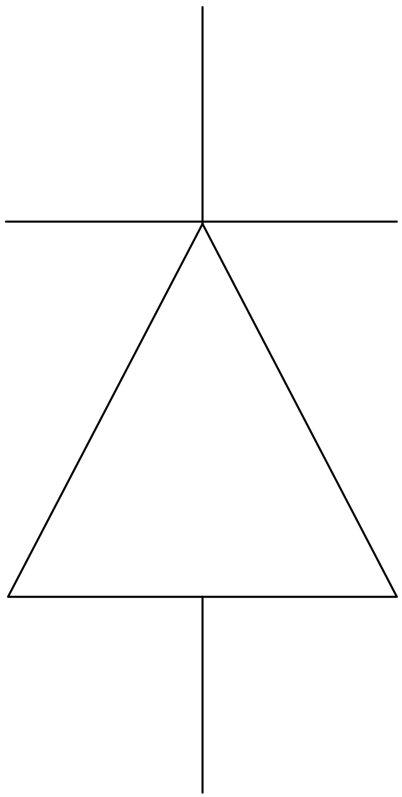
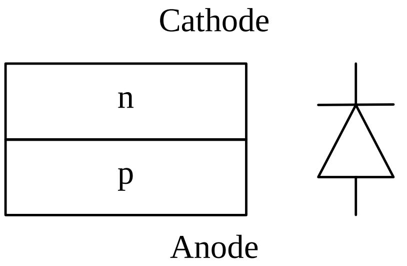
- ƒ <u>Ratings & Characteristics</u>
  - Common to all device types
    - Reverse recovery characteristics
  - Specific to fast (inverter grade) device types
    - Fast Recovery Diodes & Fast Switching Thyristors
  - Specific to slow (converter grade) device types
    - Rectifier Diodes and Phase Control Thyristors
  - Specific to thyristors only
    - Turn-off time test
- ƒ <u>Application Issues</u>
  - Snubbers
  - Selection of devices
  - Gate Drives
  - Clamping



ƒ Basic Structure & Symbol



ƒ Device Operation

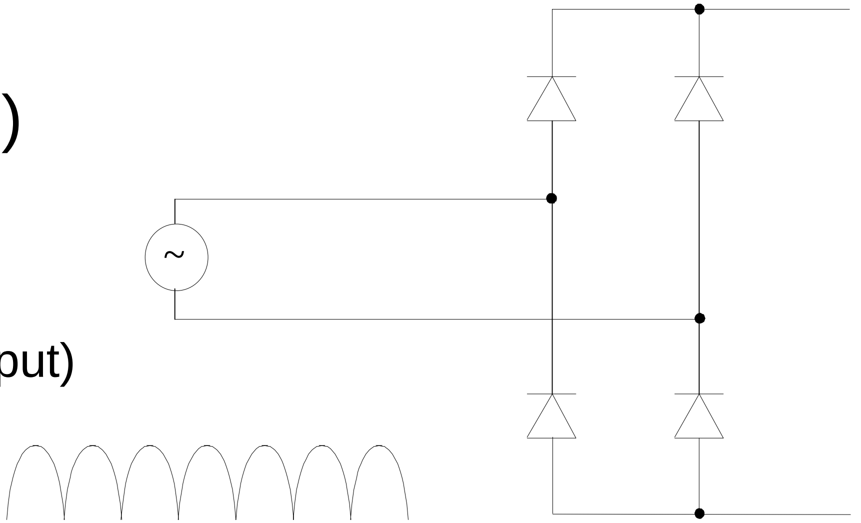
- Anode positive w.r.t. cathode = Forward conduction
  - Current flows from anode to cathode
- Cathode positive w.r.t. anode = Reverse blocking
  - No current f low (leakage)

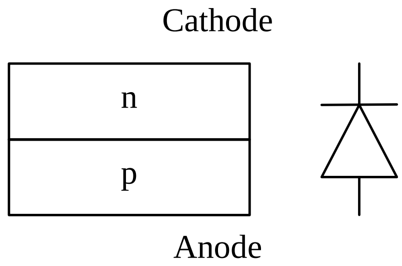
ƒ Slow device (converter grade)

- No optimisation

ƒ Application

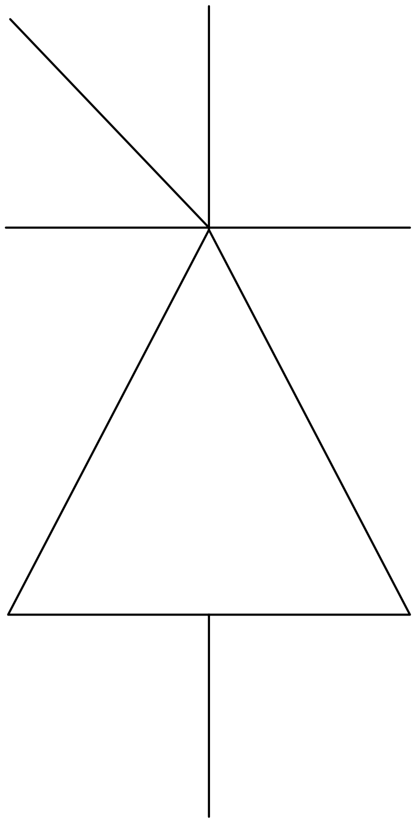
- Uncontrolled rectification (fixed output)
- Traction drives





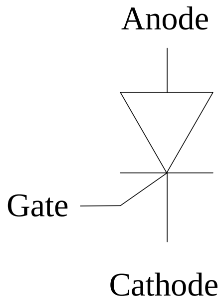
- Basic Structure & Symbol
- Basic operation as per rectifier diode
  - FRDs are fast operating devices
    - Device optimised for reverse recovery parameters (Lifetime control)
      - » Heavy metal doping (e.g. Gold, Platinum)
        - > Soft Recovery Diodes
      - » Electron irradiation (Fast Recovery Diodes)
      - » Ion implantation (e.g. Helium)
      - » Combinations also used (Extra Fast and HP Sonics)
- FRD Applications
  - Anti-parallel (freewheeling)
    - Snubber diode for GTO circuits
  - Induction heating (often with fast switching thyristors)
  - Series diode for asymmetrical operation / choppers

