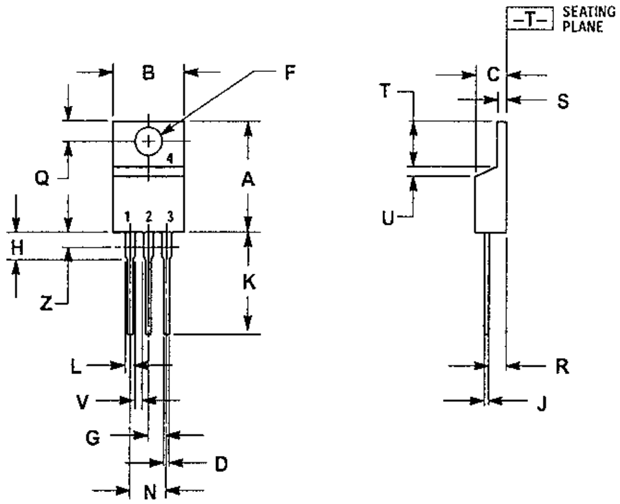


Figure 9. Typical Holding Current versus Temperature

PACKAGE DIMENSIONS

TO–220AB
CASE 221A–07
ISSUE Z



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION Z DEFINES A ZONE WHERE ALL BODY AND LEAD IRREGULARITIES ARE ALLOWED.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.570	0.620	14.48	15.75
B	0.380	0.405	9.66	10.28
C	0.160	0.190	4.07	4.82
D	0.025	0.035	0.64	0.88
F	0.142	0.147	3.61	3.73
G	0.095	0.105	2.42	2.66
H	0.110	0.155	2.80	3.93
J	0.014	0.022	0.36	0.55
K	0.500	0.562	12.70	14.27
L	0.045	0.060	1.15	1.52
N	0.190	0.210	4.83	5.33
Q	0.100	0.120	2.54	3.04
R	0.080	0.110	2.04	2.79
S	0.045	0.055	1.15	1.39
T	0.235	0.255	5.97	6.47
U	0.000	0.050	0.00	1.27
V	0.045	---	1.15	---
Z	---	0.080	---	2.04

