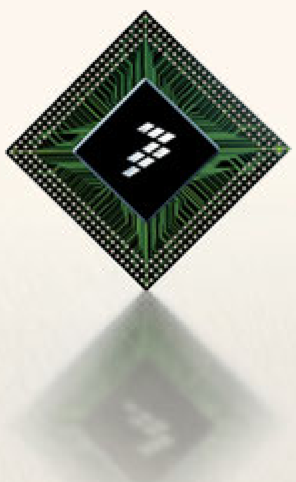
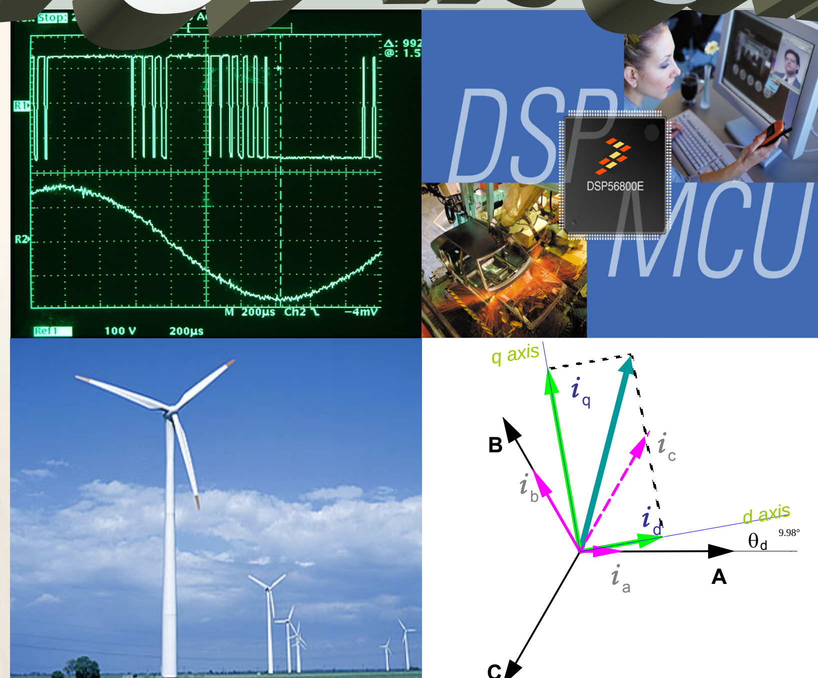
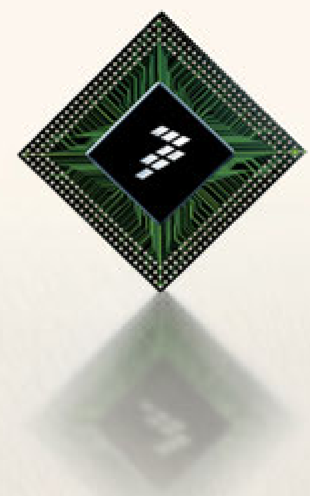
Energy Regeneration







Energy.
Don't loose it…REUSE it!

FREESCALE
ELECTRIC MOTOR
CONTROL

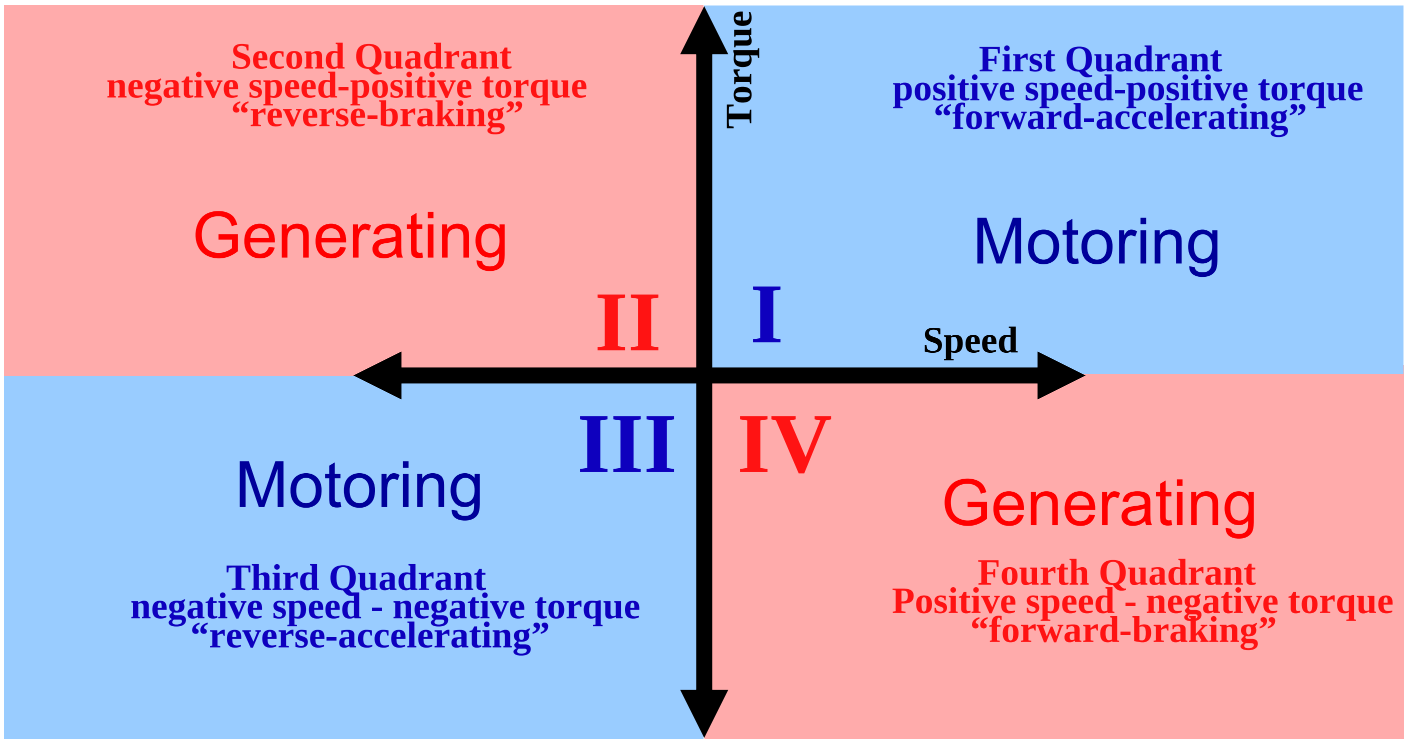
July 2nd, 2009
Freescale Webinar

freescale™ semiconductor

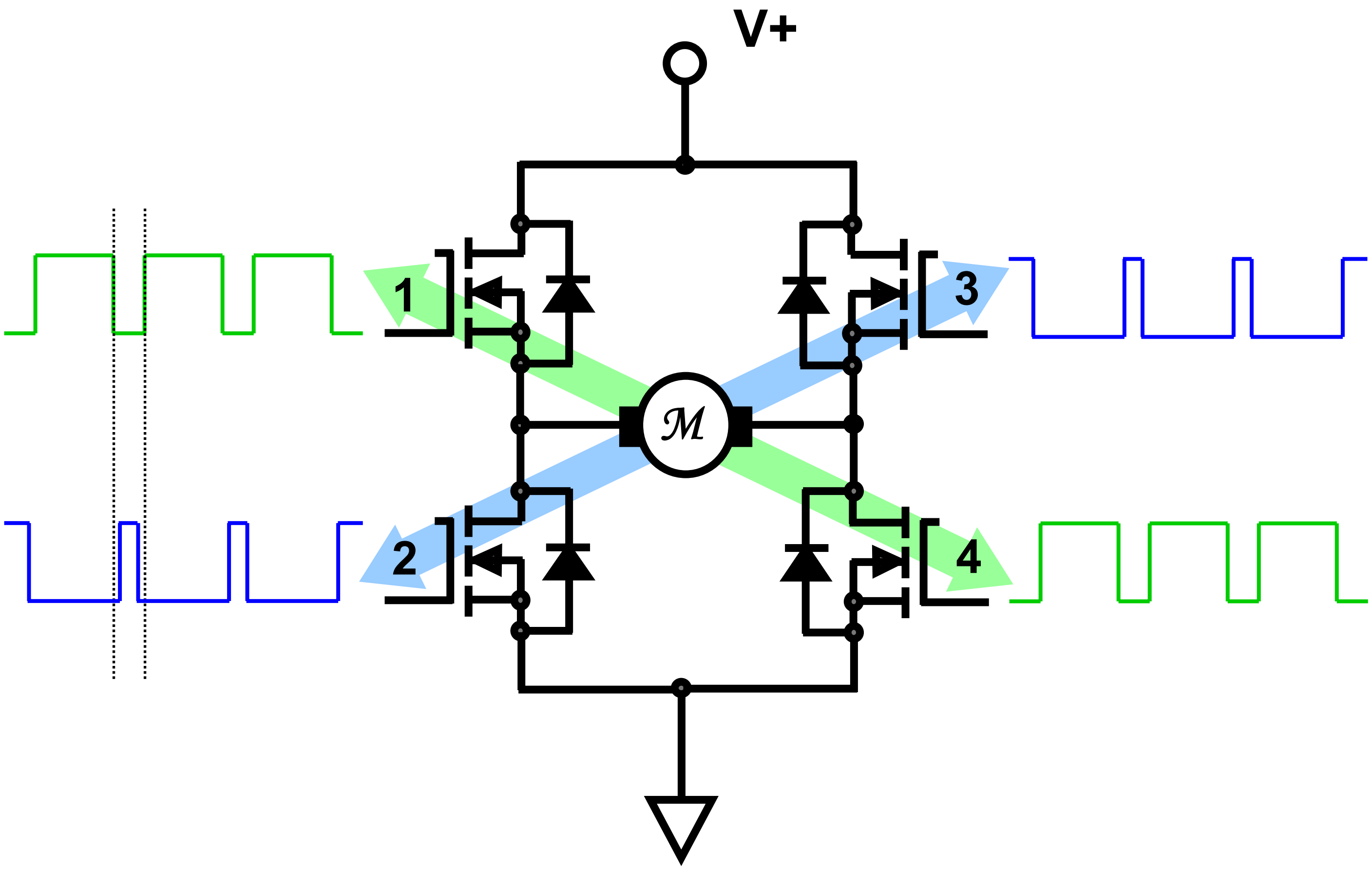
For Today's Webinar…

- Introduction to 4-Quadrant Systems
- Motor Regeneration
- Single-Phase Line Regeneration
- Three-Phase Line Regeneration
- Freescale Solutions for Regeneration