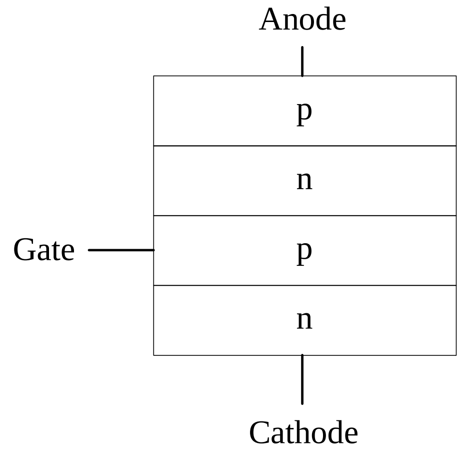
- Soft Recovery Diode applications
  - RCD snubbers
  - Voltage clamping
  - Snubberless applications
  - Note 125°C is maximum T_j on gold doped soft recovery diodes
- Extra Fast Recovery Diode applications
  - When low values of reverse recovery parameters are required
    - In association with IGBTs, GCTs
    - Pulse power
- HP Sonic FRD applications
  - Similar to XFRD applications but at higher di/dt
  - When higher operating junction temperature required
    - XFRDs limited to 125°C
  - Lower reverse recovery current than XFRD



ƒ Device symbol and basic structure

- Three modes of operation
  - Forward blocking (off-state)
    - » Anode positive w.r.t. cathode (no gate potential)
      - > No current flow (leakage)
      - > Negative gate bias required on GTOs
  - Forward conducting (on-state)
    - » Both anode and gate positive w.r.t. cathode
    - » Current flows from anode to cathode
    - » Loss of control - device cannot be commanded to turn off
      - > Core difference between conventional and GTO thyristors
  - Reverse blocking
    - » Cathode positive w.r.t. anode
      - > No current flow (leakage)



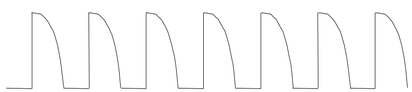


ƒ N series device operation

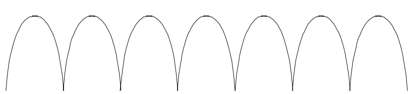
- Slow device (converter grade)
  - Not optimised for reverse recovery (except by special request/requirement)
  - Gate pattern not widely distributed
    - » Ring pattern (≤ 50mm diameter)
    - » Cross pattern (≥ 63mm diameter)
    - » Spoke pattern (100mm diameter)

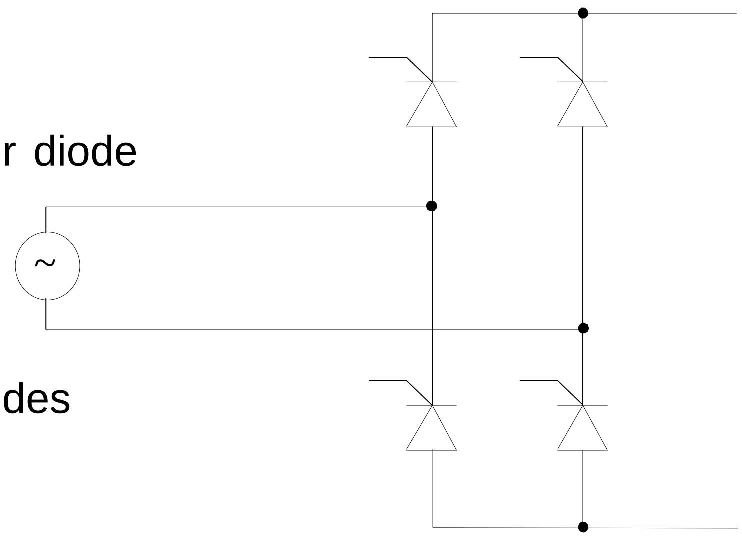
ƒ Applications

- Fully controlled rectification
  - Gate controlled device unlike r   ectif ier diode
  - Hence, possible output:

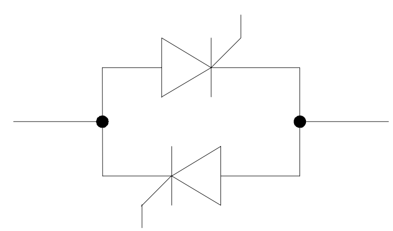


  - Compare w ith output using rectifier diodes





- Electro-chemical power supplies
- HVDC projects & utilities
- Cyclo-converters
- Soft start systems
- AC switches



- The term ‘Medium voltage’ is derived from target applications
- Not considered a ‘fast’ device
- These are essentially modified PCT’s (Westcode P type)
  - Distributed gate patterns
    - 53mm & 75mm diameter
    - 87mm & 100mm diameter
  - Degree of lifetime control
- Controlled switching characteristics
  - Increased di/dt capability
  - Improved turn-off time
  - Better candidate for series operation

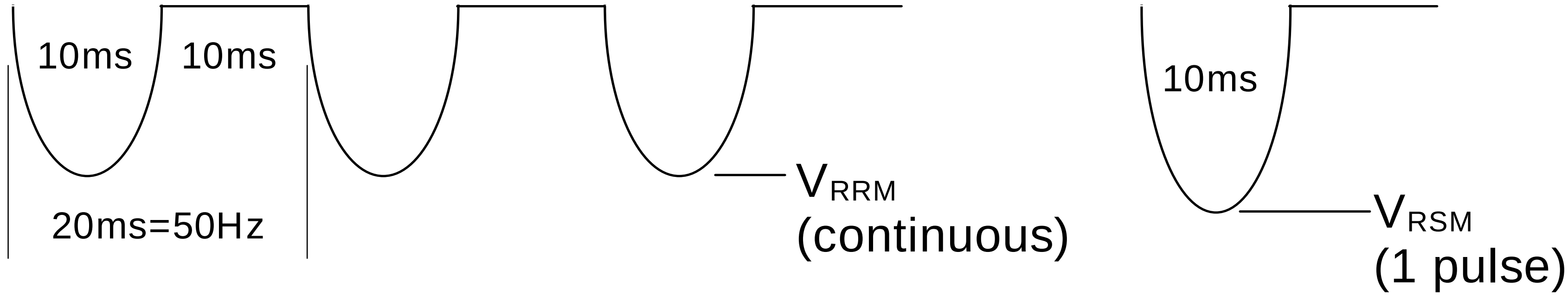
- Summary
  - Essentially PCT with gate distribution
  - P-type gate structure most common in MVT
  - Higher di/dt capability than PCT
  - Controlled recovery and turn-off time (not fast)
- Applications
  - Medium voltage utilities
  - High power dc drives
  - Trackside substations
  - Power conditioning
  - Induction melting