STYLE 3:
PIN 1. CATHODE
2. ANODE
3. GATE
4. ANODE

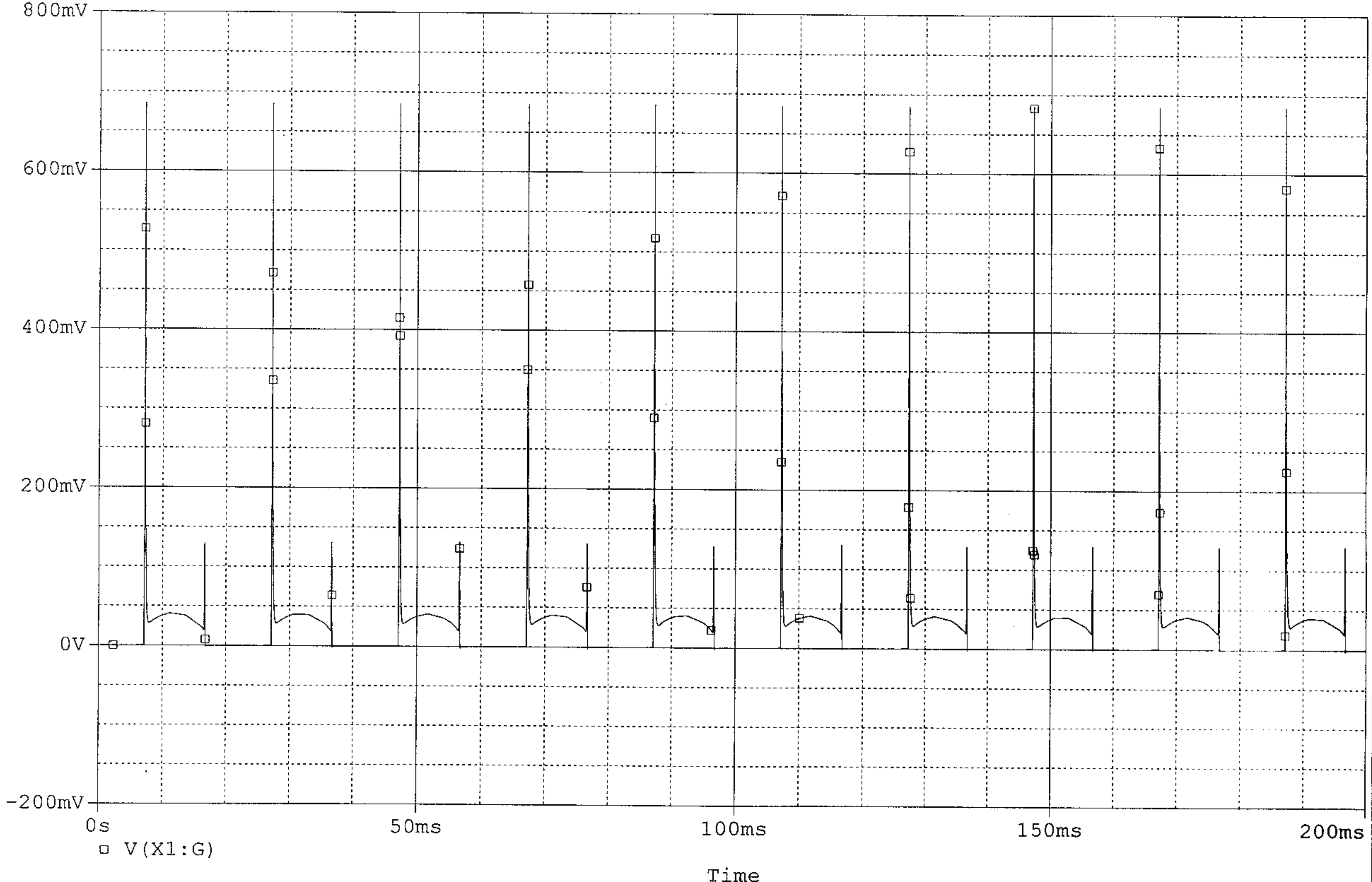
APPENDIX C
SCR TRIGGERING SIMULATION