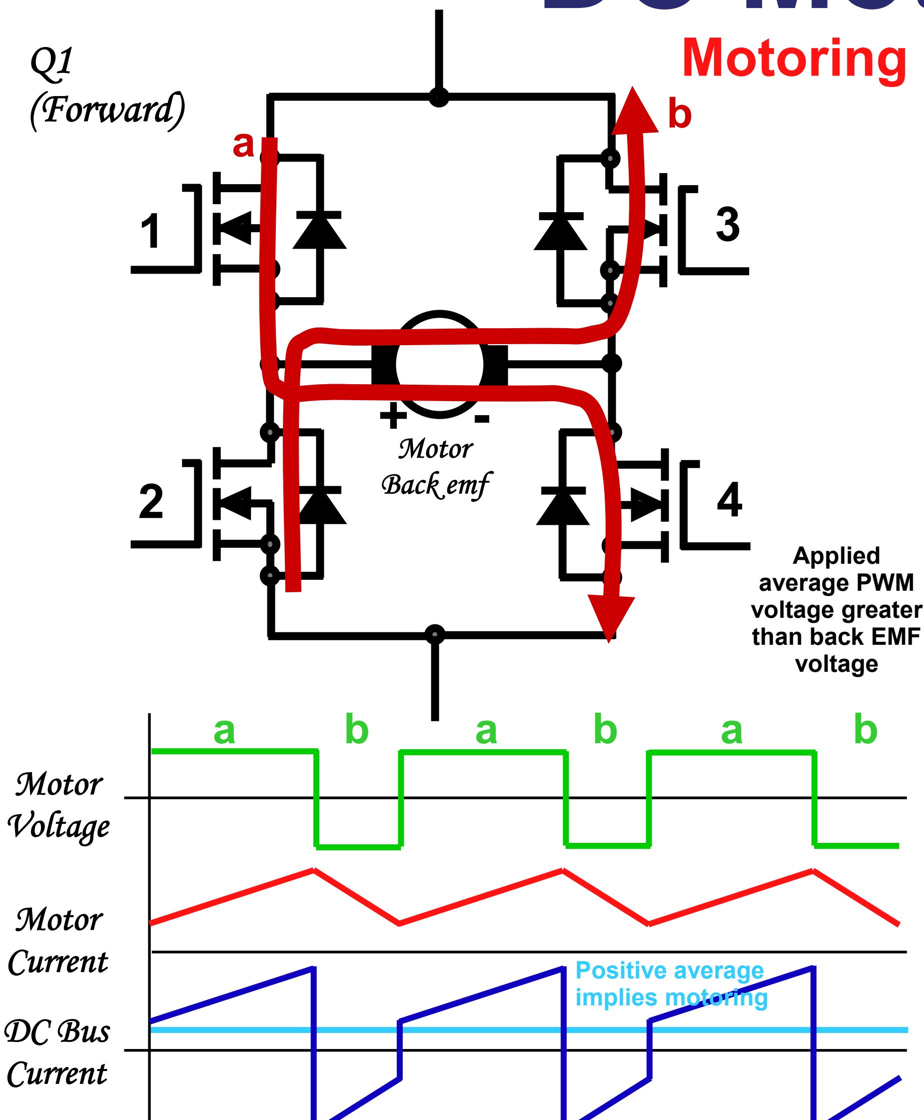
Quadrants of Operation

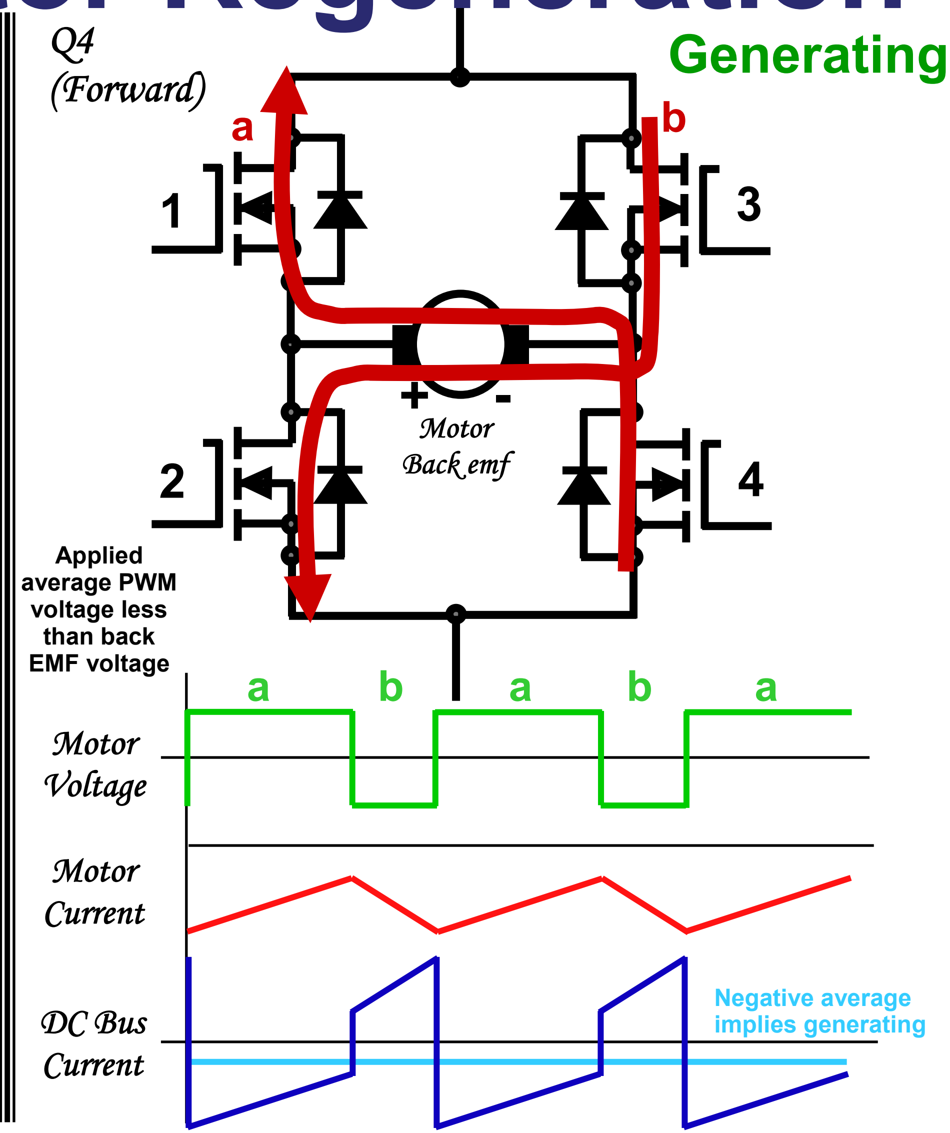


Example 4-Quadrant System

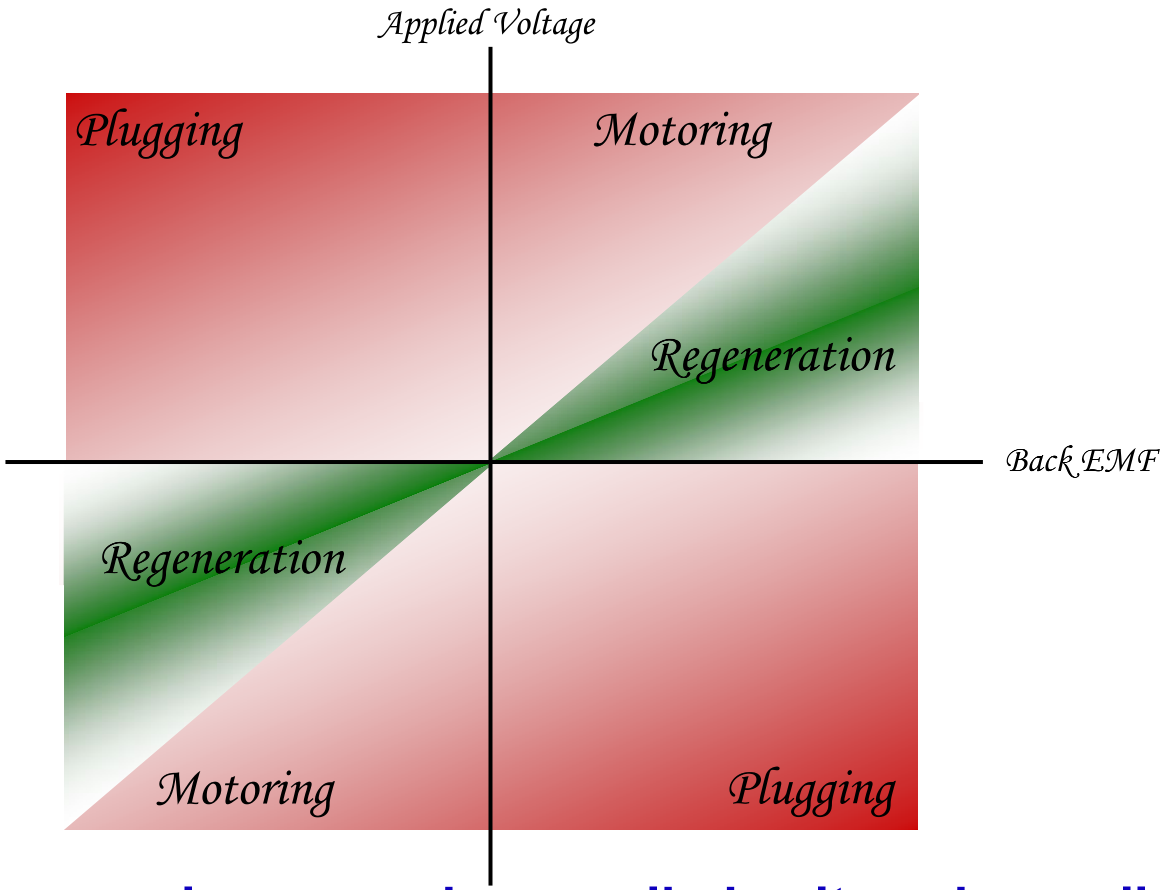


DC Motor Regeneration





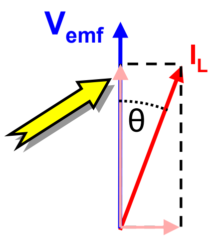
Conditions for DC Motor Regeneration



Bus regen. can only occur when applied voltage is smaller in magnitude than the motor back-EMF, and of the same polarity.

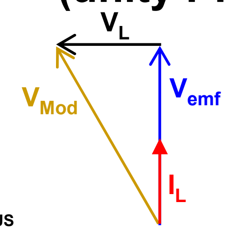
Dave Wilson

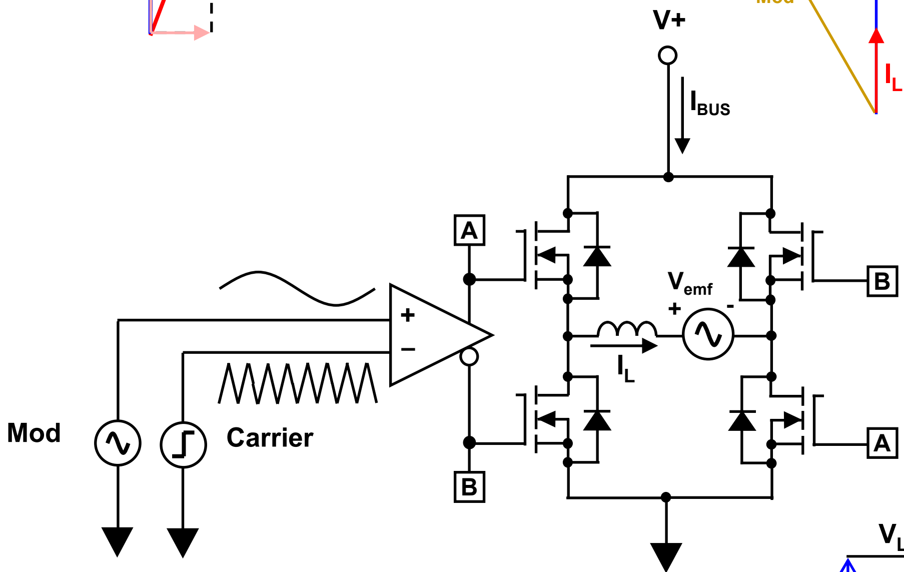
AC Motor Regeneration

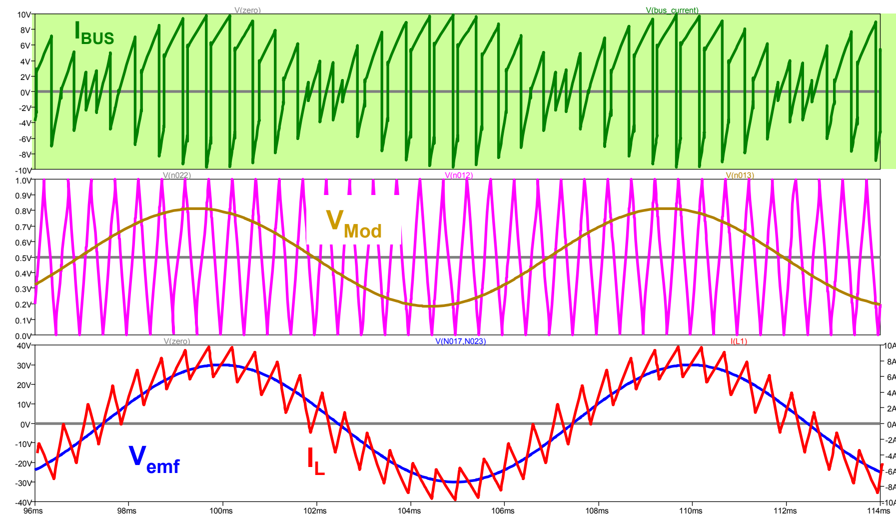


$P = \frac{1}{2} V_{emf} I_L \cos(\theta)$

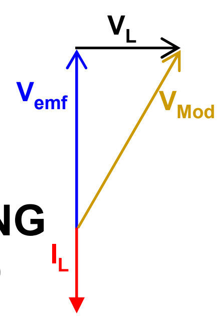
MOTORING
(unity PF)



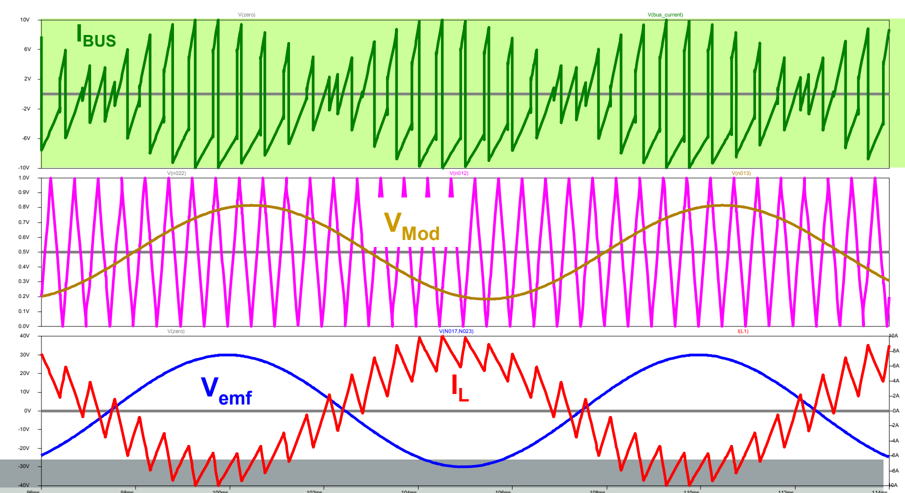




SPICE SIMULATION

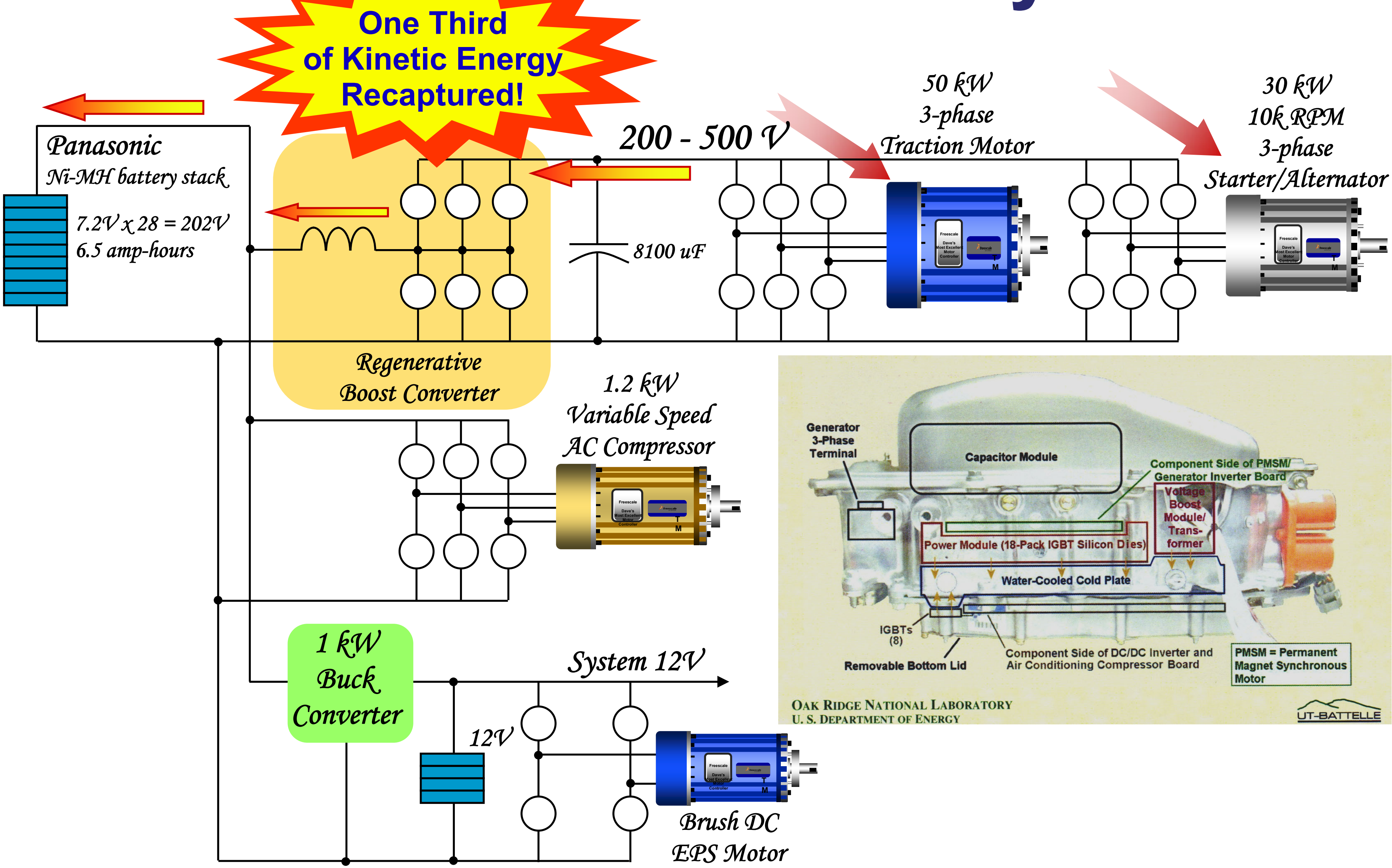


GENERATING
(unity PF)