- R series device operation
  - Fast switching device (inverter grade)
    - Optimised for recovery parameters
      - Extensive use of lifetime control techniques
    - Widely distributed gate patterns (more so than MVT)
      - Up to 50mm diameter inclusive
      - 53mm diameter
      - 87mm and 100mm diameter
  - Basic device operation as per PCT and MVT
  - Controlled recovery characteristics and turn-off performance
- Note: Old 'D' series no longer exists as a part number
  - Such devices are now part of the 'R' series

- Applications
  - Inverters
  - High frequency welders
  - DC chopper drives
  - Uninterruptible power supplies (UPS)
  - Induction heating
- Fast turn-off thyristors (FTO)
  - Regenerative gate structure
  - Used in similar applications to DGT
    - At lower frequencies
  - Most now reassigned as MVT

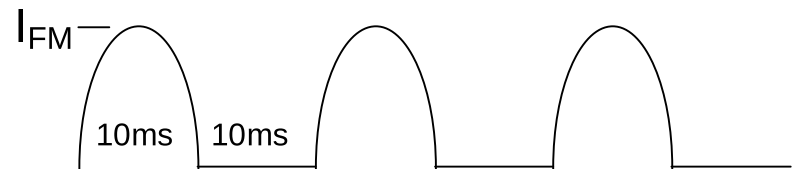
ƒ Maximum ratings

- Maximum operating junction temperature T_{jop} (T_{jmax} T_{vj})
- Maximum storage temperature T_{stg}
- Maximum repetitive reverse voltage V_{RRM}
  - Maximum repetitive reverse current I_{RRM} (at V_{RRM})
- Maximum non-repetitive reverse voltage V_{RSM}
- V_{RRM}/V_{RSM} <u>NOT</u> dc values (also applies to V_{DRM}/V_{DSM} on thyristors)



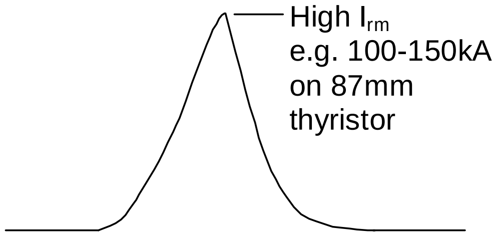
- Values for V_R (dc) is approximately 50% of V_{RRM}
- V_{RSM} typically 100V greater than V_{RRM}

Maximum ratings (cont.)



- Forward (on-state) current ratings (at specified heatsink temp.)
  - Average half sinewave current $I_{F(av)}/I_{T(av)}$ ($I_{FM} \div \pi$)
  - RMS half sinewave current $I_{F(RMS)}/I_{T(RMS)}$ ($I_{FM} \div 2$)
  - DC current I_F/I_T
- Max. non-repetitive forward (on-state) current - Surge
  - Overload (fault) condition
  - Single cycle of half-sinewave current, 10ms width
  - Two separate ratings:
    - » Followed by reverse voltage (60% V_{RRM}) $I_{FSM(1)}/I_{TSM(1)}$
    - » Followed by no reverse voltage ($\leq$10V) $I_{FSM(2)}/I_{TSM(2)}$
  - Load limit integral I^2t (value for fusing)
    - » Calculated by

$$I^2t = \int_0^{t_p} I_F{}^2(t) \cdot dt = \frac{I_{FSM}{}^2 \cdot t_p}{2}$$



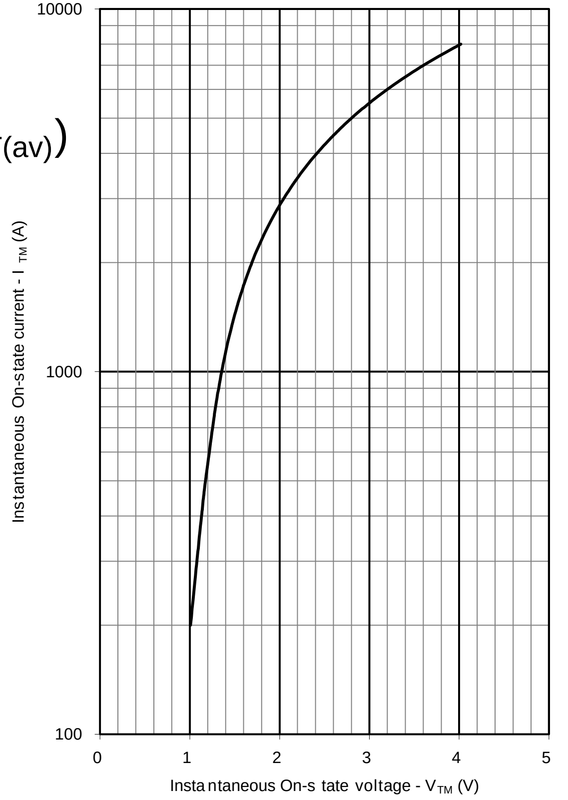
- Explosion rating (Case non-rupture rating)
  - Effectively a test of the housing, not the device
    - » Enhancements (arc-shielding) can be added within housing
  - Simulation of major rectifier fault - device made short-circuit prior to test
  - High level of <u>reverse</u> current passed through failed device and a fuse
  - Pass/fail criteria may vary - usually need to pass a following leak-test
  - Use rating by selecting a fuse with a lower I^2t
  - Important rating as when things go wrong…..

f Characteristics

- Maximum forward (on-state) voltage V_{FM}/V_{TM}
  - Test limit V_{FM}/V_{TM} set at I_{FM}/I_{TM} (Usually 3 × $I_{F(av)}/I_{T(av)}$)
- Limit forward (on-state) voltage curves
  - ABCD Coefficients

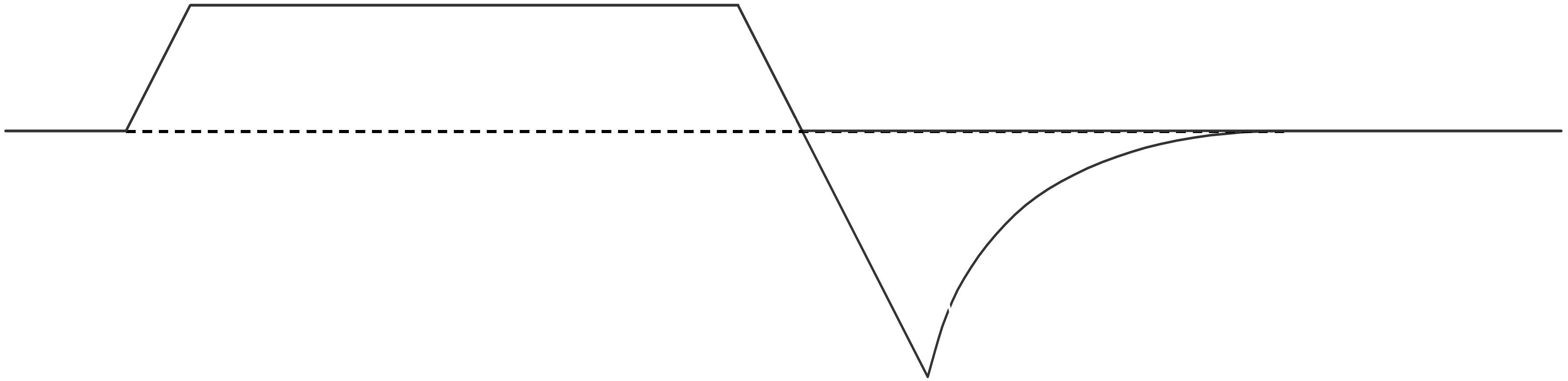
$$V_F = A + B \cdot \ln(I_F) + C \cdot I_F + D \cdot \sqrt{I_F}$$