* C:\TEMP\Schematic1.sch

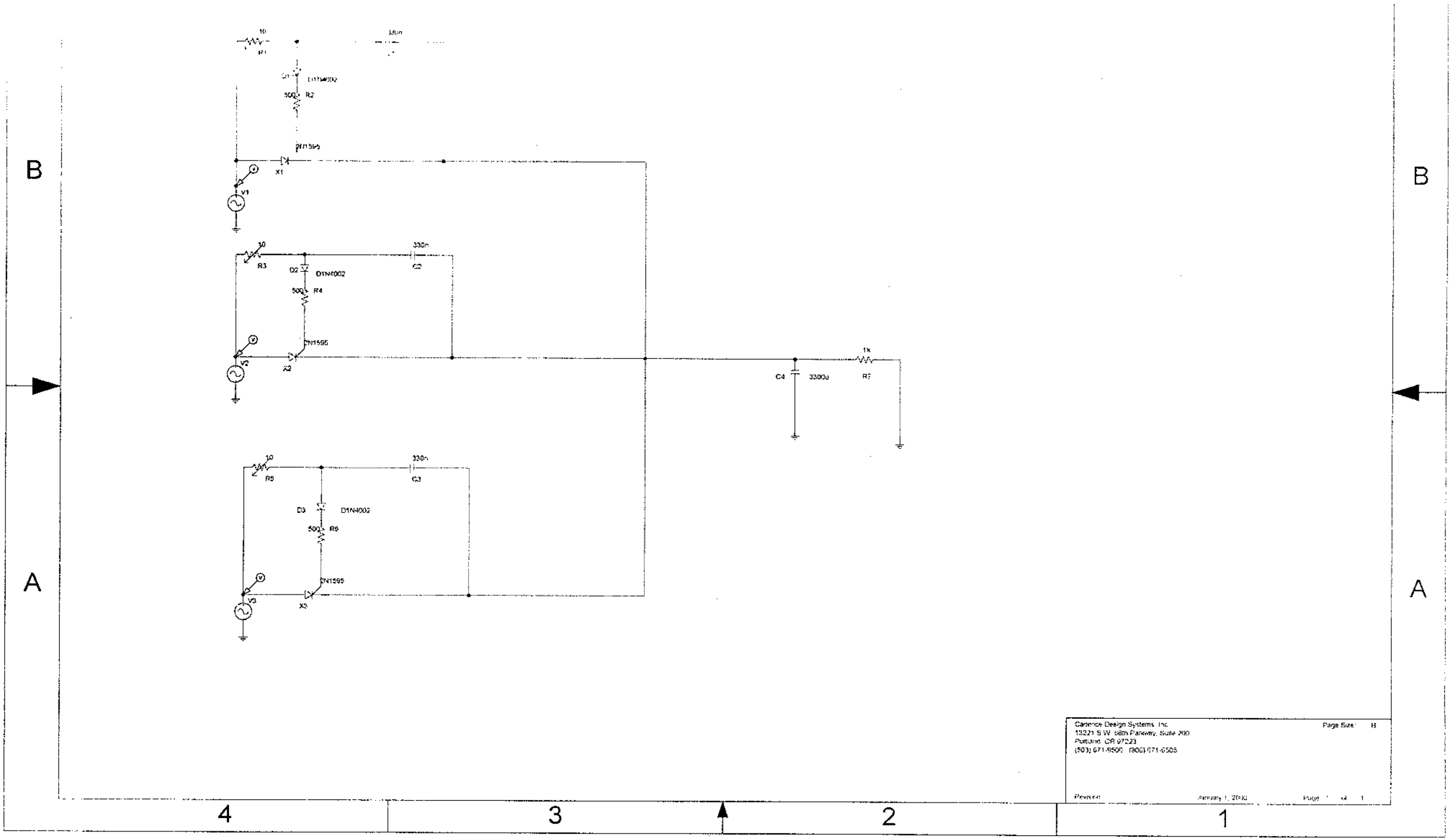
Date/Time run: 04/20/04 15:59:12

Temperature: 27.0

(B) Schematic1.dat (active)