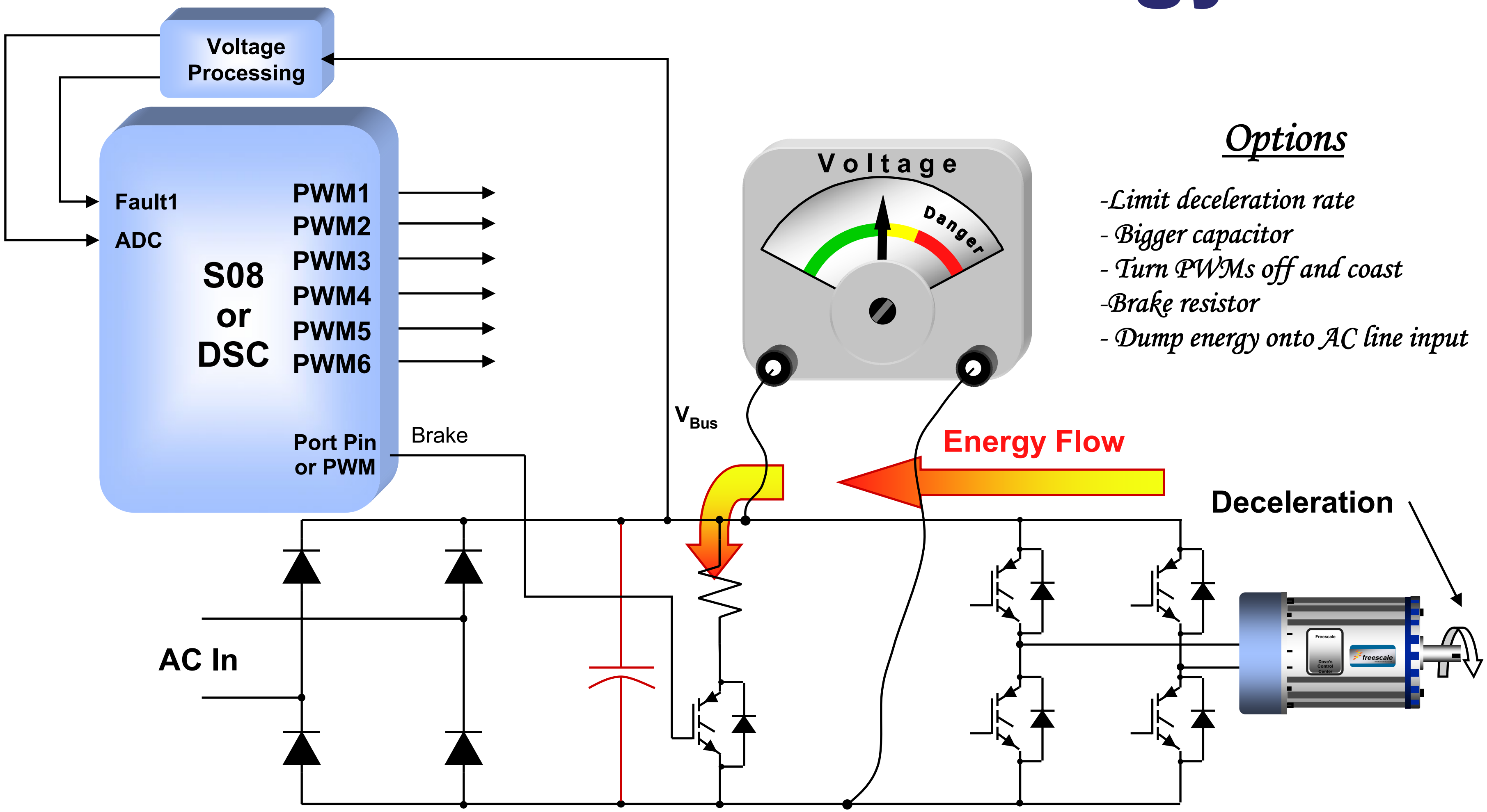


Dave Wilson

Regeneration in Toyota Prius



Where Does the Energy Go?

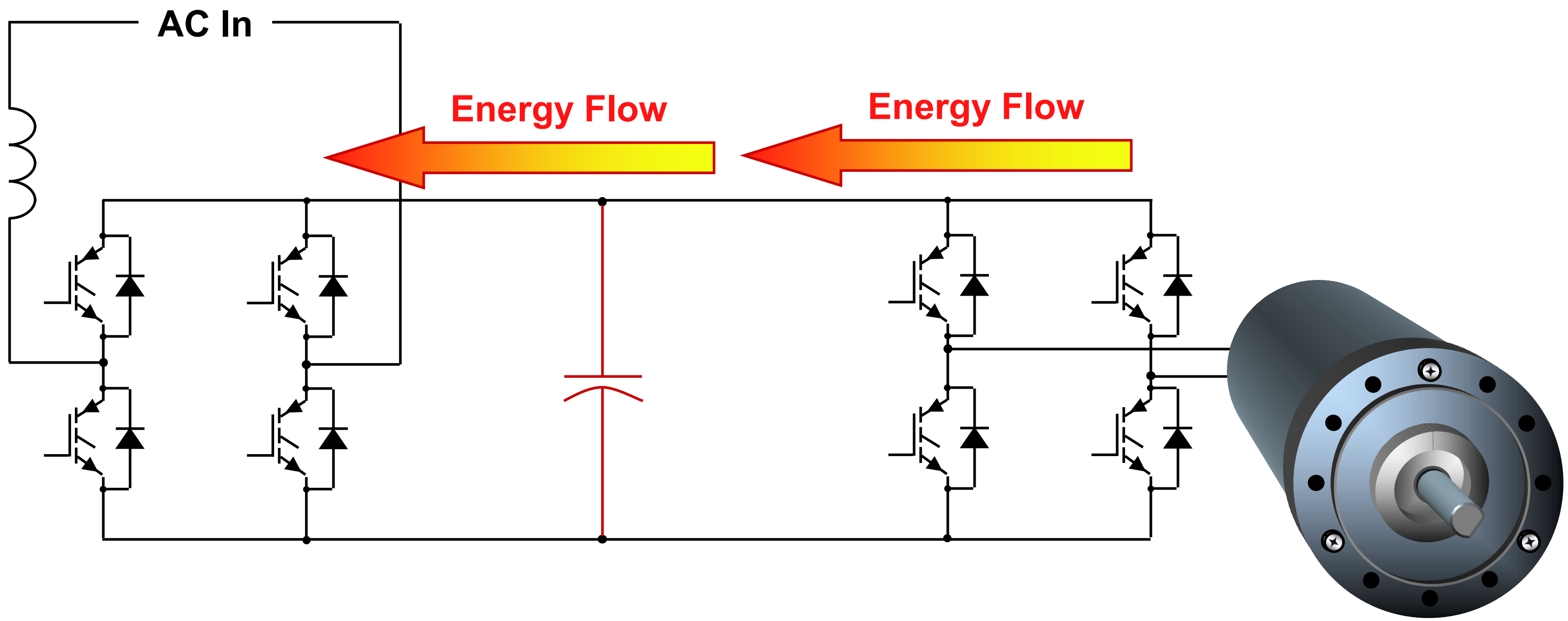


Options

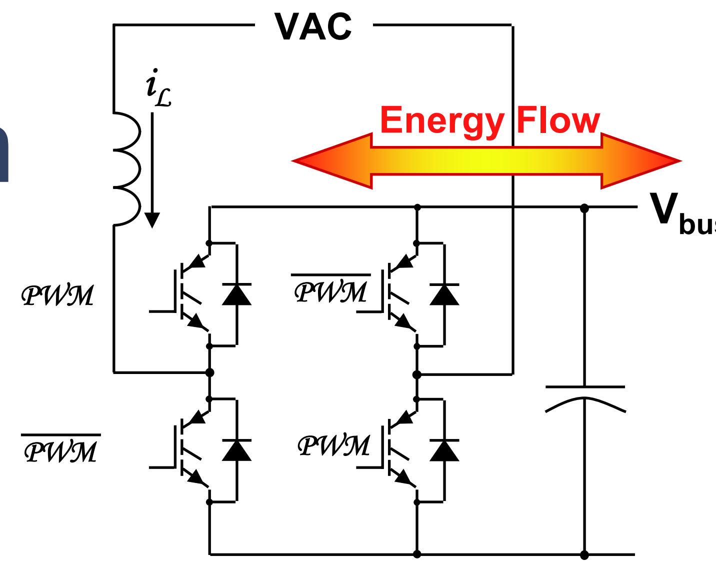
- *Limit deceleration rate*
- *Bigger capacitor*
- *Turn PWMs off and coast*
- *Brake resistor*
- *Dump energy onto AC line input*

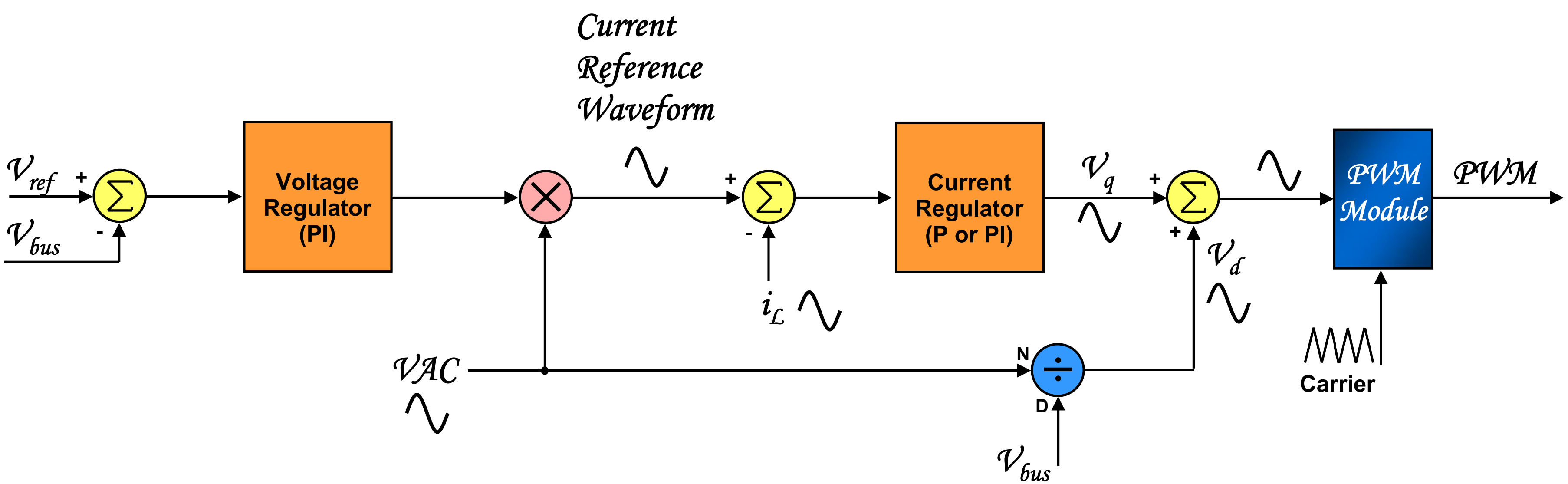
Rectifiers block current flow back on to AC line from the dc bus, thus preventing line regeneration. All motor energy gets dumped in the bus capacitor.

