EE 330
Lecture 29
Thyristor Circuits
### SCR Terminology

### Issues and Observations

- Trigger parameters ($V_{GT}$ and $I_{GT}$) highly temperature dependent
- Want gate “sensitive” but not too sensitive (to avoid undesired triggering)
- SCR can switch very large currents but power dissipation is large
- Heat sinks widely used to manage power
- Trigger parameters affected by both environment and application
- Trigger parameters generally dependent upon $V_F$
- Exceeding $V_{BRR}$ will usually destroy the device
- Exceeding $V_{BGF0}$ will destroy some devices
- Lack of electronic turn-off unattractive in some applications
- Can be used in alarm circuits to attain forced reset
- Maximum 50% duty cycle in AC applications is often not attractive
Review from Last Lecture

The Triac

• Can define two cross-coupled transistor pairs in each side

As for SCR, both circuits have regenerative feedback

Can turn ON in either direction with either positive or negative current

Defines 4 quadrants (in $V_{MT2}$-$V_{G-MT1}$ plane) for operation

$$V_{MT2}>V_{MT1} \quad V_{G-MT1}>0 \quad \text{Quadrant 1}$$
$$V_{MT2}>V_{MT1} \quad V_{G-MT1}<0 \quad \text{Quadrant 2}$$
$$V_{MT2}<V_{MT1} \quad V_{G-MT1}<0 \quad \text{Quadrant 3}$$
$$V_{MT2}<V_{MT1} \quad V_{G-MT1}>0 \quad \text{Quadrant 4}$$

Usually use only one $V_G$:$V_{MT}$ for control

Different voltage, duration strategies exist for triggering

Can’t have single $V_G$:$V_{MT}$ control with two SCRs
The ideal Triac

Consider the basic Triac circuit
Assume ideal Triac

Load Line: \[ V_{AC} = I_T R_L + V_{TR} \]

Analysis:

The solution of these two equations is at the intersection of the load line and the device characteristics.

Two stable operating points for both positive and negative \( V_{AC} \)

If \( V_{AC} \) is a sinusoidal signal, will stay OFF
The Basic Triac Circuit

Assume ideal Triac

Load Line: \( V_{CC} = I_T R_L + V_{TR} \)

Analysis:

\[
V_{AC} = I_T R_L + V_{TR} \]

\[
I_T = f_A(V_{TR}, V_{GT1})
\]

Single solution for both positive and negative \( V_{AC} \)

If \( V_{AC} \) is a sinusoidal signal will stay ON

(except for small time when \( I_T = 0 \) but then ON and OFF state of Triac do not alter current in circuit)
The Basic Triac Circuit

Assume ideal Triac
The Actual Triac

\[ I_{G4} > I_{G3} > I_{G2} > I_{G1} = 0 \]
The Actual Triac in Basic Circuit

Two stable operating points

$I_G=0$ State
The Actual Triac in Basic Circuit

Can turn on for either positive or negative $V_{AC}$ with single gate signal
Phase controlled bidirectional switching with Triacs
Quadrants of Operation Defined in $V_{M21}-V_{GT1}$ plane

(not in the $I_T-V_{M21}$ plane)

But for any specific circuit, can map quadrants from the $V_{M21}-V_{GT1}$ plane to $I_T-V_{M21}$ plane
Identification of Quadrants of Operation in $I_T - V_{M21}$ plane

Quadrant 1:
- $I_G > I_G^2 > I_G^3 > I_G^1 = 0$

Quadrant 2:
- $I_G^4 < I_G^3 < I_G^2 < I_G^1 < 0$

Quadrant 3:
- $I_G^4 < I_G^3 < I_G^2 < I_G^1 < 0$

Quadrant 4:
- $I_G^4 < I_G^3 < I_G^2 < I_G^1 < 0$
Identification of Quadrants of Operation in $I_T-V_{M21}$ plane

Curves may not be symmetric between $Q_1$ and $Q_3$ in the $I_T-V_{M21}$ plane

Turn on current may be large and variable in $Q_4$ (of the $V_{M21}-V_{GT1}$)

Generally avoid operation in $Q_4$ (of the $V_{M21}-V_{GT1}$ plane)

Most common to operate in $Q_2$-$Q_3$ quadrants or $Q_1$-$Q_3$ quadrants (of the $V_{M21}-V_{GT1}$ plane)
Some Basic Triac Application Circuits

Quad 1 : Quad 4

(Quad 2 : Quad 3)

(V_{GG} often from logic/control circuit)

(V_{GG} often from logic/control circuit)

(not attractive because of Quad 4)
Some Basic Triac Application Circuits

Limitations?

If $V_{AC}$ is the standard 120VAC line voltage, where do we get the dc power supply?