APPENDIX D
3-PHASE CONTROLLED RECTIFIER



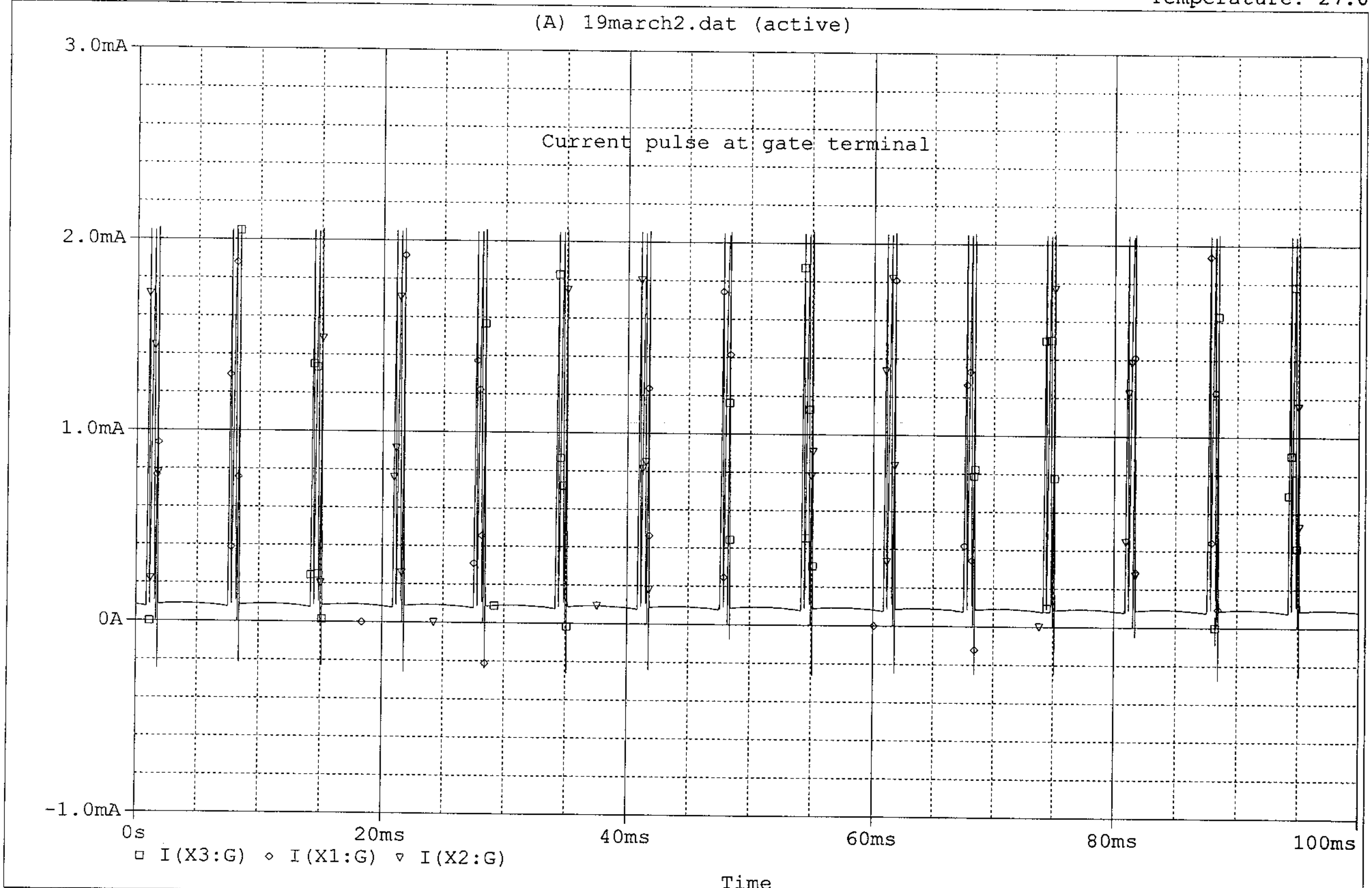
B
A
4
3
2
1
10
R1
D1N4002
500
R2
1N1595
X1
V1
10
R3
D2
D1N4002
500
R4
330n
C2
1N1595
V2
X2
C4
3300u
1k
R7
10
R5
330n
C3
D3
D1N4002
500
R6
1N1595
V3
X3
Cadence Design Systems, Inc.
13221 S.W. 68th Parkway, Suite 200
Portland, OR 97223
(503) 671-9500 (800) 671-6505
Page Size: B
Page 1 of 1

