Voltage Sourced Converter Topologies

- Single phase bridge (H-bridge)
- Three phase bridge
  - » Called 6-pulse or 6-step converter
  - » Often connect several converters together with phase shifted inputs to improve voltage waveforms
    - – Multipulse arrangements
    - – Use magnet circuit configurations to improve waveform
    - – Can reduce voltage ratings on devices too

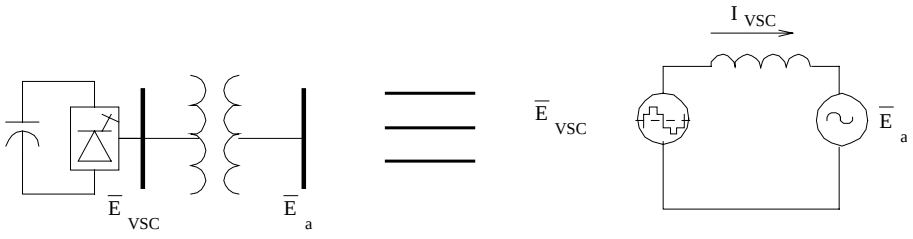
Higher Voltage VSC Topologies

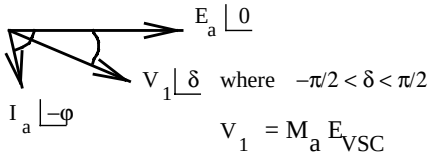
- Multilevel converter
  - » Originally called neutral point clamped
  - » Allows higher voltage ratings without series connected devices
  - » Smoother voltage waveforms without as many bridges (increased number devices)
- Chain Link Converters

VSC Modeling in EMTP/ATP - Six Step

- VSC appears to ac system as controlled ac voltage source
- The equivalent source is able to vary voltage magnitude
- A conventional VSC bridge varies phase angle and not voltage magnitude

Basic VSC Relations





$$V_1 = M_a E_{VSC}$$

Basic VSC Relationships

- Must have a capacitive ac source to operate in line-commutated mode
- Majority of VSC applications require self-commutating switches
- Bi-directional switch currents
- Switch voltage does not reverse
- Modules (connect in series or parallel) if no PWM

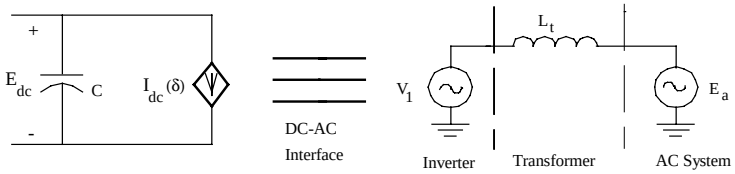
Fundamental Component Representation

- Only the fundamental component of voltage transfers useful power
- Approximate steady-state behavior with fundamental component equations
- AC equivalent is a controlled voltage source
- DC equivalent is a controlled current source in parallel with a capacitor

Fundamental Component Model

- Based on power balance equations
- M_a is PWM Modulation Ratio
- E_{dc} varied with phase angle if no DC source

$$V_1 = \frac{\sqrt{2} M_a E_{dc}}{\pi} \qquad I_{dc} = \frac{3\sqrt{2} M_a E_a \sin\delta}{\pi \omega L}$$



Device Models

- A VSC will require self-commutating switch
- Large applicatins will utilize GTO's or IGBT
- Requires representation of current reversal
- Detailed turn-on/turn-off not needed
- Several representations possible
- Paired with anti-parallel diodes to allow current reversal

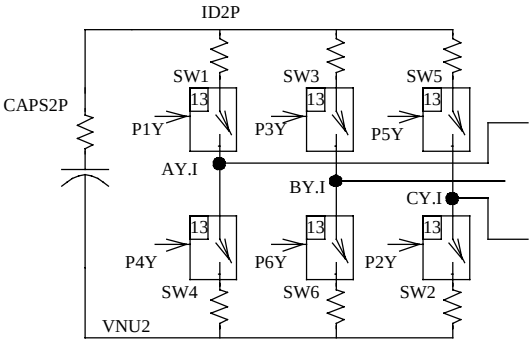
Device Models

- Requires a TACS controlled switch to represent external gate pulses
- Options:
  - » EMTP Type 13 switch (with or without anti-parallel diode
  - » EMTP Type 11 switch using OPEN/CLOSE input as GTO with a second Type 11 switch as the anti-parallel diode.

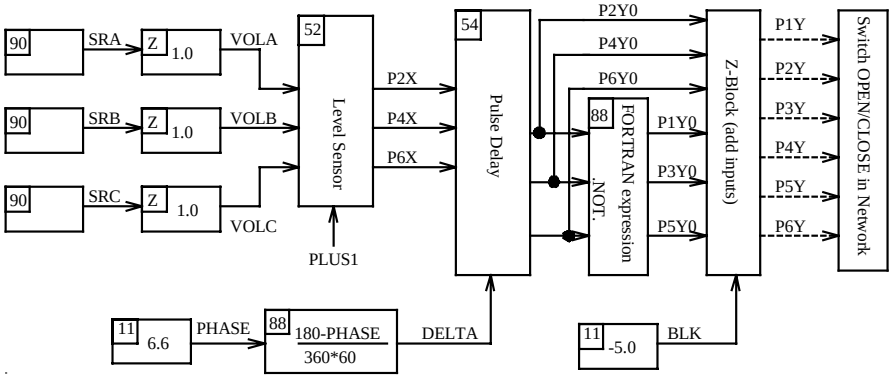
Type 13 TACS Controlled Switch

- Allow to stay on for entire period
- Bidirectional current in switch, no need for added diode in normal operation
  - » Potential for errors, so better to add diode
- Send gate pulses to OPEN/CLOSE input
- OPEN > 0.0 ----> Close next time step
- OPEN <= 0.0 ----> Open next time step