Direct digital control of trigger voltage/current with dedicated IC
Some Basic Triac Application Circuits

Quad 1 : Quad 3

Quad 1 : Quad 3

Quad 1 : Quad 3
Some Basic Triac Application Circuits

Quad 1/ Quad 2 : Quad 3/Quad 4

Real popular

Not real popular
Thyristor Types

Some of the more major types:

- SCR
- Triac
- Bidirectional Phase-controlled thyristors (BCT)
- LASCR (Light activated SCR)
- Gate Turn-off thyristors (GTO)
- FET-controlled thyristors (FET-CTH)
- MOS Turn-off thyristors (MTO)
- MOS-controlled thyristors (MCT)
Thyristor Applications

Thyristors are available for working at very low current levels in electronic circuits to moderate current levels such as in incandescent light dimmers to very high current levels

$I_{TRIAC}$ from under $1\text{mA}$ to $10000\text{A}$

Applications most prevalent for moderate to high current thyristors
SCR, rated about 100 amperes, 1200 volts, 1/2 inch stud, photographed by C J Cowie. Uploaded on 4 April 2006.
APPLICATONS

- Pulse Power
- Crowbars
- Igniton Replacement

KEY PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{DRM}$</td>
<td>4500V</td>
</tr>
<tr>
<td>$I_{T(AV)}$</td>
<td>760A</td>
</tr>
<tr>
<td>$I_{TSM}$</td>
<td>13000A</td>
</tr>
<tr>
<td>$dl/dt$</td>
<td>5000A/μs</td>
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</tbody>
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From ABB Web Site

Bi-Directional Control Thyristor

$V_R M = 6500 \text{ V}$
$I_{T(\text{AV})M} = 1405 \text{ A}$
$I_{T(\text{RMS})} = 2205 \text{ A}$
$I_{TSM} = 22 \times 10^3 \text{ A}$
$V_{TO} = 1.2 \text{ V}$
$r_T = 0.6 \text{ mΩ}$

5STB 13N6500

Diameter = 140mm
Thanks to Prof. Ajjarapu for providing the following slides:

THE BIDIRECTIONAL CONTROL THYRISTOR (BCT)

by

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ABSTRACT

The Bidirectional Control Thyristor (BCT) is a new concept for high power thyristors integrated on a single silicon wafer with separate gate contacts. This unique design, based on free-floating silicon technology, successfully overcomes the traditional problems of interference experienced by bidirectional thyristors during dynamic operation which previously prevented the use of such devices. Such components are suitable for applications at high voltages like a normal thyristor but where triacs can no longer be used.
Abstract—This presentation is about the work done on design, built-up, production and test of ready-to-use solid state switch assemblies using Thyristor- or IGCT technology. The presented thyristor switch assemblies, using 120 mm wafer size, are made to switch 3MJ stored energy into a load. The maximum charge voltage of the assembly is 12 kVdc, current capability more than 260kA@tp=3.3ms and a pulse repetition rate of up to 6 shots per minute with convection air cooling. New very large thyristors with 150 mm wafer diameter will be available from fall 2008. As second a 70 kA/21kVdc switch using IGCT technology will be presented. The switch is designed for fast discharge in the micro-second range and has a very high di/dt capability. Because for adapted standard products which can fulfill the requirements for pulsed applications. Beside the semiconductor devices, ABB is also in the position to supply complete custom made ready-to-use solid state switch assemblies including clamping, triggering, cooling and with application oriented testing. The presentation describes both, the loose semiconductor components as well as some custom made solid state switches for single pulse or low repetition rate pulsing.

II. DEVICE TECHNOLOGY

2008 Paper
Thanks to Prof. Ajjarapu for providing the following slides:

Fig. 3: Thyristor Switch Assembly A-STP 5742U-18-CC
Stud-Mounted SCR
110 Amp RMS Rating

Thanks to Prof. Ajjarapu for providing the following slides:

Auxiliary Cathode Lead (Red)
Extends cathode potential to the control circuit.

Gate Lead (White)

Cathode Lead

Stud Anode
Cross-section of a BCT wafer showing the antiparallel arrangement of the A and B component thyristors. The arrows indicate the convention of forward blocking for A and B.
Thyristor Valve - 12 Pulse Converter (6.5Kv, 1568 Amp, Water cooled)

Thanks to Prof. Ajjarapu for providing the following slides:
Thyristor Observations

Many different structures used to build thyristors

Range from low power devices to extremely high power devices

Often single-wafer solutions for high power applications

Usually formed by diffusions

Widely used throughout society but little visibility

Applications somewhat restricted
Thyristors

The good

SCRs
Triacs

The bad

Parasitic Device that can destroy integrated circuits
The Thyristor
A bipolar device in CMOS Processes

Consider a Bulk-CMOS Process

If this parasitic SCR turns on, either circuit will latch up or destroy itself

Guard rings must be included to prevent latchup

Design rules generally include provisions for guard rings
End of Lecture 29