APPENDIX E
3-PHASE CONTROLLED RECTIFIER TRIGGERING

* C:\TEMP\19march2.sch

Date/Time run: 04/07/04 16:14:09

Temperature: 27.0

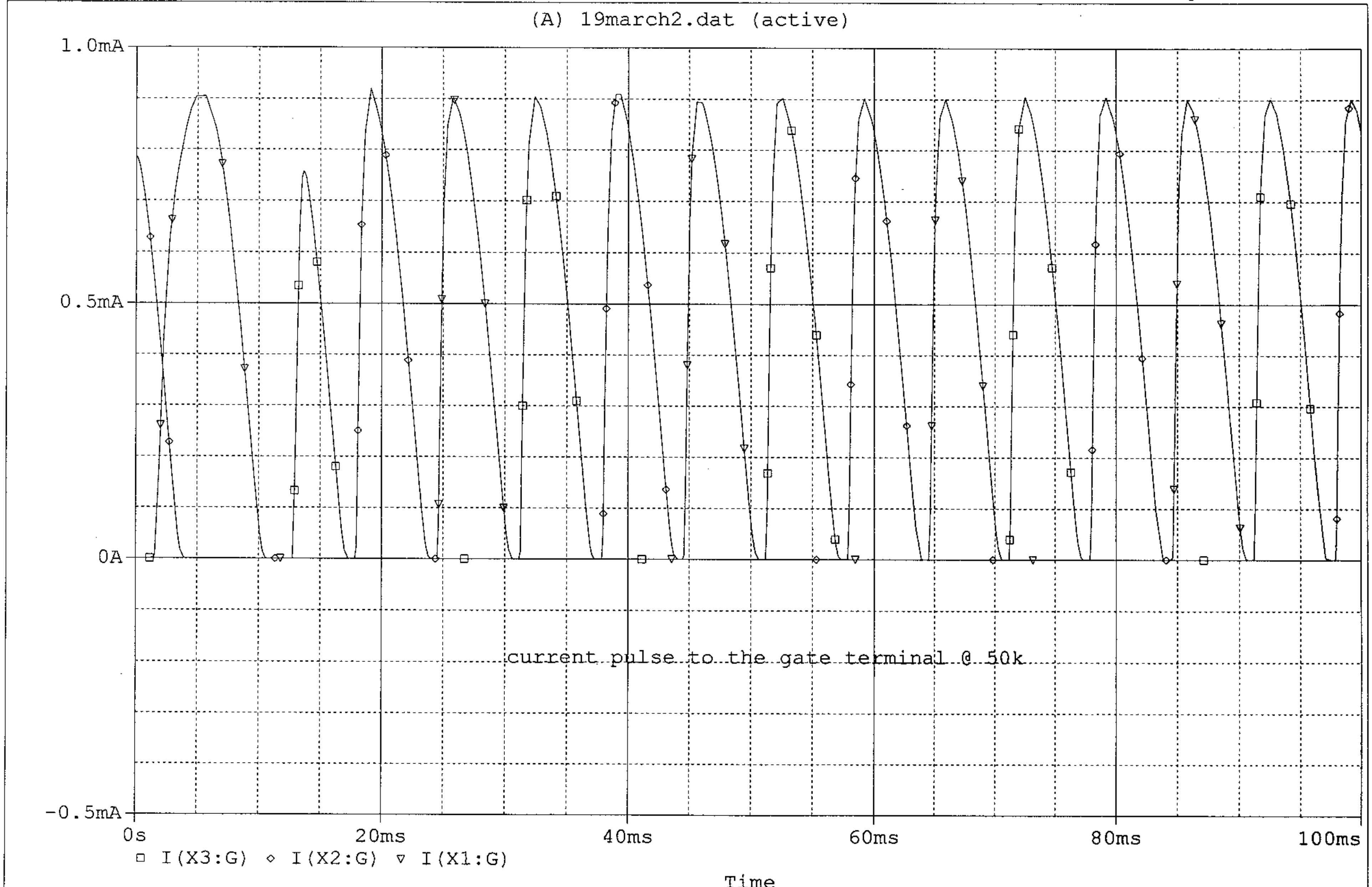