Regeneration to a Single Phase AC Line

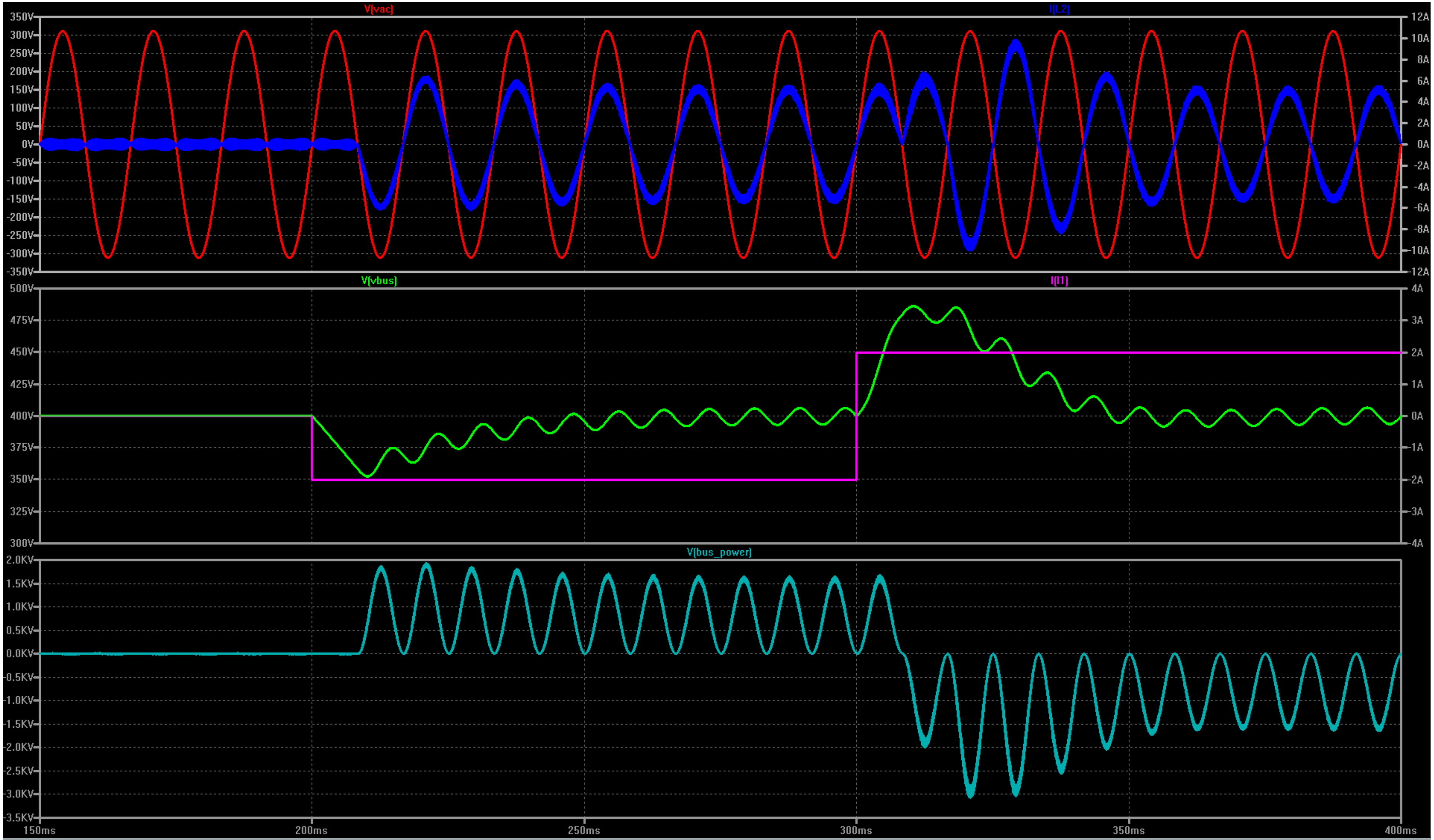


Single Phase AC Line Regeneration

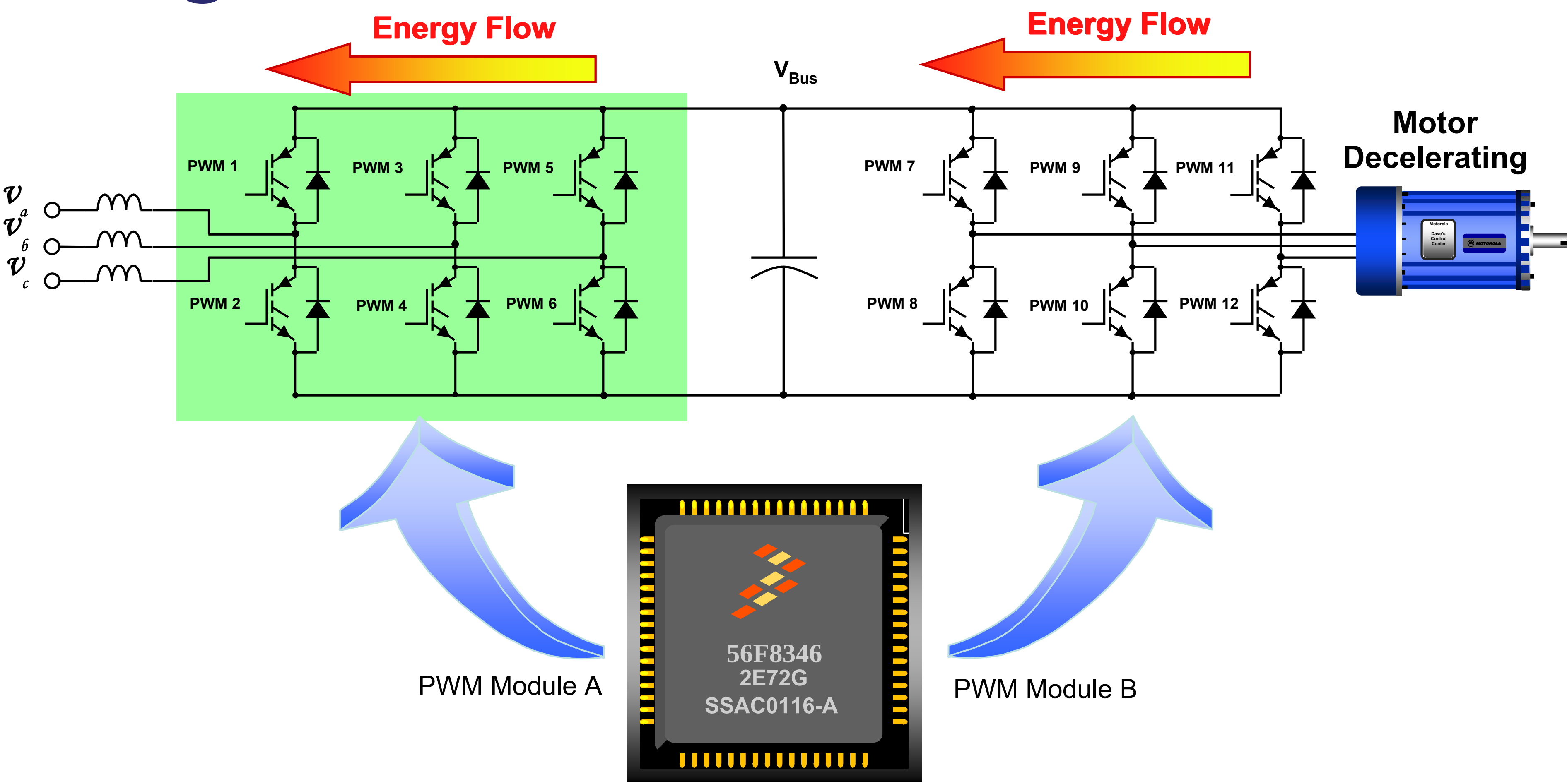




Simulation Results of Single-Phase Regenerative System



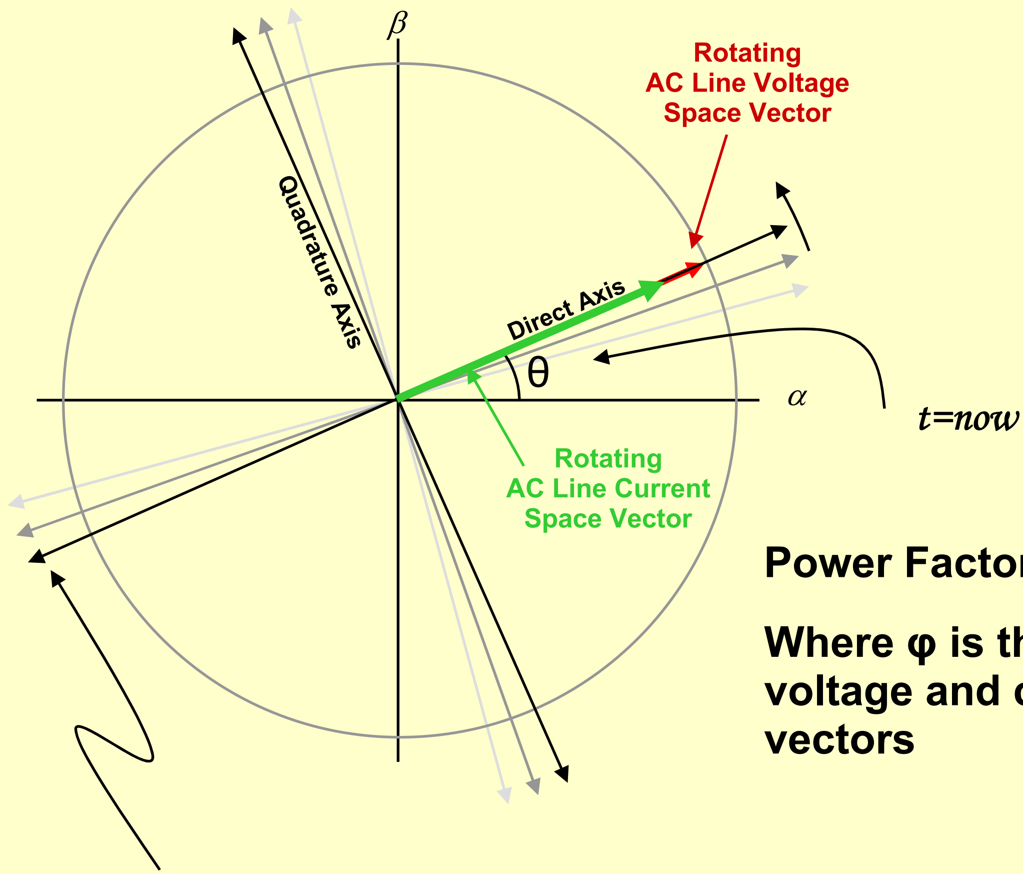
Regeneration to a 3-Phase AC Line

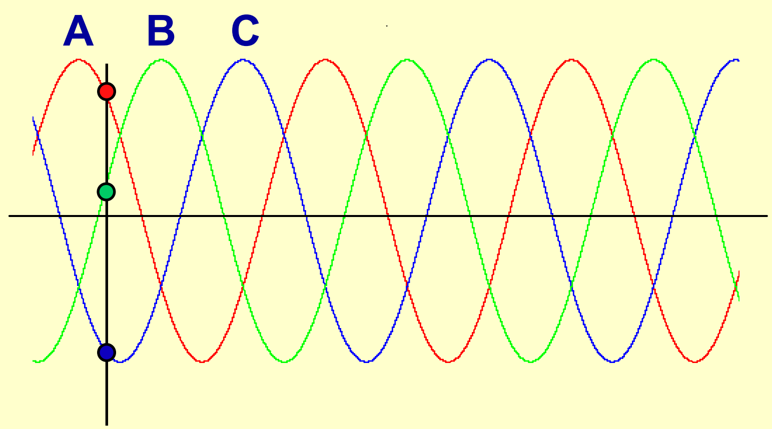


Freescale offers several controller solutions with the required MIPS and peripherals for this application.

D and Q Axes Representation

Field Oriented Techniques applied to three-phase system





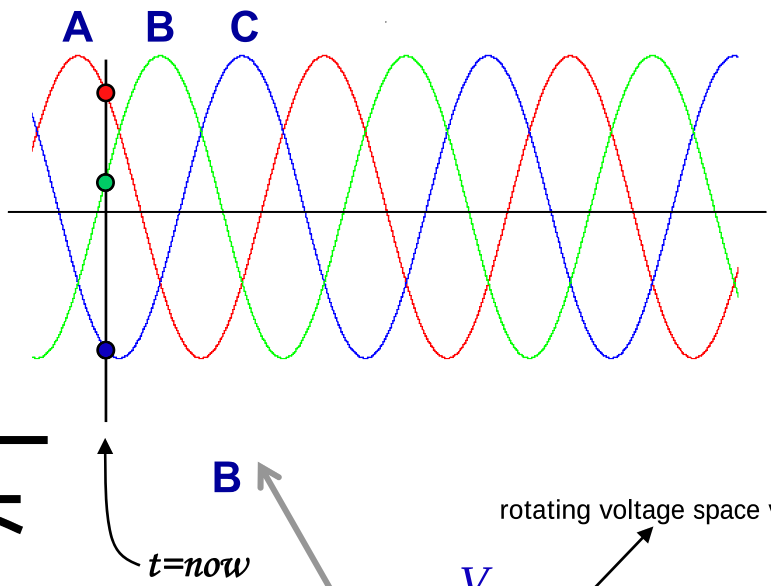
Power Factor = Cos(φ)

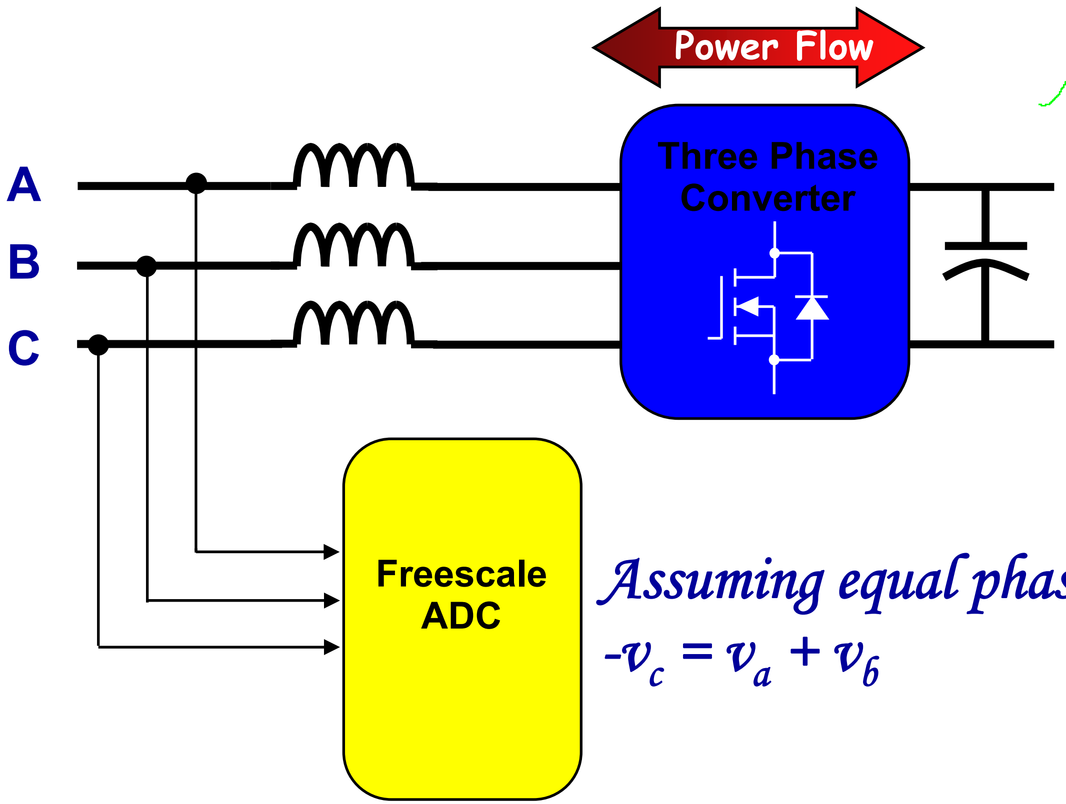
Where φ is the angle between the voltage and current space vectors

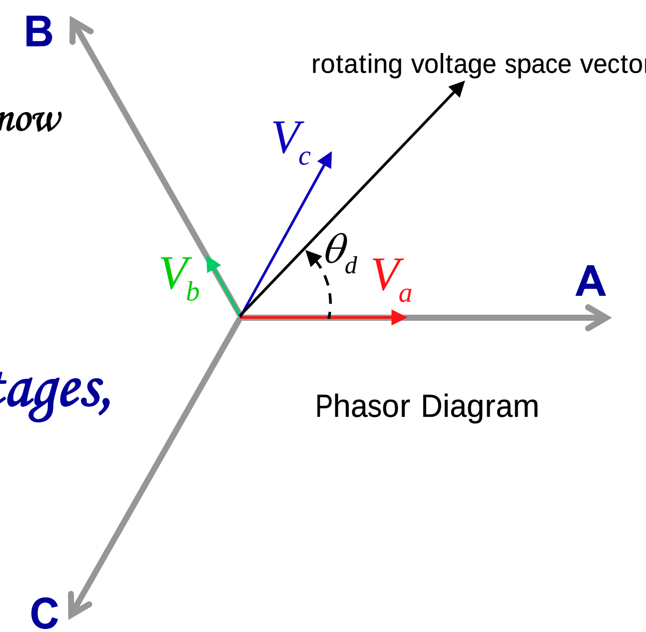
Put current vector on this axis for unity PF.