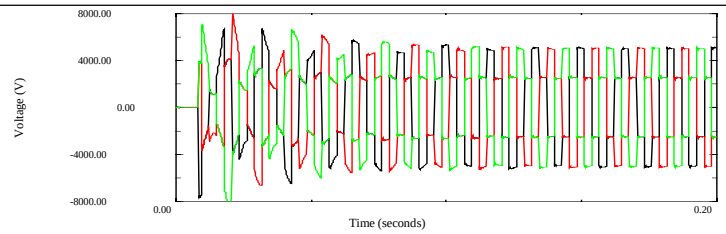
Power Circuit

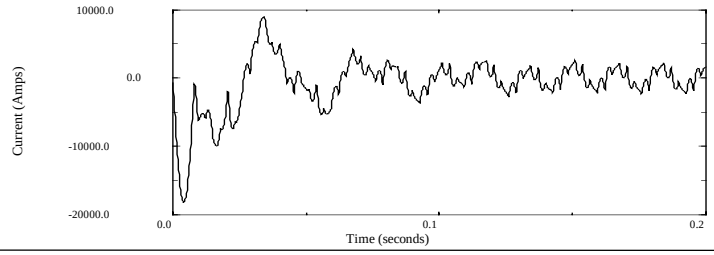


Firing Pulse Generator



Simulation Results

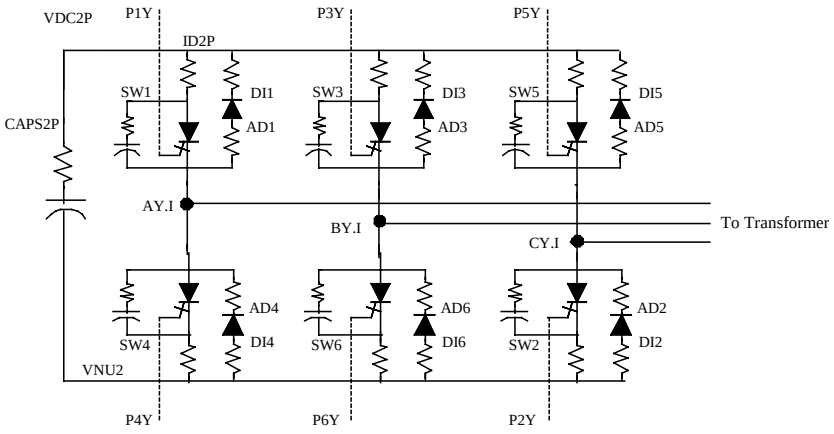




Type 11 Switches

- Use short GRID pulse to turn on as thyristor
  - » Negative OPEN/CLOSE to open switch
- Or can use the open/close signal as did with type 13
- Must add anti-parallel diodes (type 11 switch with no TACS Input)
- Requires RC turn-off snubbers

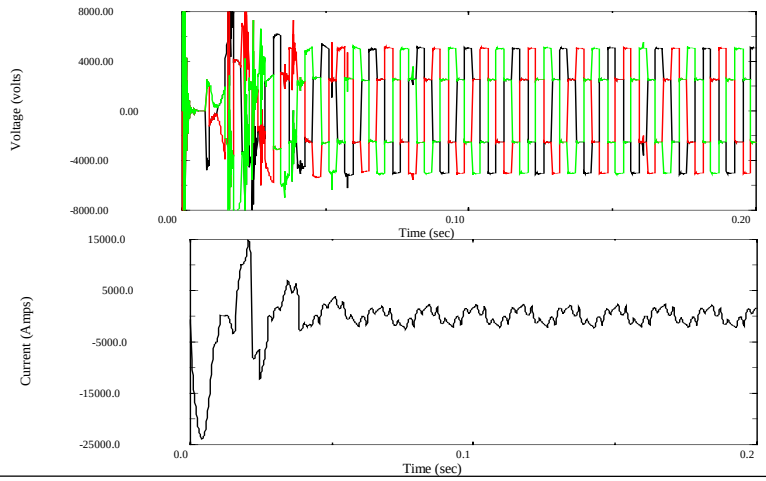
Type 11 Switches



Type 11 Switches Gating

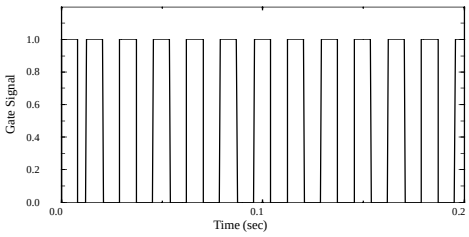
- In both cases can use ramp generator
- May want PLL due to voltage distortion
- Slightly different gate pulses

Simulation Results:

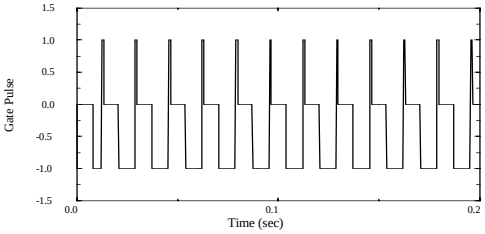


Simulation Results: Gate Pulses

Type 13



Type 11



Using 6-Step Converters

- Indirect control of V_q
  - » Can't easily go from capacitive to inductive series voltage injection
  - » Draw real power to increase V_q
  - » Discharge capacitor to decrease V_q
- Multipulse configuration to clean up voltage waveform
  - » Requires multiwinding transformer

PWM Converters

- Better to use type 13 switch with anti-parallel diode (type 11)
- Can use same circuit as earlier
- Gating for the type 11 case too difficult
- Generate carrier signal synchronized with power system

PWM Converters- Circuit Configuration