  - Threshold voltage V_{T0} / Slope resistance r_T
    - » Calculation of max. current ratings
    - » Calculation of max. power dissipation
- Thermal resistance
  - Steady state value (junction to heatsink) R_{thJK}
  - Transient thermal impedance curve



ƒ What is reverse recovery?

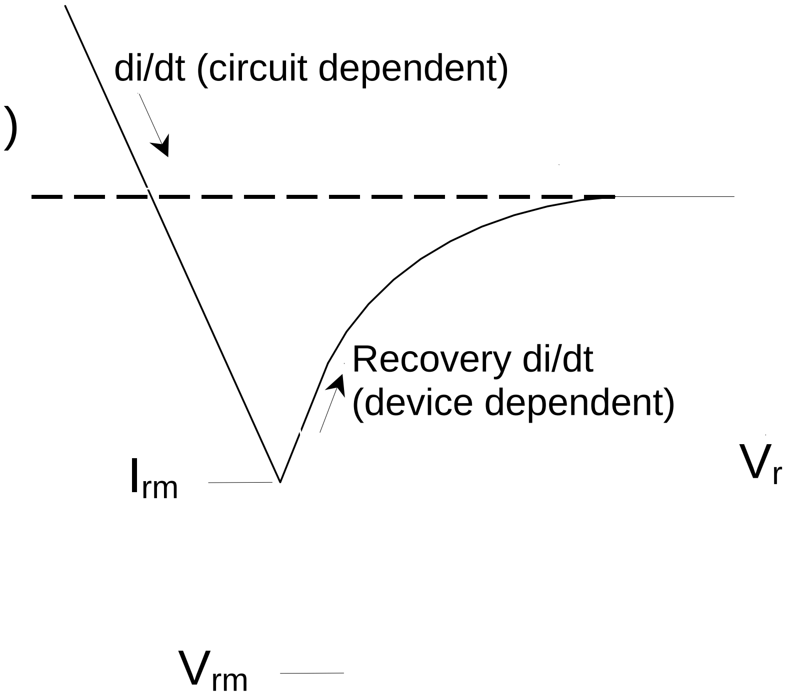
- Consider current waveform
  - Ideal sit uation
  - Real sit uation



- Generates recovery voltage
- Major issue when multiple devices connected in series
- Creates additional power loss $\Rightarrow$ heat

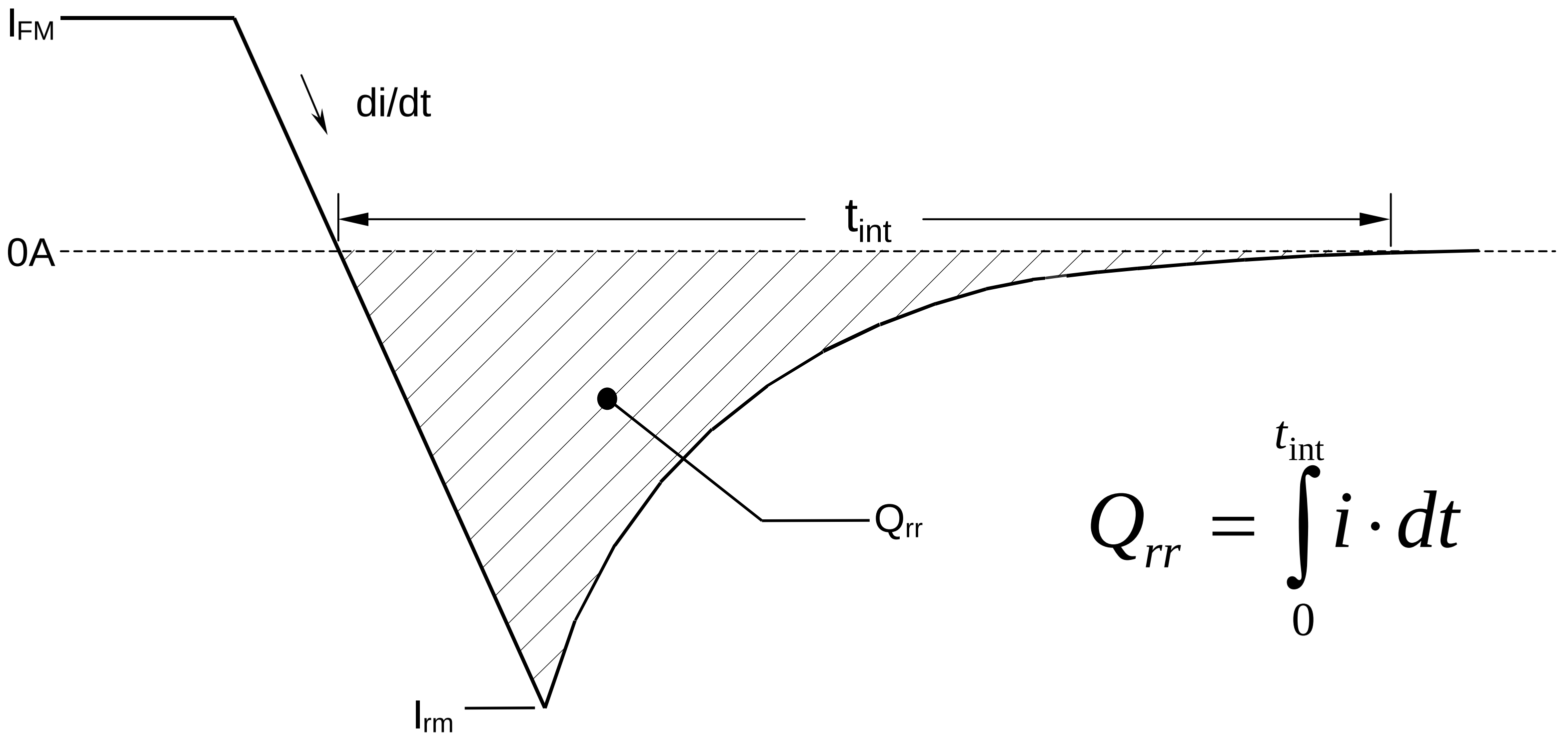
ƒ Reverse recovery parameters

- Peak reverse recovery current I_{rm} (I_{rr})
- Total recovered charge Q_{rr}
- Recovered charge Q_{ra}
  - With specified chord level
- Reverse recovery time t_{rr}
  - With specified chord level