Date: April 07, 2004

* C:\TEMP\19march2.sch

Date/Time run: 04/07/04 16:17:12

Temperature: 27.0



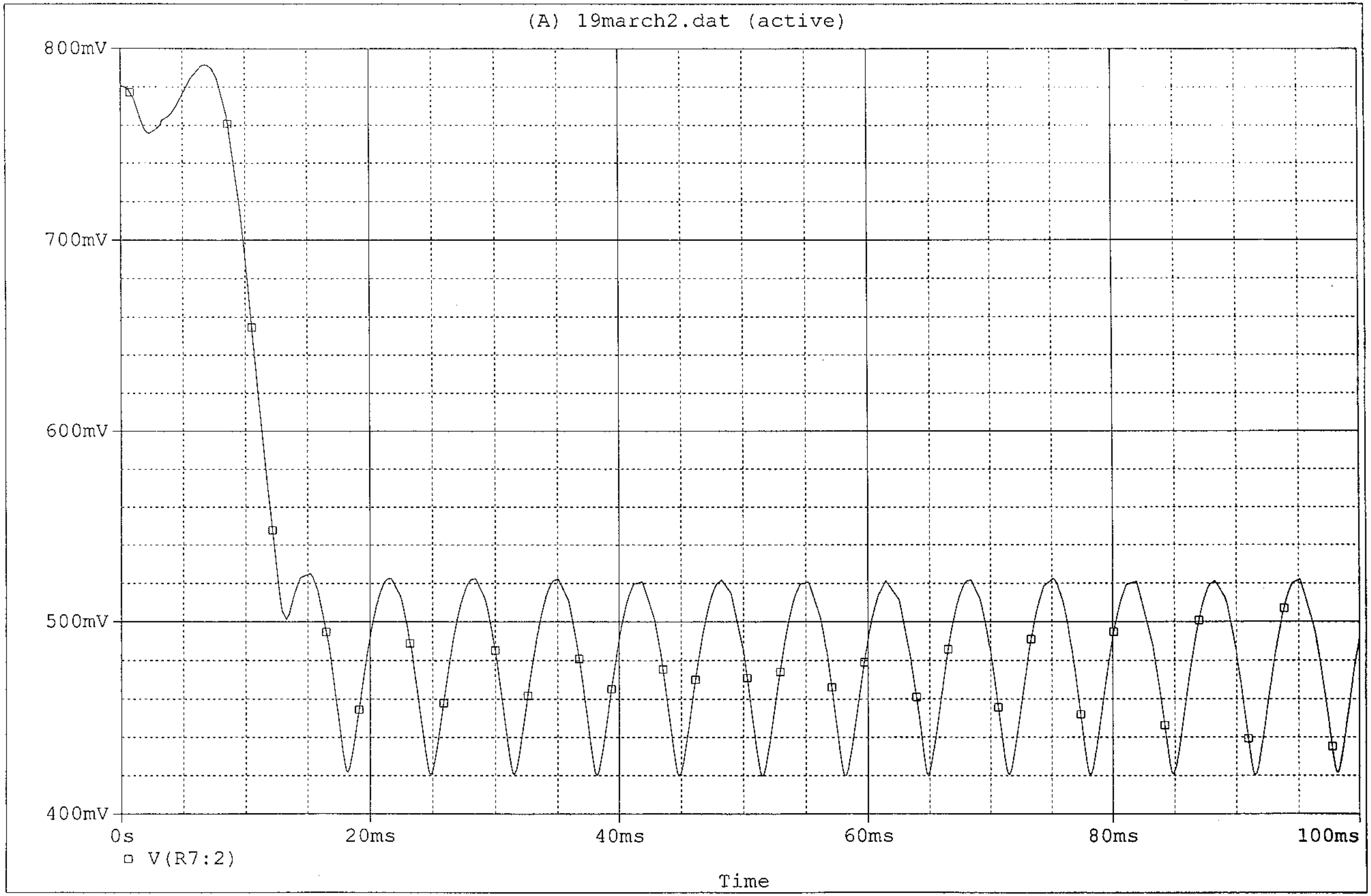
Date: April 07, 2004

Time: 16:17:44