Step 1: Voltage Measurement

Measure the instantaneous AC line voltages. These scalar values represent the instantaneous magnitudes of the vectors along the A, B, C axes.







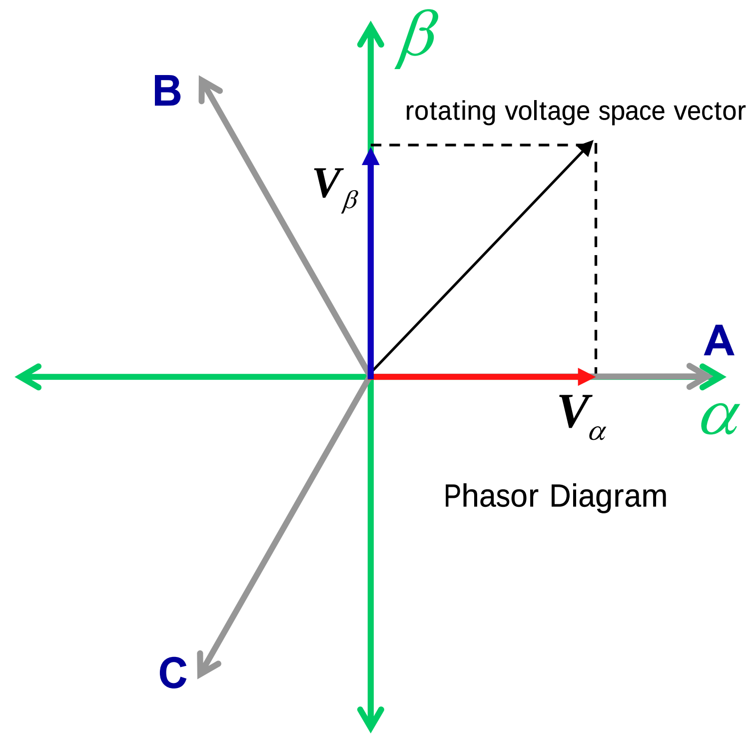
Assuming equal phase voltages,

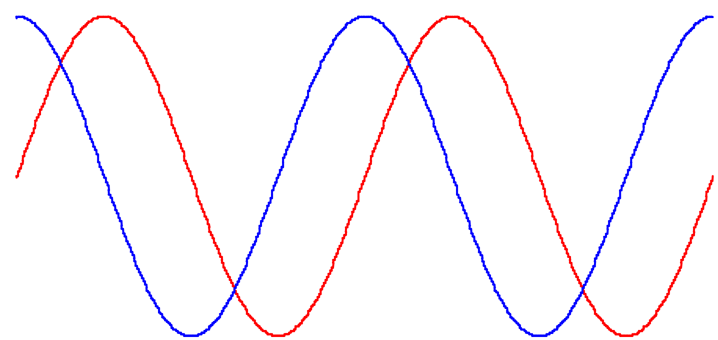
$-v_c = v_a + v_b$

Step 2: 3-phase to 2-phase transformation

$$V_\alpha = \frac{3}{2} V_a$$

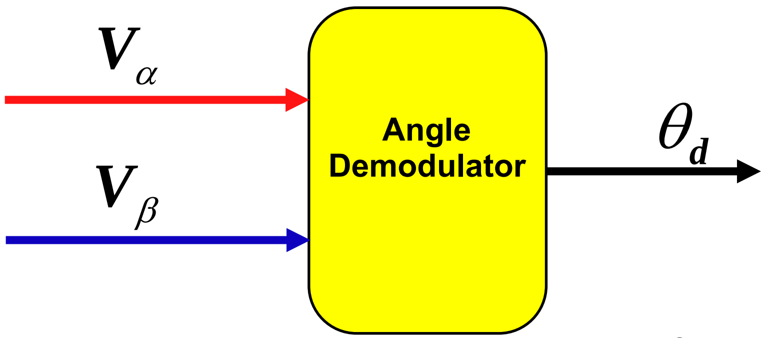
$$V_\beta = \frac{\sqrt{3}}{2} V_b - \frac{\sqrt{3}}{2} V_c$$



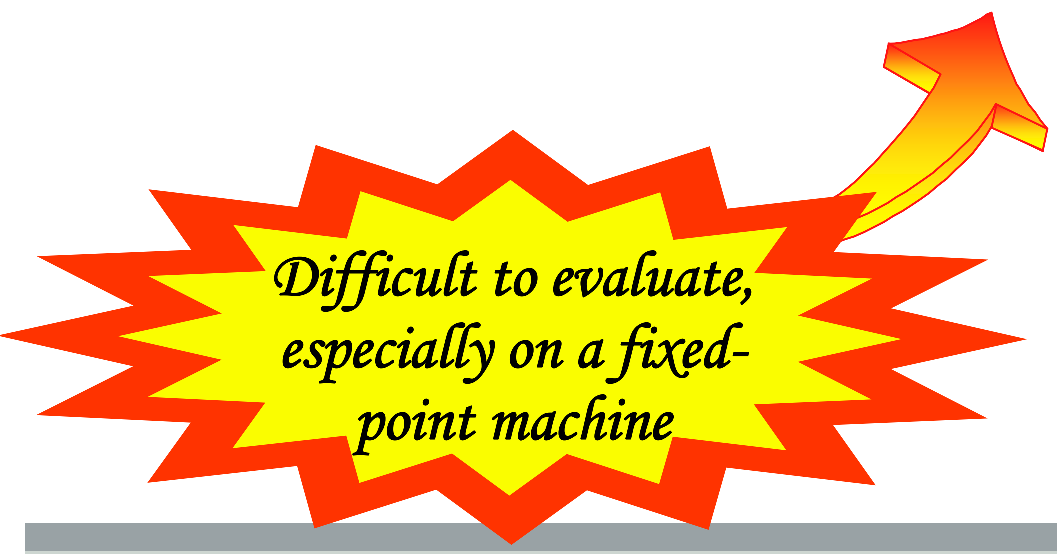


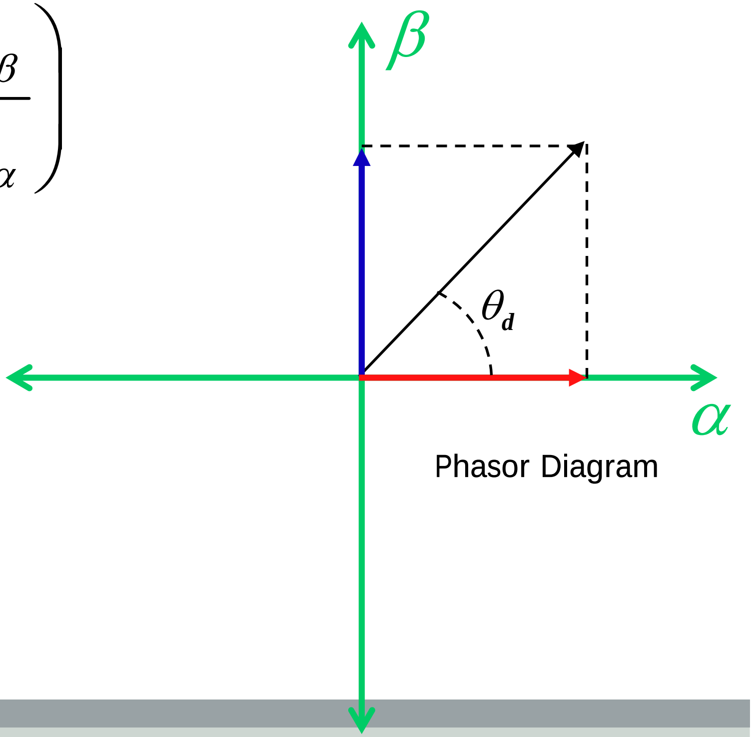
This is sometimes referred to as the FORWARD CLARK transformation