- This information is frequently required on ALL product types

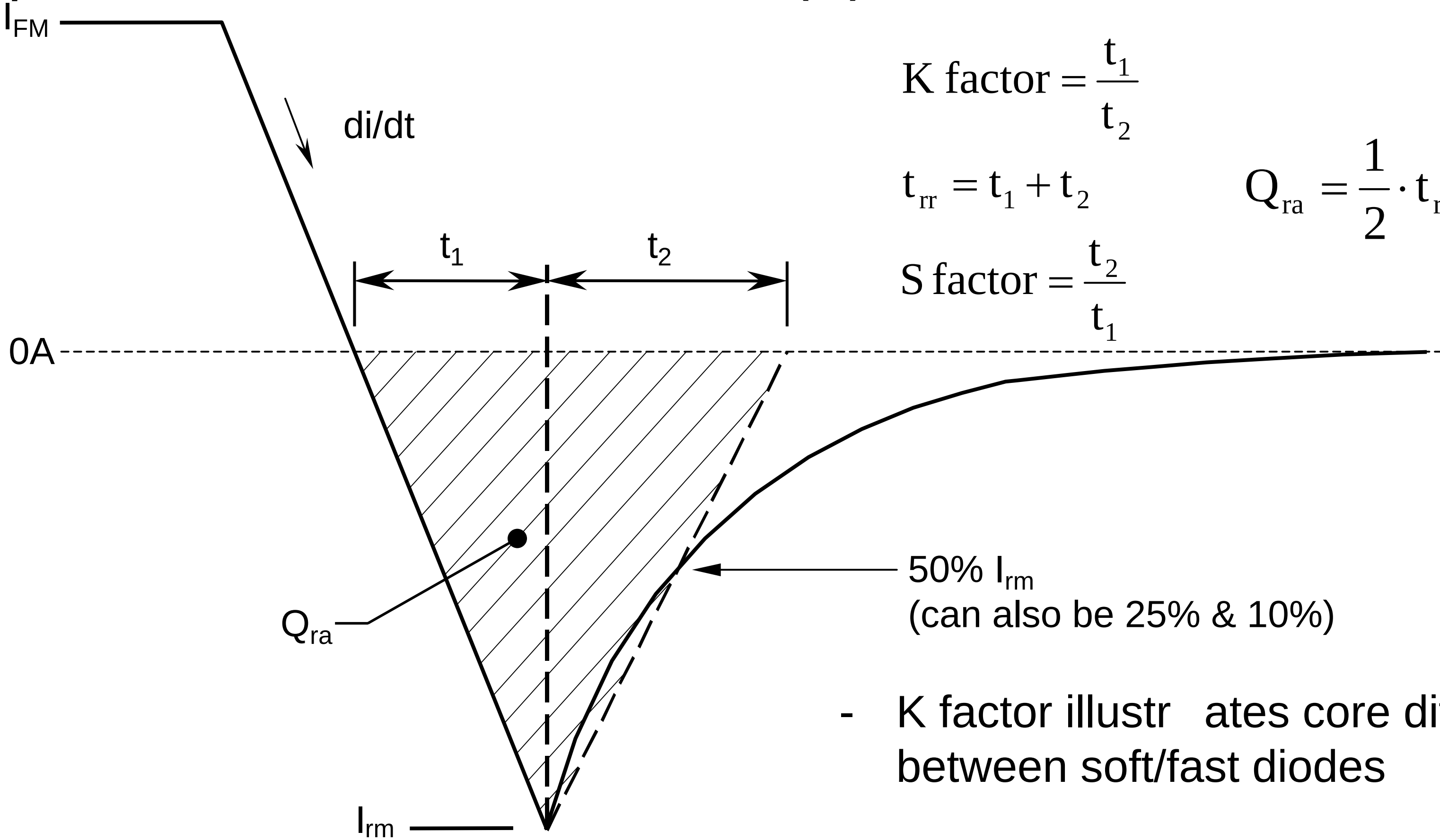
ƒ Definition of Q_{rr} (total stored charge)



$$Q_{rr} = \int_0^{t_{int}} i \cdot dt$$

- ƒ Area under curve from I=0A to t_{int} (Standard=150µs)
- ƒ Q_{rr} may appear as Q_s, Q_r, Q_{rec} etc.