APPENDIX F
OUTPUT OF THE 3-PHASE CONTROLLED RECTIFIER

* C:\TEMP\19march2.sch

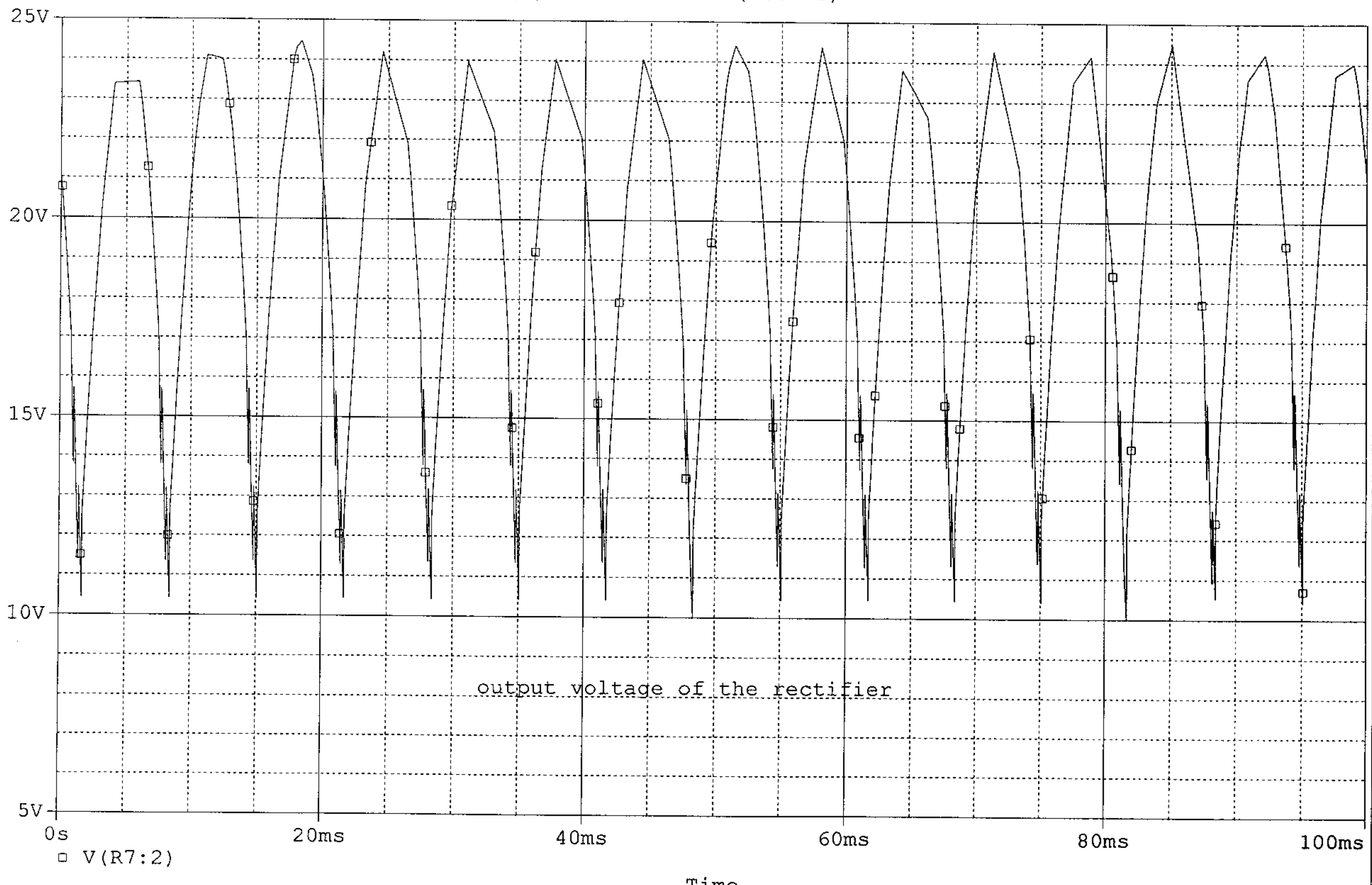
Date/Time run: 04/20/04 15:47:12 Temperature: 27.0