Step 3: Angle Demodulation



$$\theta_d = \tan^{-1}\left(\frac{V_\beta}{V_\alpha}\right)$$

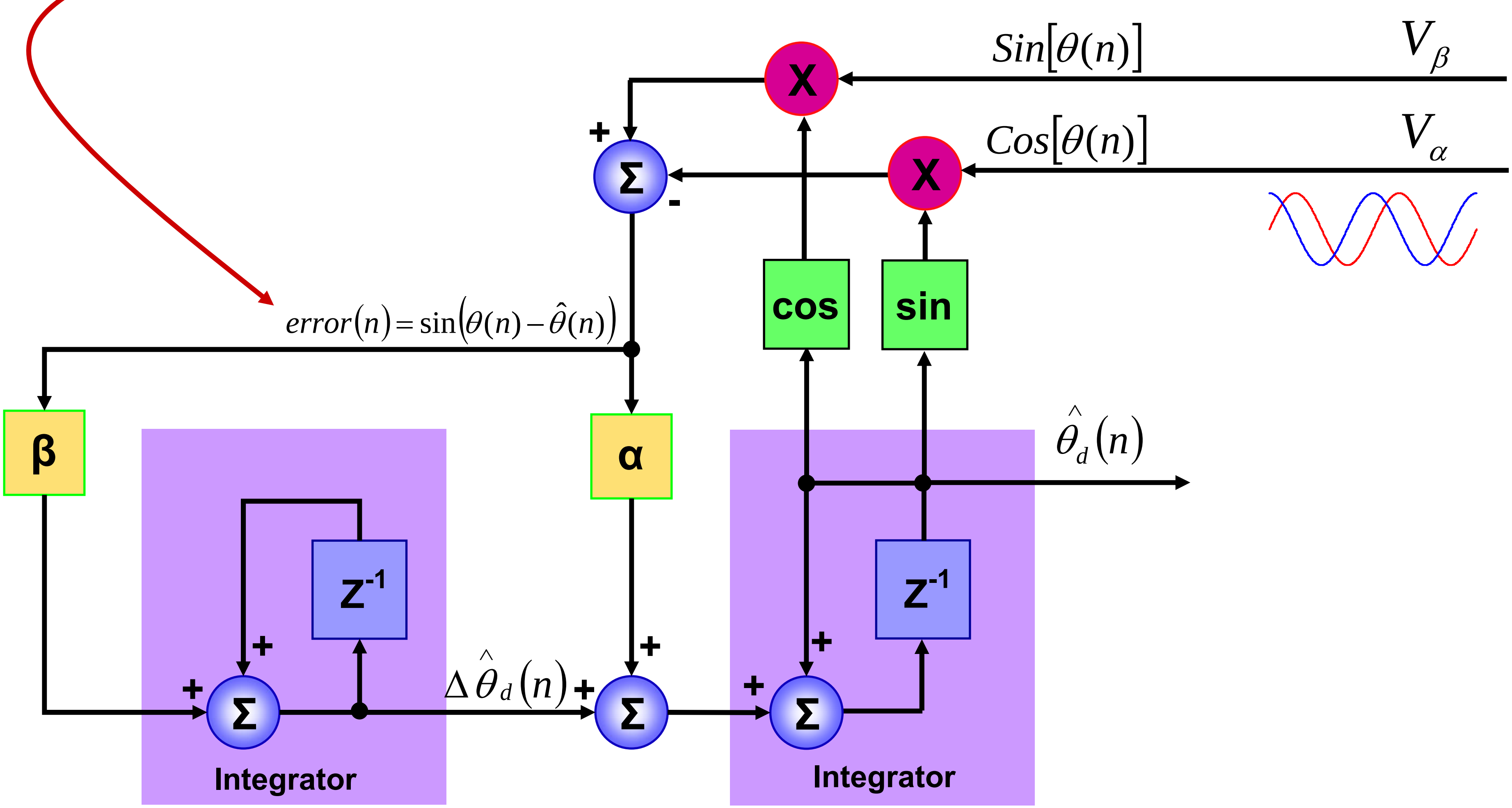




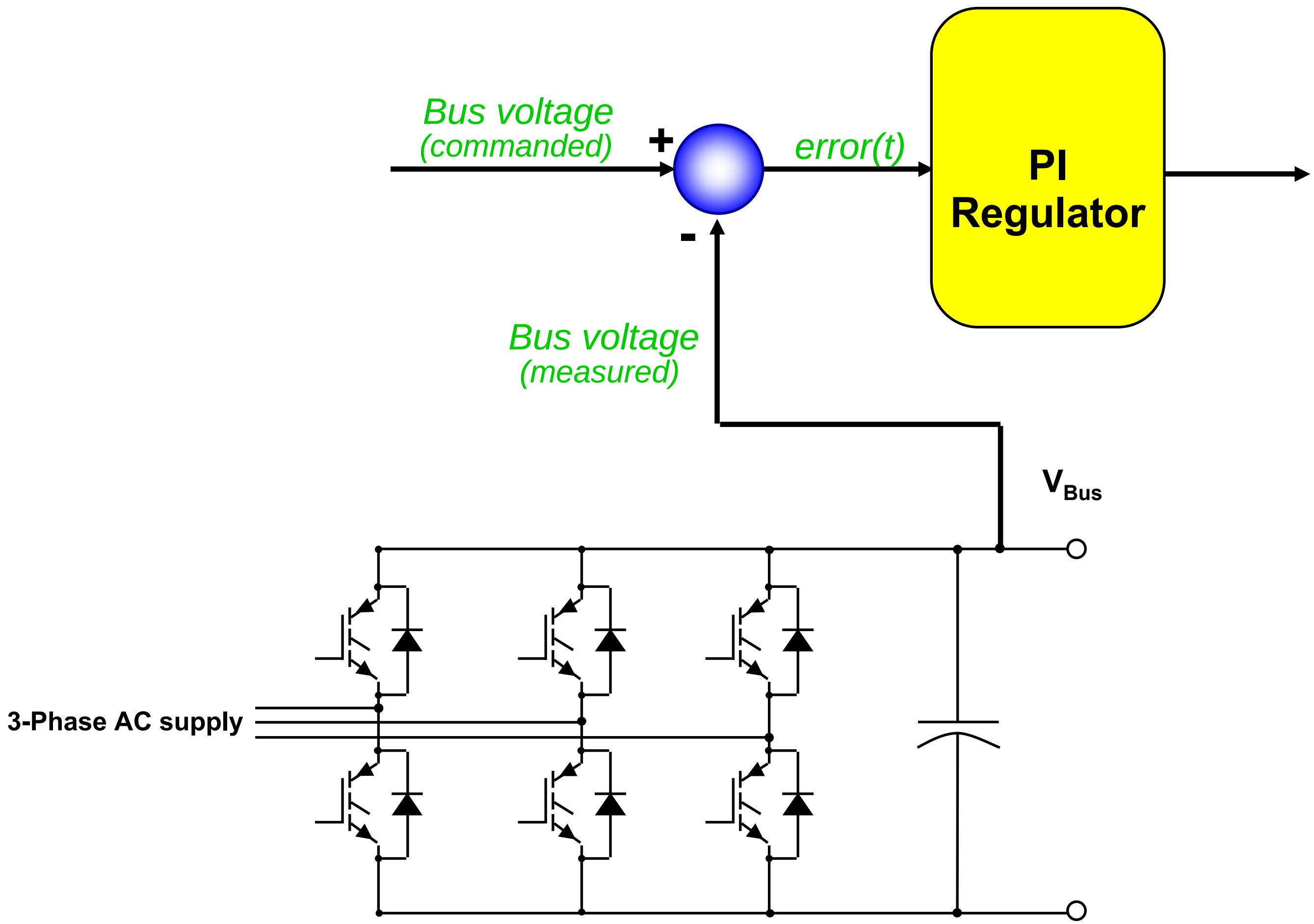
Phasor Diagram

Tracking Filter Used for Angle Demodulation

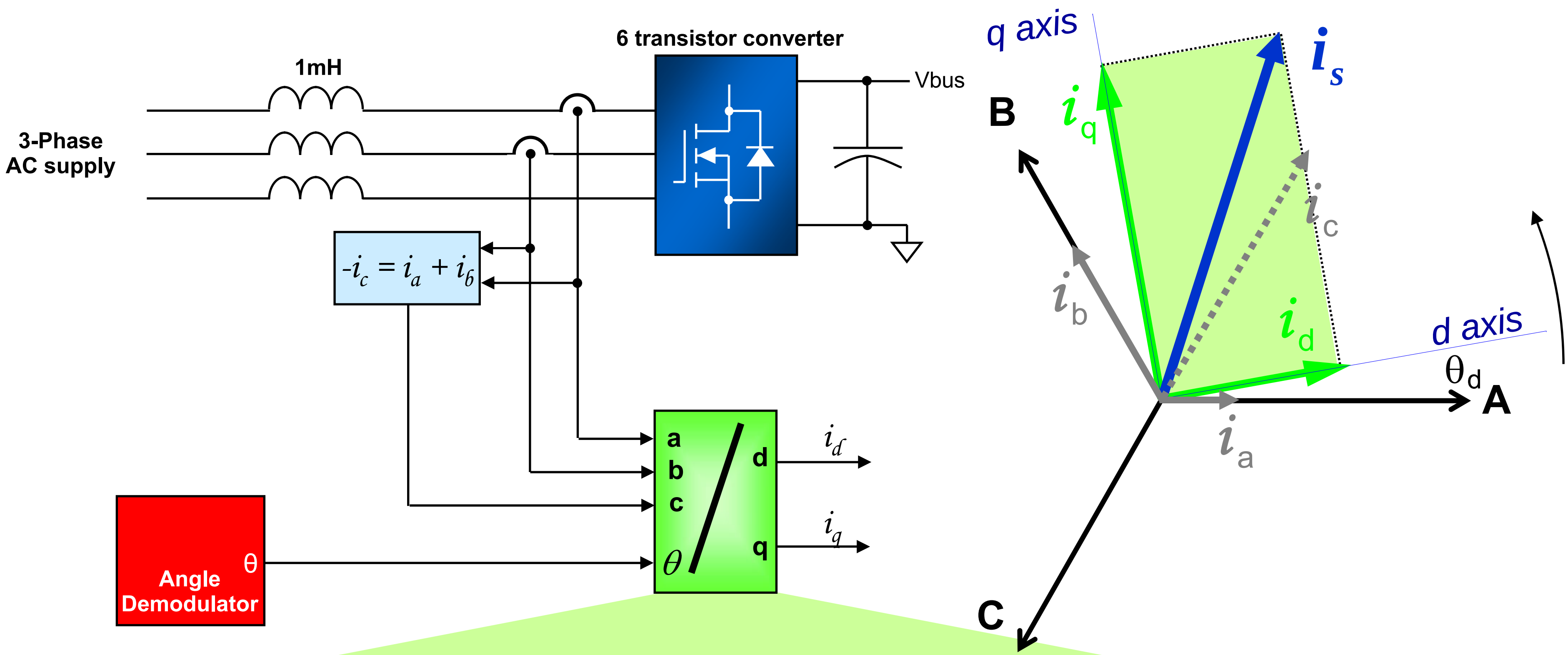
$$\sin\left(\theta(\boldsymbol{n}) - \hat{\theta}(\boldsymbol{n})\right) = \sin(\theta(\boldsymbol{n}))\cos\left(\hat{\theta}(\boldsymbol{n})\right) - \cos(\theta(\boldsymbol{n}))\sin\left(\hat{\theta}(\boldsymbol{n})\right)$$



Step 4: Bus Voltage Regulator



Step 5. Establish i_d and i_q

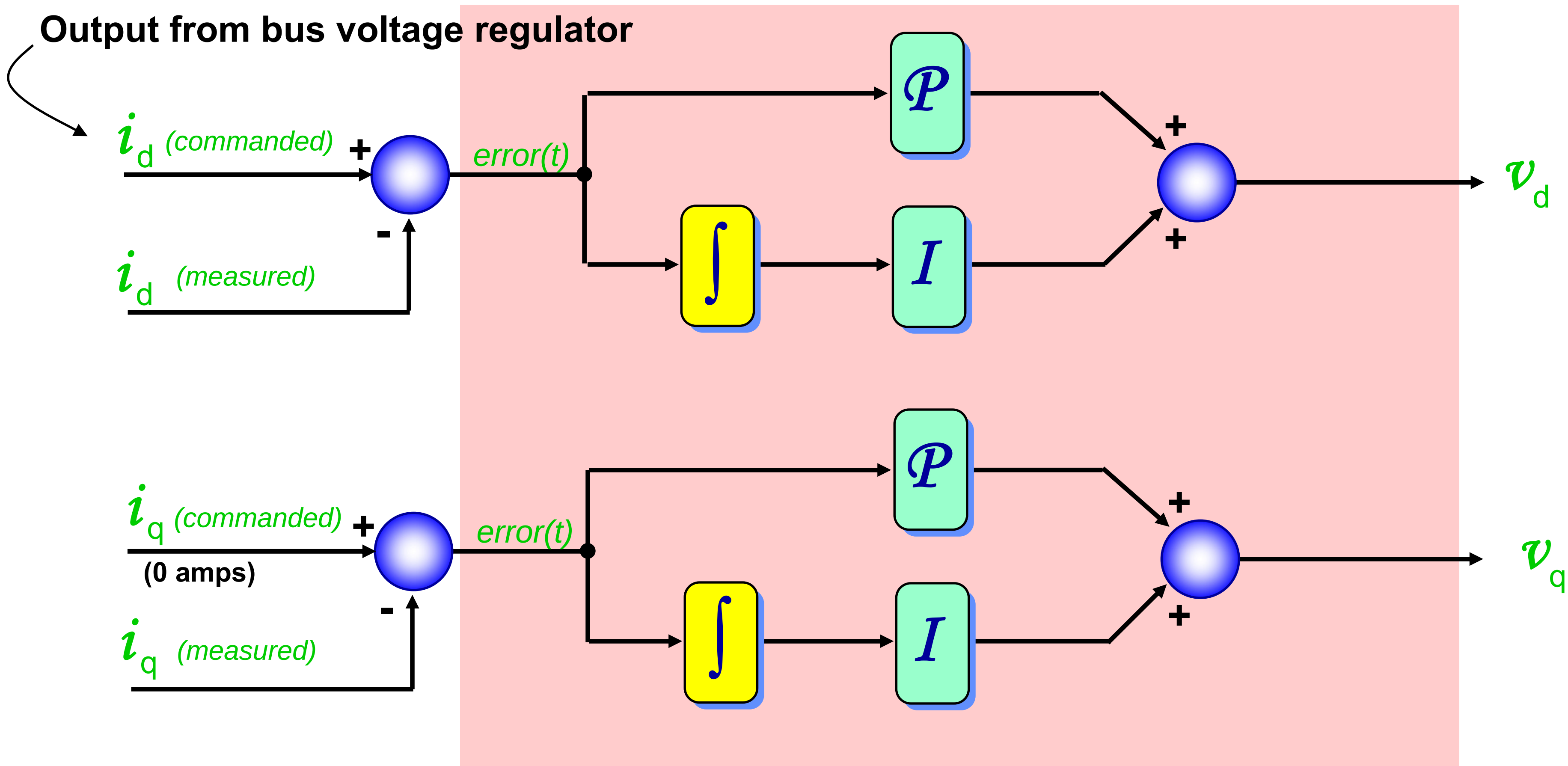


i_d = sqrt(2/3) * (cos(θ)*i_a + cos(θ - 2*π/3)*i_b + cos(θ - 4*π/3)*i_c)

i_q = sqrt(2/3) * (-sin(θ)*i_a - sin(θ - 2*π/3)*i_b - sin(θ - 4*π/3)*i_c)

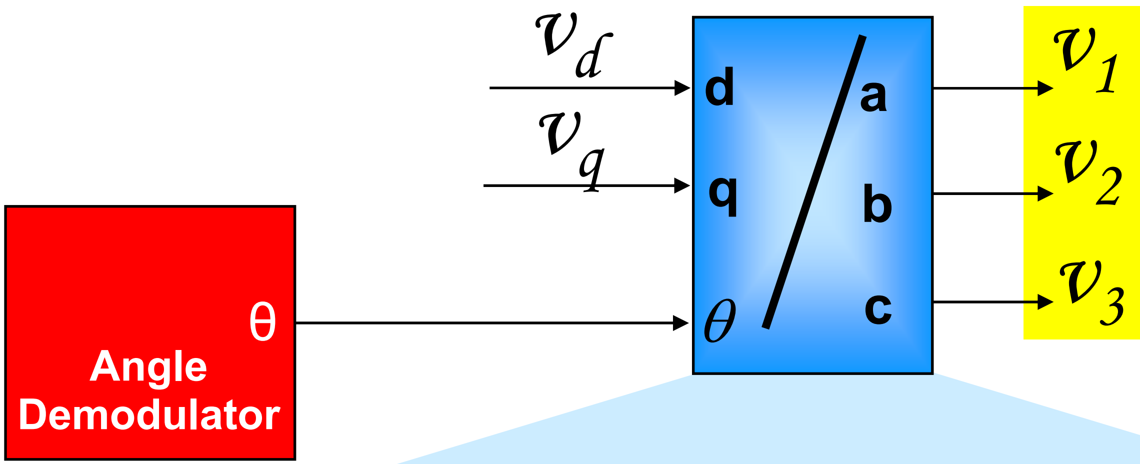
Forward Clark-Park Transformation

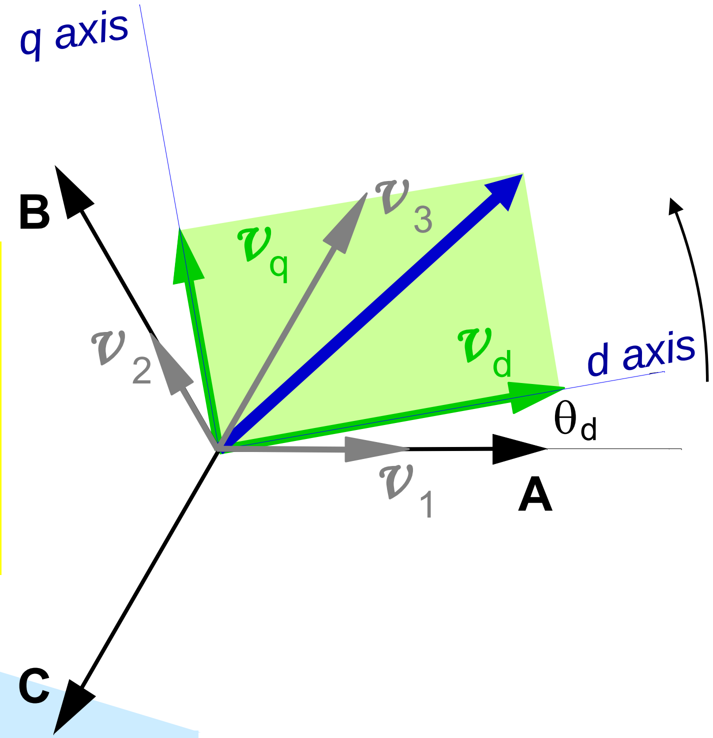
Step 6. Synchronous Frame Current Regulation



P or PI regulators work well.