ƒ Definition of Q_{ra}, t_{rr} and K (S) factor



$$\text{K factor} = \frac{t_1}{t_2}$$

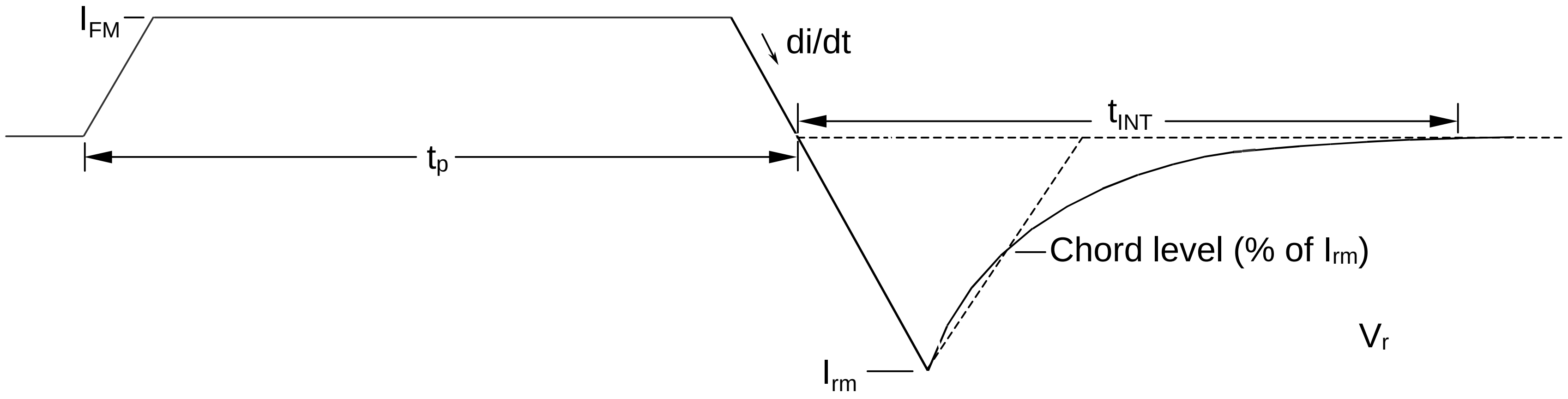
$$t_{rr} = t_1 + t_2$$

$$\text{S factor} = \frac{t_2}{t_1}$$

$$Q_{ra} = \frac{1}{2} \cdot t_{rr} \cdot I_{rm}$$

- K factor illustrates core difference between soft/fast diodes

ƒ Information required for recovery measurements



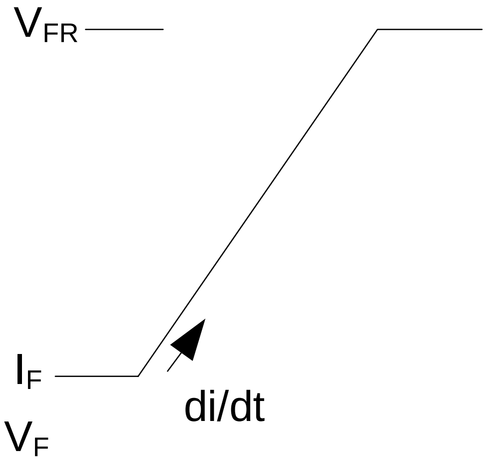
- All of the above, plus….
- For Q_{ra}, t_{rr} or K factor, chord level MUST be specified
  - Normally 50% but can also be 25% and 10%
- For Q_{rr}, specify t_{int}
- Test temperature - CRITICAL
- Where charge appears only as Q_r, Q_s etc.
  - Must clarify whether Q_{rr} or Q_{ra} required

ƒ Fast product ratings

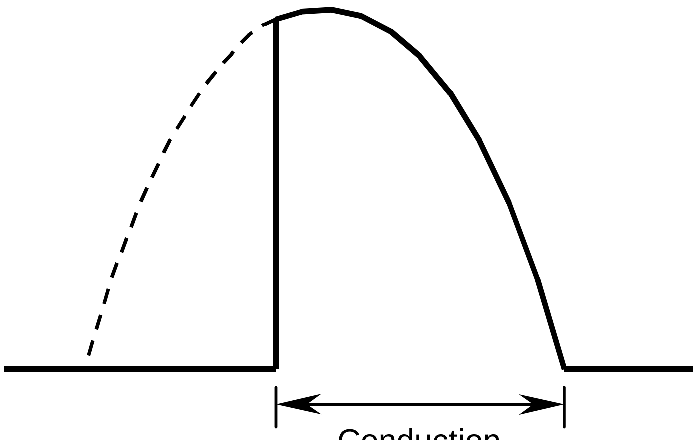
- Frequency/energy ratings
  - Energy vs. pulse width $T_j = T_j$ max
  - Frequency vs. pulse width
    - » 55°C / 85°C heatsink temperature
  - Square wave (various di/dt's)
  - Sine wave

ƒ Forward recovery voltage V_{FR}

- Measured exclusively on fast diodes



- Power dissipation curves
  - Mean forward current vs. power dissipation
    - Square wave and sine wave
    - Various conduc tion angles

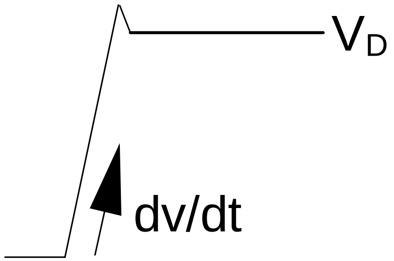


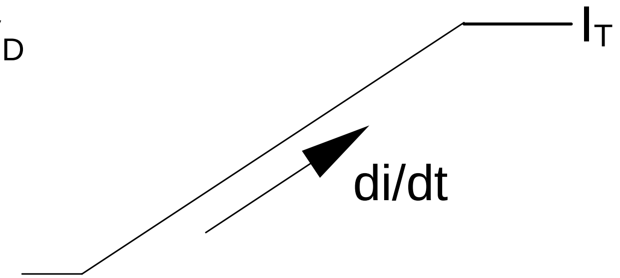
- Maximum permissible heatsink temperature
  - Mean forward current vs. heatsink temperature
    - Square wave
    - Sine wave
    - Various conduc tion angles

$$P_{\max} = \frac{T_{j_{\max}} - T_{\mathrm{K}}}{R_{thJK}}$$

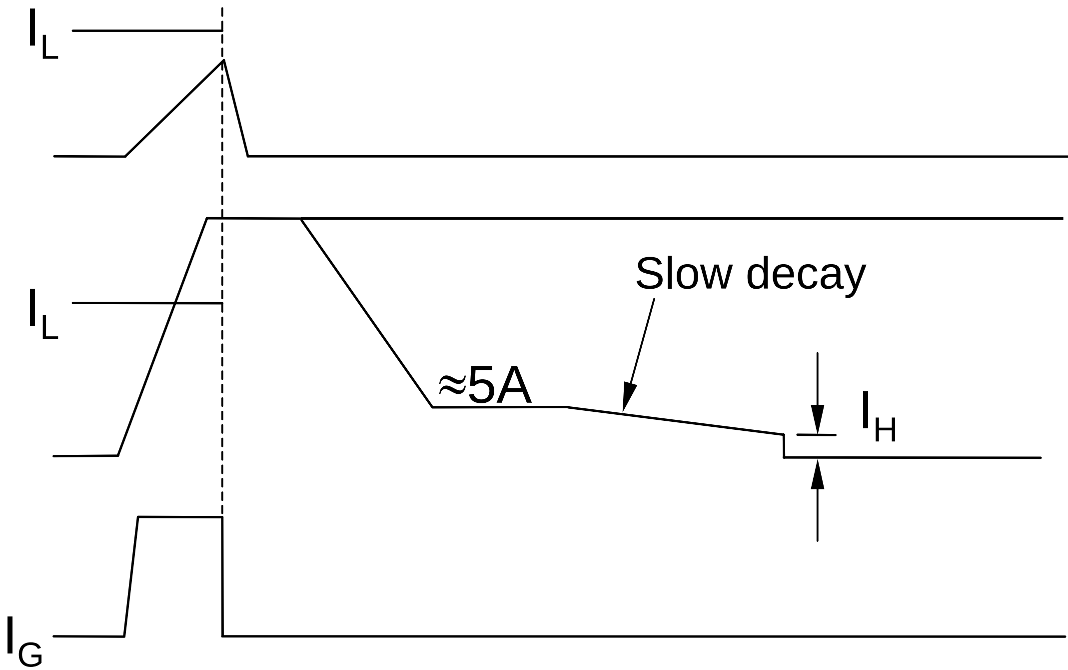
- Equivalent shown for dc, ½ wave, 3ph, 6ph on diodes