* C:\TEMP\19march2.sch

Date/Time run: 04/07/04 16:15:42 Temperature: 27.0

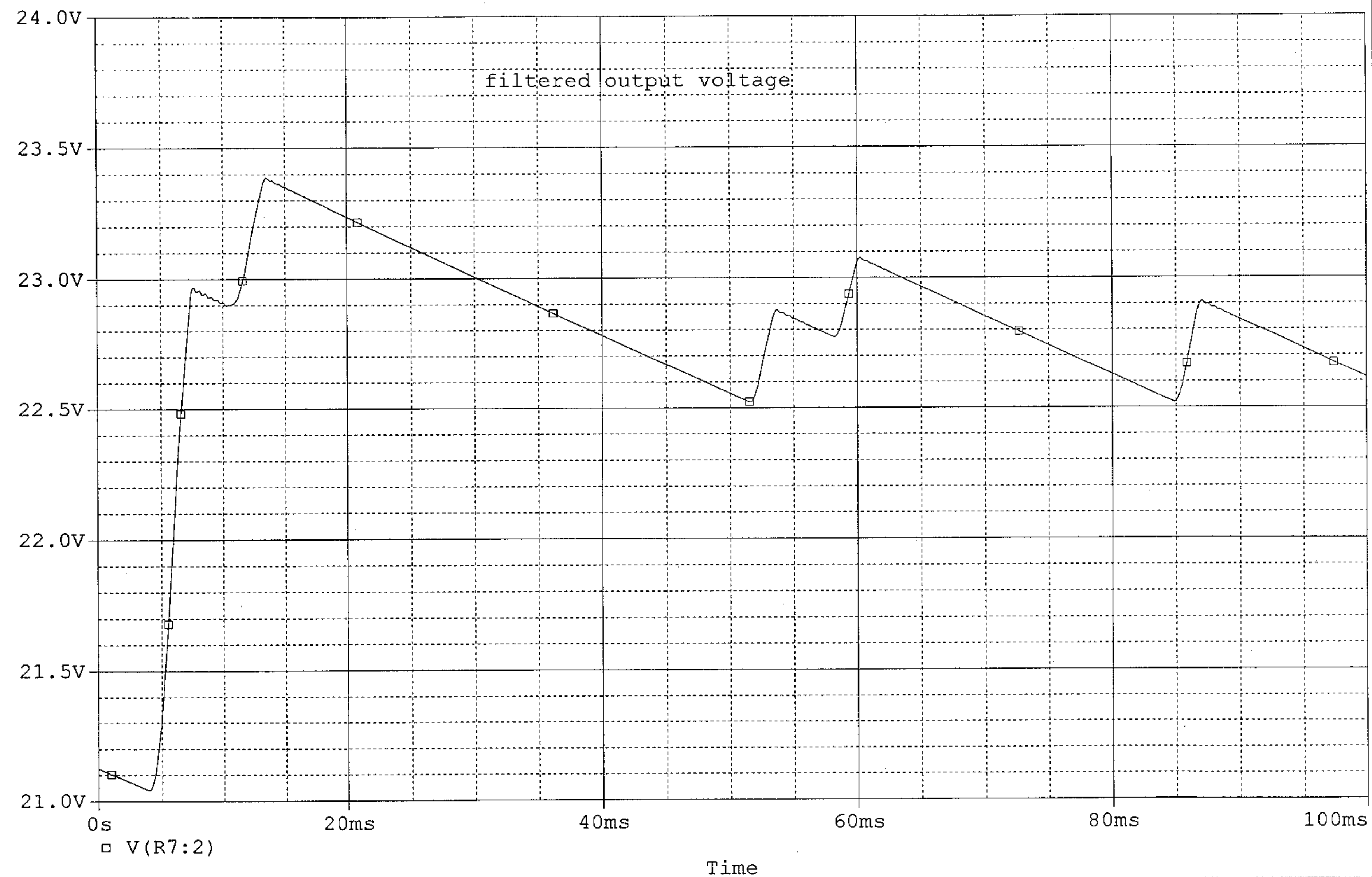
(A) 19march2.dat (active)



APPENDIX G
FILTERED OUTPUT VOLTAGE

Date/Time run: 04/07/04 14:42:40 Temperature: 27.0

(A) 19march2.dat (active)



Date: April 07, 2004 Page 1 Time: 16:12:32