Step 7: Synchronous to Stationary Frame Transformation





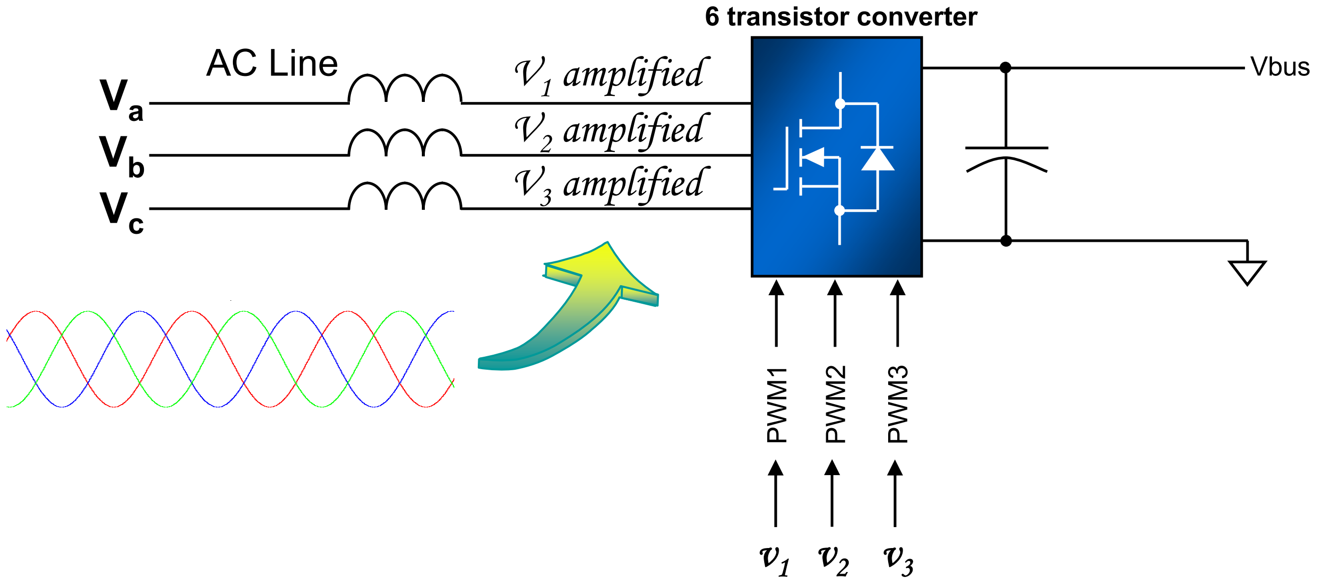
V_1 = sqrt(2/3)*(cos(θ)*V_d - sin(θ)*V_q)

V_2 = sqrt(2/3)*(cos(θ - 2*π/3)*V_d - sin(θ - 2*π/3)*V_q)

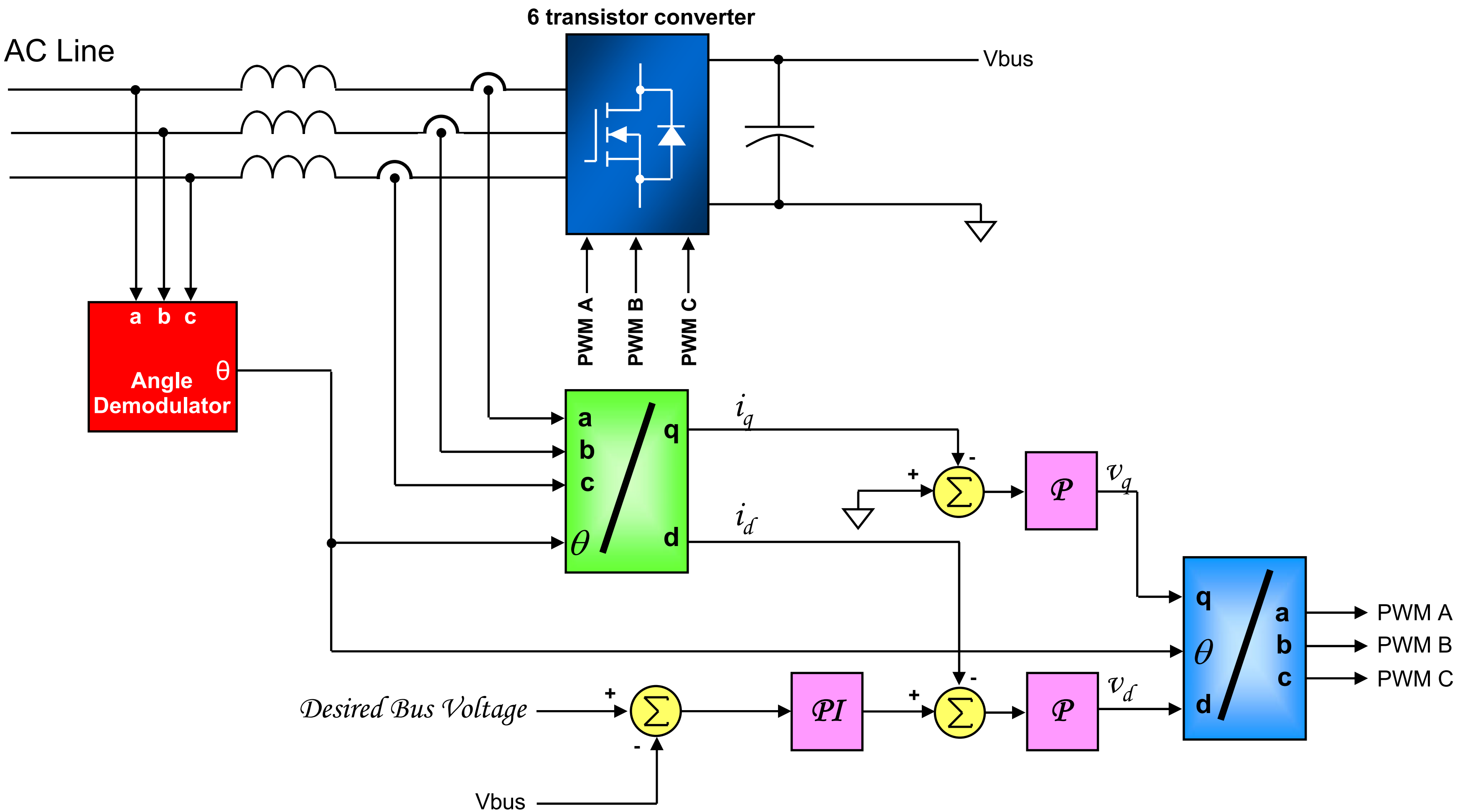
V_3 = sqrt(2/3)*(cos(θ - 4*π/3)*V_d - sin(θ - 4*π/3)*V_q)

Reverse Clark-Park Transformation

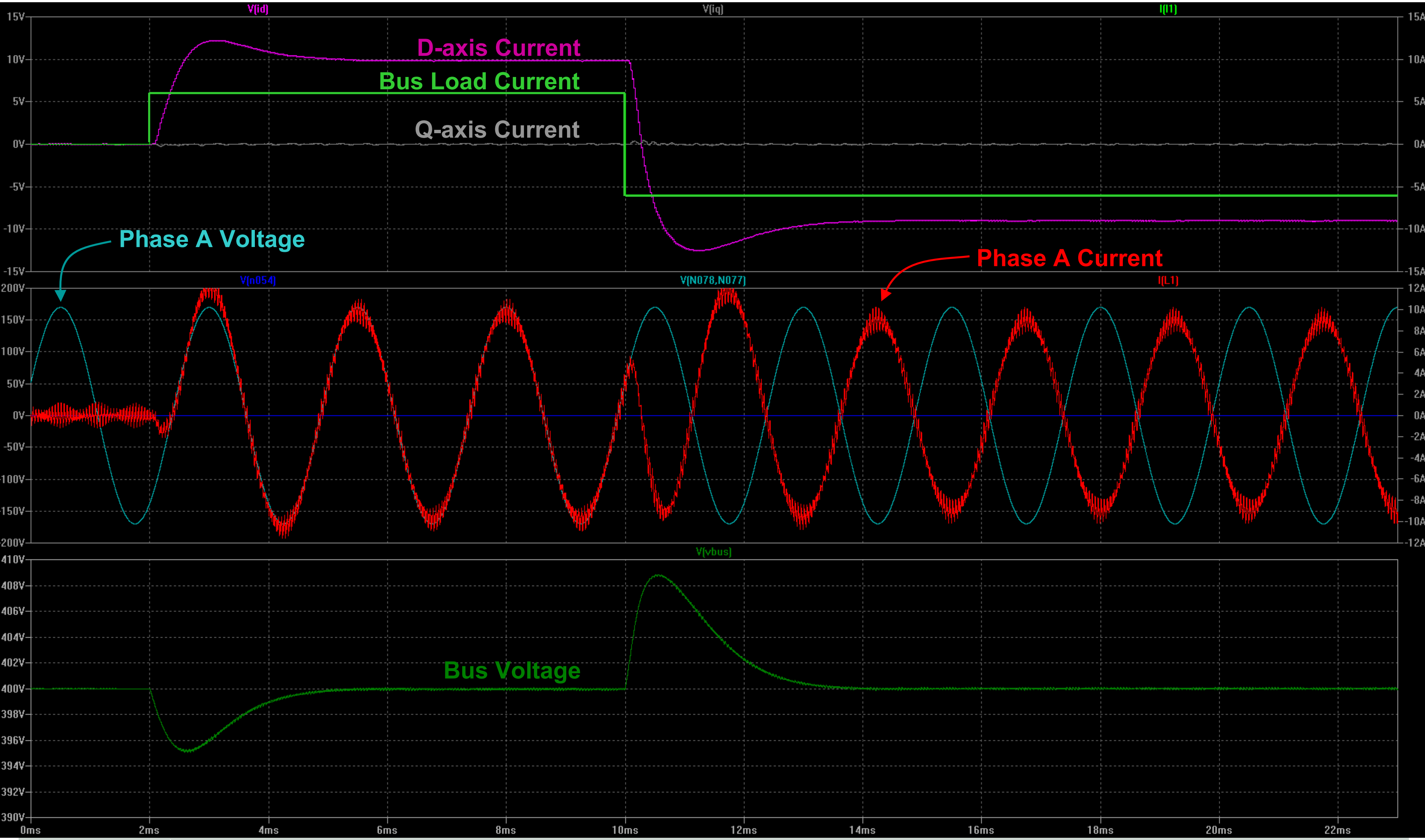
Step 8. Output Voltage Modulation



Three-Phase System Overview



Simulation Results of 3-Phase Regenerative System



Applications

Standby Power Supplies

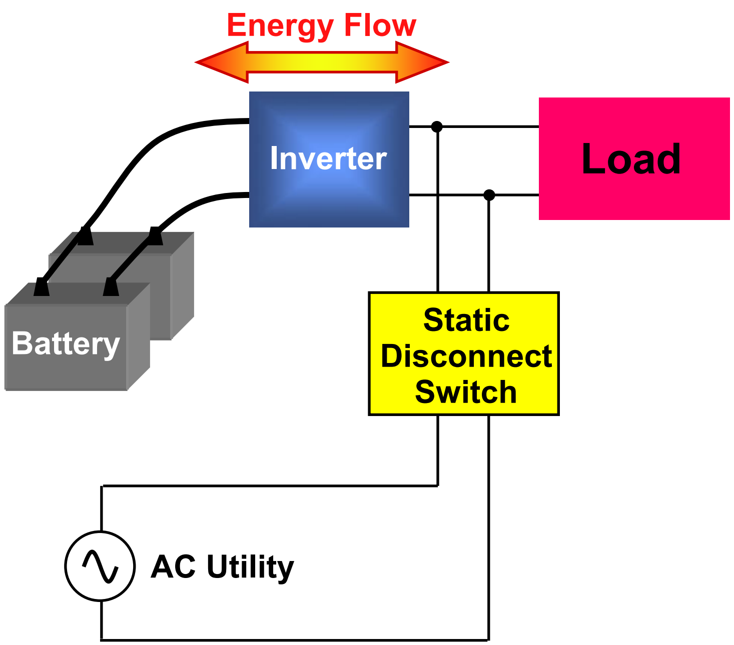
Connecting asynchronous power sources

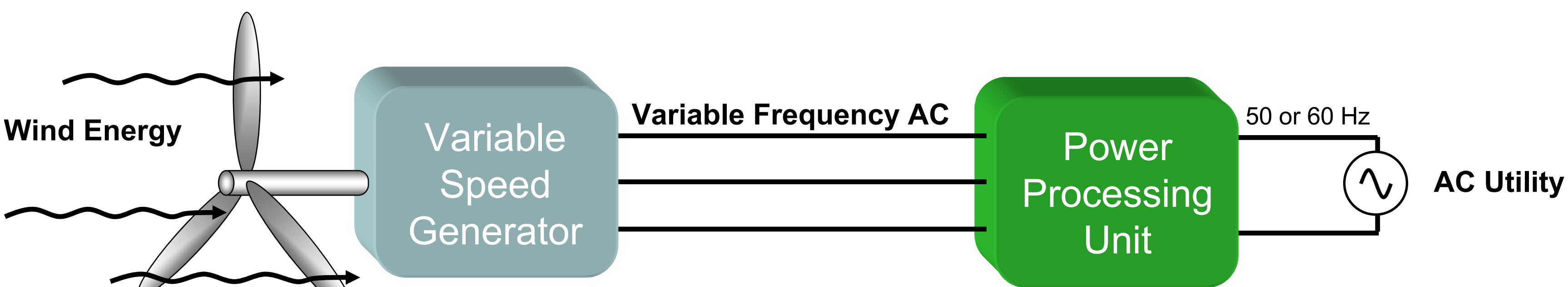
Hybrid vehicles

Combined starter/alternator

Elevator Drives

Driving high inertial loads





High-Performance Power Architecture sockets

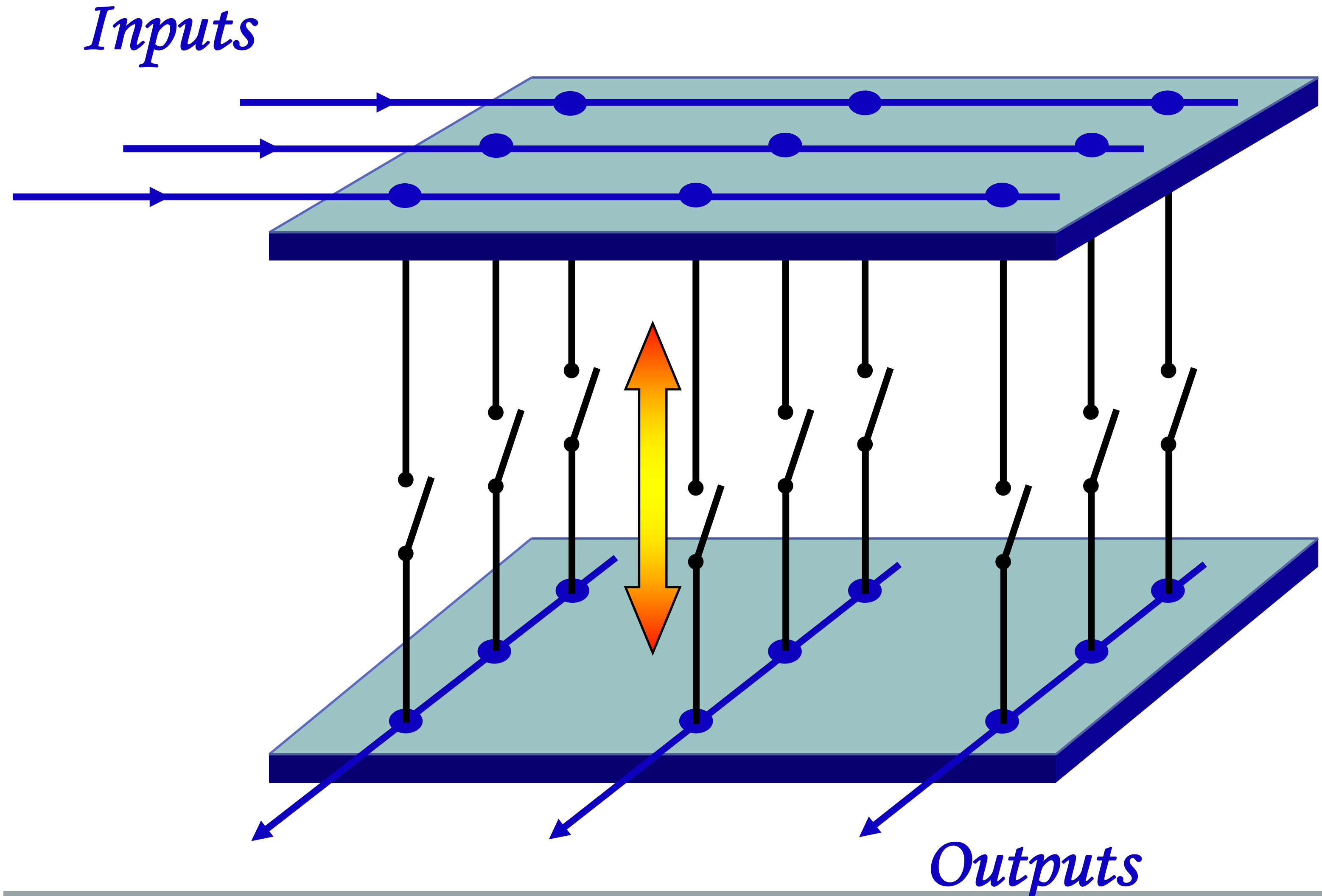
System Benefits

- *Bidirectional control of power*
- *Sinusoidal Currents*
- *Unity Power Factor (or ANY Power Factor for that matter)*
- *Since Vbus is regulated, and currents are sinusoidal, the semiconductor volt-amp ratings are reduced*
- *Vbus is less sensitive to AC line fluctuations*
- *For three-phase AC systems, FOC algorithms can be used for both converter and inverter control*