- ƒ Max. repetitive forward (off-state) voltage V_{DRM}
  - Maximum repetitive off-state current I_{DRM} (at V_{DRM})
- ƒ Maximum non-repetitive off-state voltage V_{DSM}
- ƒ Critical rate of rise of off-state voltage $(dv/dt)_{cr}$
  - Measured to V_D=80% V_{DRM} (linear voltage ramp)
  - Failure is destructive
- ƒ Critical rate of rise of on-state current $(di/dt)_{cr}$
  - Quoted for repetitive (50Hz) and non-repetitive duty
  - Simple turn-on test
  - Failure is destructive

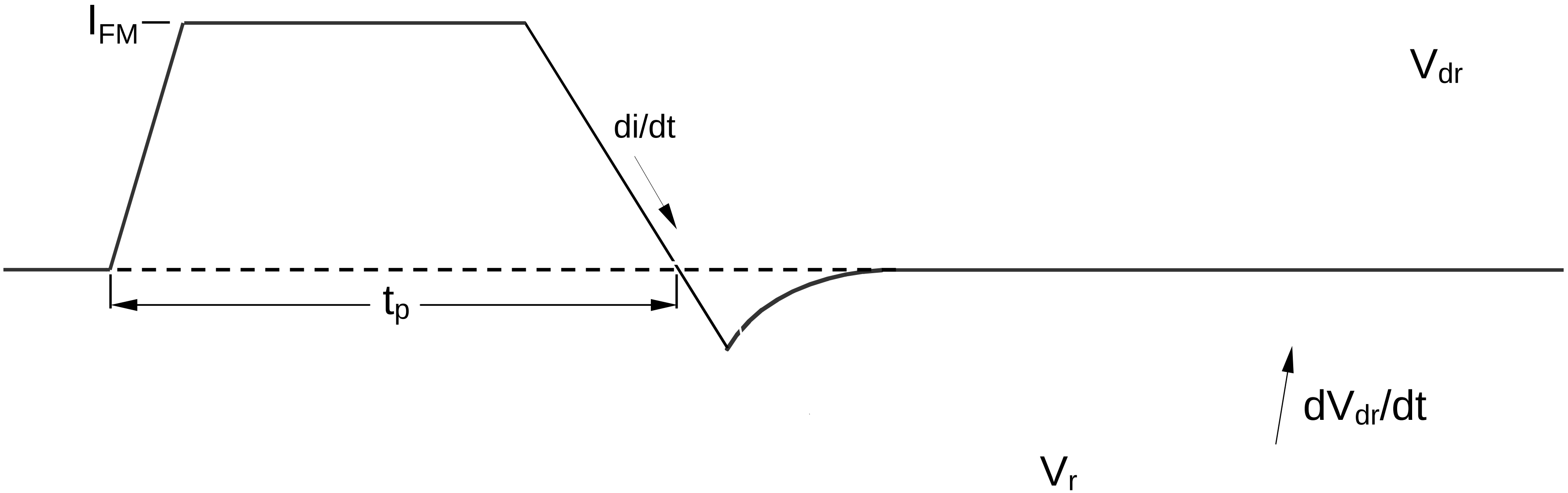




- Gate trigger voltage V_{GT} and current I_{GT}
- Gate non-trigger voltage V_{GD} and current I_{GD}
- Peak forward gate current I_{FGM}
- Peak reverse gate voltage V_{RGM}
- Mean forward gate power $P_{G(av)}$
- Peak gate power P_{GM}
- Latching current I_L
- Holding current I_H



ƒ Definition of turn-off time test and terms

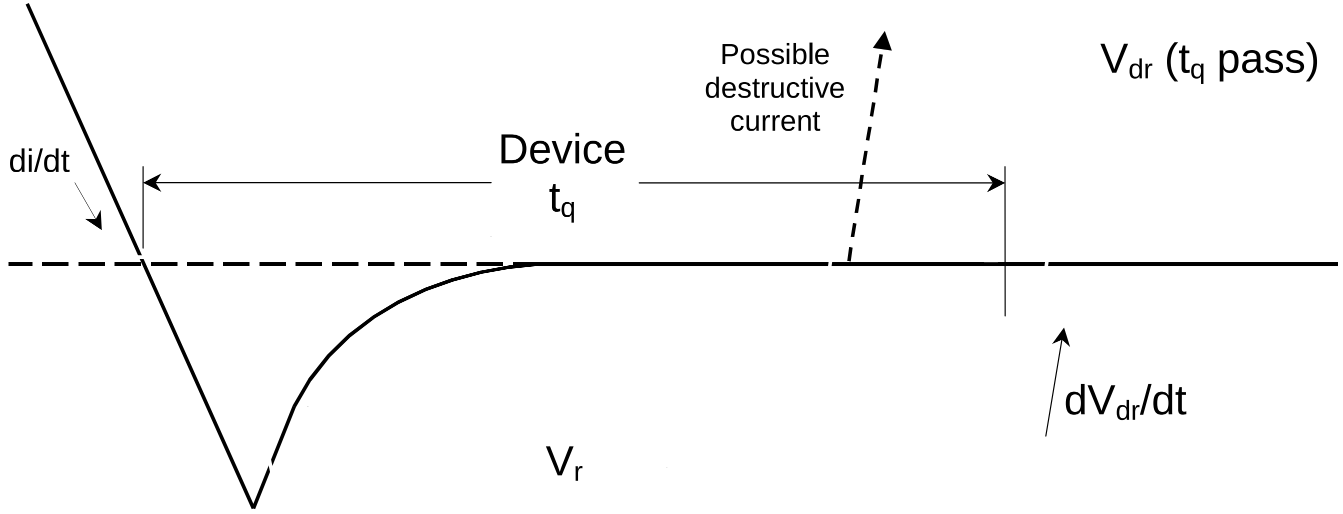


ƒ All of this information is required

- Plus test temperature - CRITICAL

ƒ Turn-off time t_q

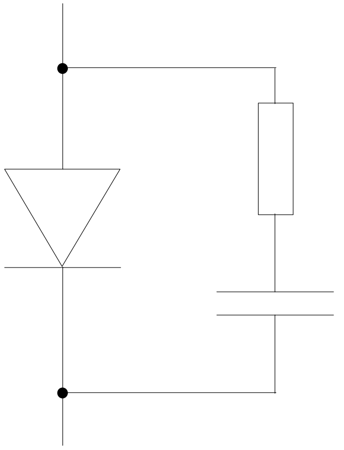
- Time before off-state voltage may be safely re-applied

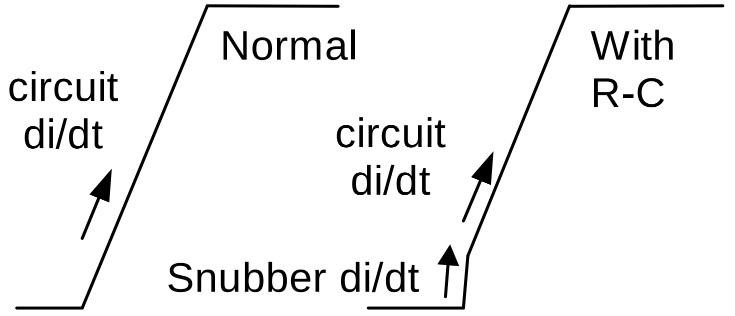


- Value of t_q affected by ALL illustrated parameters
- Often asked for on all thyristor types

ƒ Snubbers

- Resistor and capacitor connected in series
- Snubber then connected across device anode/cathode
  - Important to minimise inductance
- Used to restrict dv/dt and V_{rm} to safe values
- Affects reverse recovery waveform
  - Care needed when devices in series
- Changes turn-on waveform
  - Implications on di/dt performance
  - Snubber di/dt must be within device rating
- Careful design calculations
  - Min. resistance/max. capacitance limits





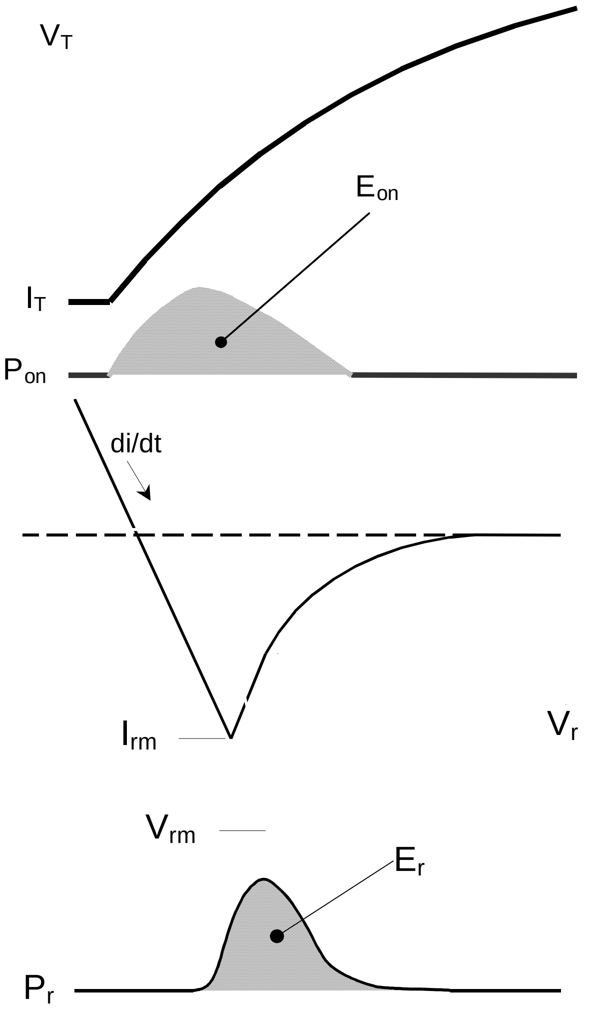
ƒ Switching energy losses

- Turn-on power P_{on}
- Turn-on energy loss E_{on}

$$P_{on} = V_T \cdot I_T \qquad E_{on} = \int_0^{t_{on}} V_T \cdot I_T$$

- Reverse recovery power P_r
- Reverse recovery energy loss E_r

$$P_r = V_r \cdot I_r \qquad E_r = \int_0^{t_r} V_r \cdot I_r$$

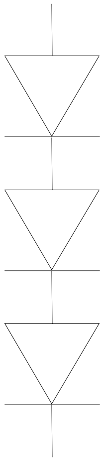


Selection of thyristor type

- Why select a Phase Control Thyristor (N type)
  - When a low V_T is important
  - High Average Current & Surge Current Ratings are required
  - Low frequency (up to 60Hz) applications and low di/dt
    - Examples are cyclo-converters and AC switches
- Why select a Medium Voltage Thyristor (K type)
  - Higher voltage devices/medium voltage applications
    - Line/power frequency applications (50/60Hz and up to 400Hz)
  - For multiple device operation e.g. series/parallel
    - N-types are inappropriate due to lack of lifetime control
  - High power drives are a typical application
- Why select a Distributed Gate Thyristor (R type)
  - When a fast <u>switching</u> device is required (even at low frequencies)
  - R types always considered first for induction heating

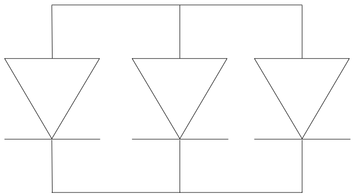
ƒ Series operation

- Multiple devices required for system voltage rating
- Considerations needed are:
  - K series device most likely preferable to N series
  - Banding on reverse recovery parameters
  - Matching on leakage current
  - Matching on gate trigger parameters



ƒ Parallel operation

- Multiple devices required for system current rating
- Considerations needed are:
  - Banding on V_T
  - Banding on delay time (turn-on time)
  - Matching on gate trigger parameters



ƒ Thyristor gate drive

- Important note concerning gate trigger parameters
  - V_{GT}/I_{GT} are the bare minimum amounts required to trigger the device
  - They are absolutely NOT practical values
    - » The full di/dt capability of a device CANNOT be used this way
- Refer to gate drive note in any thyristor data sheet
  - Most important figures are:
    - » Open circuit voltage
    - » I_G rise time - especially when using device's full di/dt capability
    - » I_{GM} - especially for larger devices
  - Keep to maximum ratings (Voltage & Power)

ƒ Clamping

- Important to clamp at correct force and EVENLY
- Failure to do this results in higher power dissipation, high V_T and reduced device lifetime