Matrix Converters

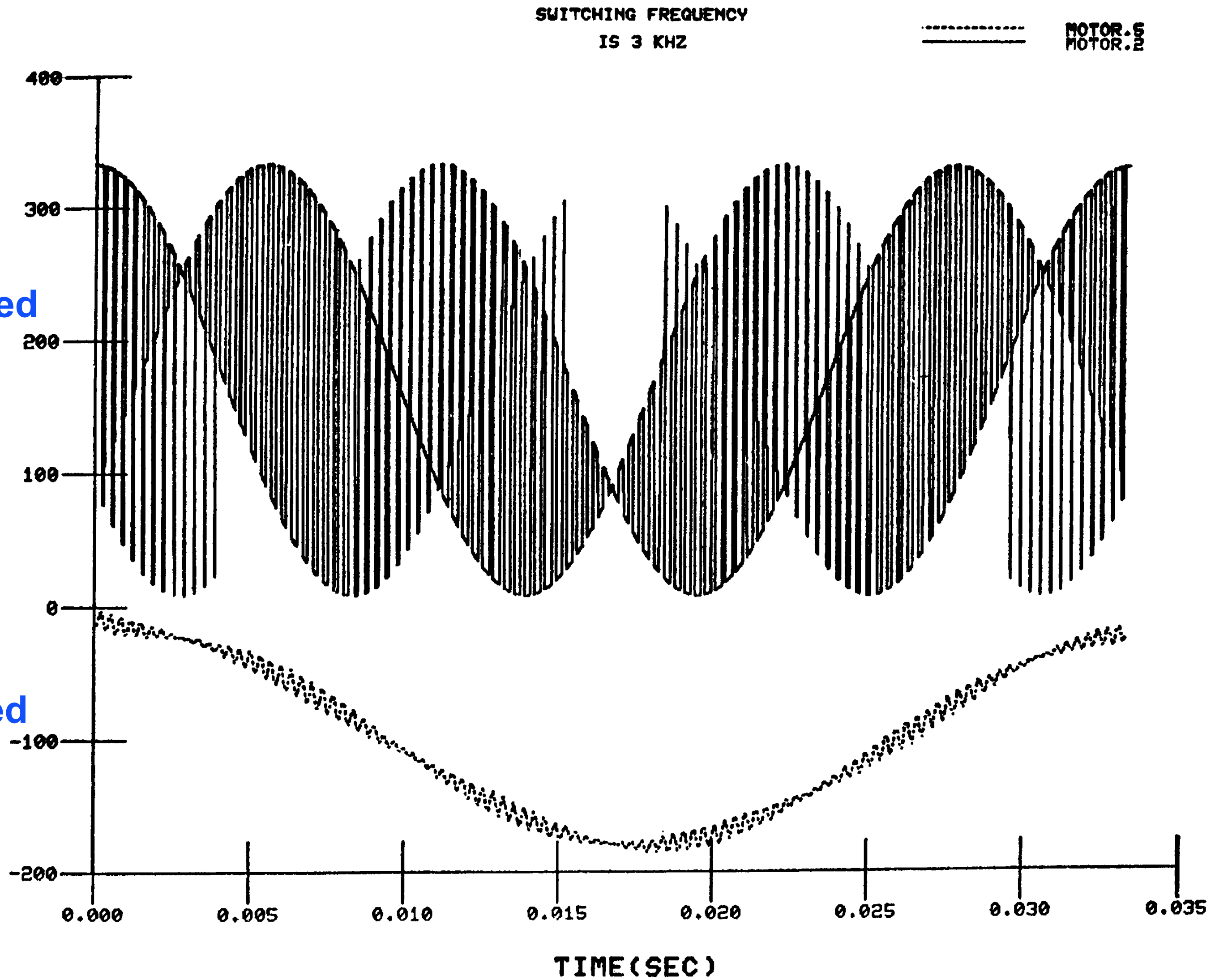
- Direct AC to AC waveform conversion
- No energy storage elements required
- Inherent regeneration to input supply
- Sinusoidal line currents possible
- Unity (or any) power factor is possible

Matrix Converter Topology



Matrix Converter Output Waveform Example

Unfiltered



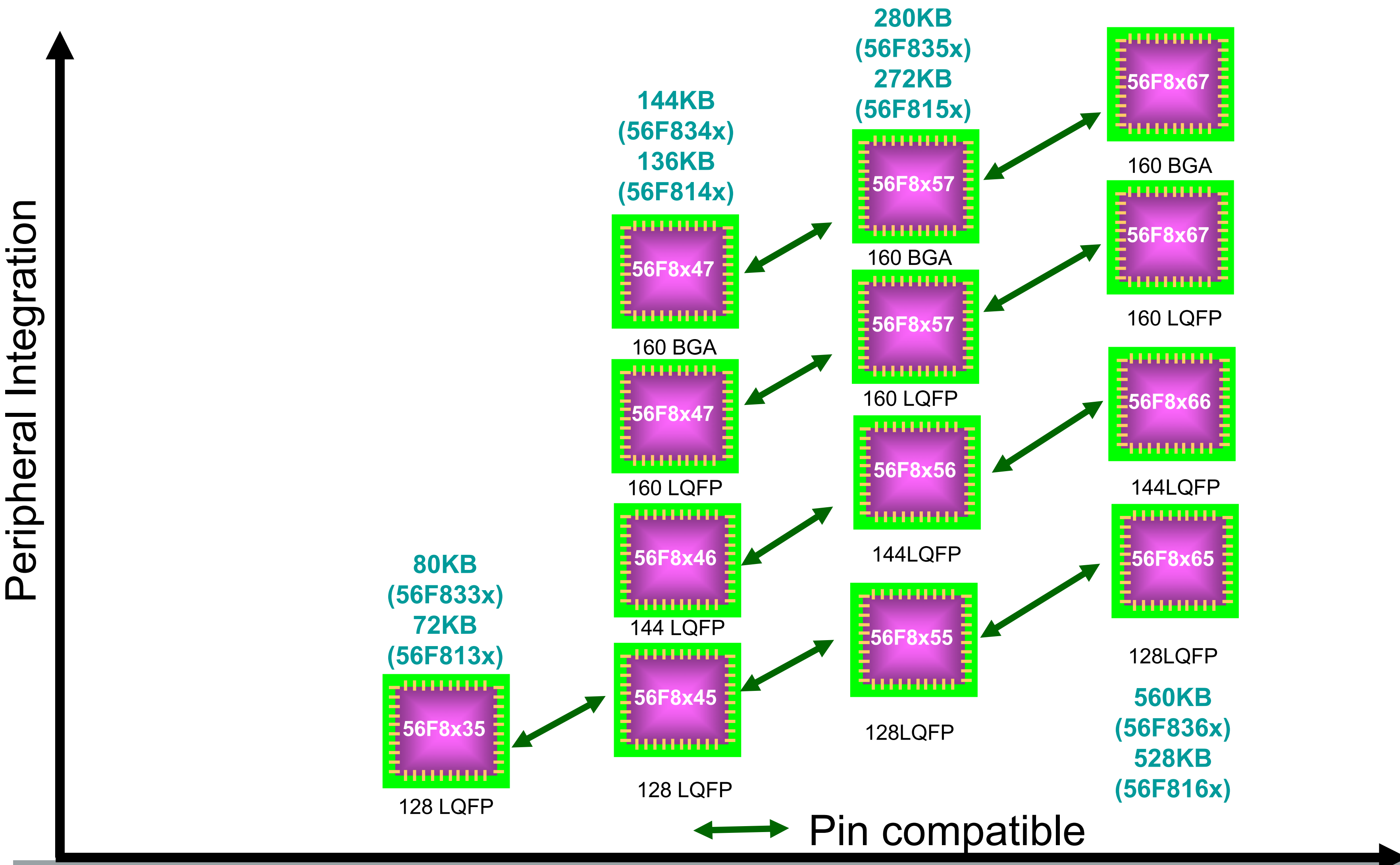
Filtered

Dual Converter-Inverter DSC Solutions

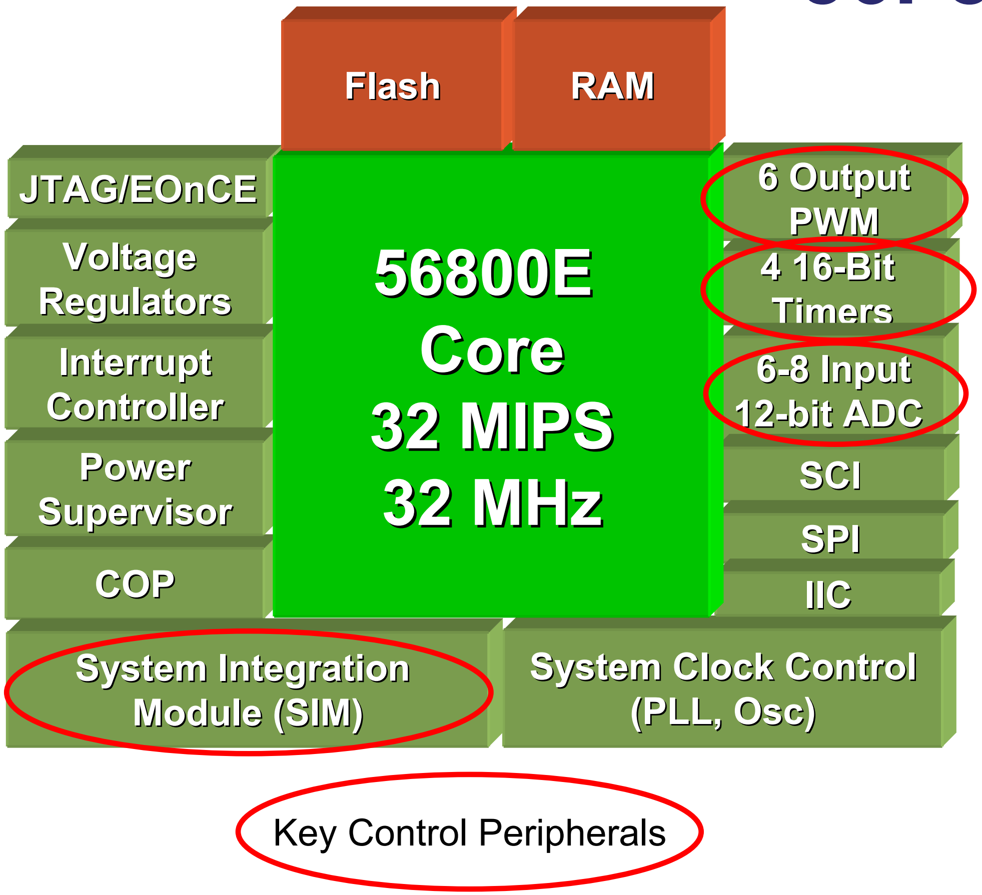
	56F8335	56F8345	56F8346	56F8347	56F8355	56F8356	56F8357	56F8365	56F8366	56F8367
Voltage (Core / I/O)	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V
On-Chip Flash	80KB	144KB	144KB	144KB	280KB	280KB	280KB	560KB	560KB	560KB
Program Flash	64KB	128KB	128KB	128KB	256KB	256KB	256KB	512KB	512KB	512KB
Data Flash	8KB	8KB	8KB	8KB	8KB	8KB	8KB	32KB	32KB	32KB
Boot Flash	8KB	8KB	8KB	8KB	16KB	16KB	16KB	32KB	32KB	32KB
On-Chip RAM	12KB	12KB	12KB	12KB	20KB	20KB	20KB	36KB	36KB	36KB
Program RAM	4KB	4KB	4KB	4KB	4KB	4KB	4KB	4KB	4KB	4KB
Data RAM	8KB	8KB	8KB	8KB	16KB	16KB	16KB	32KB	32KB	32KB
Flash security	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ext. Memory Interface	-	-	Yes	Yes	-	Yes	Yes	-	Yes	Yes
On-Chip Relax. Osc.	Yes	No	No	No	No	No	No	No	No	No
16-bit Timers	16	16	16	16	16	16	16	16	16	16
Quadrature Decoder	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch
PWM	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch
PWM Fault Input	4 + 4	4 + 4	3 + 4	3 + 4	4 + 4	3 + 4	3 + 4	4 + 4	3 + 4	4 + 4
PWM Current Sense	3 + 3	3 + 3	3 + 3	3 + 3	3 + 3	3 + 3	3 + 3	3 + 3	3 + 3	3 + 3
12-bit ADC	4 x 4ch	4 x 4 ch	4 x 4 ch	4 x 4 ch	4 x 4ch	4 x 4ch	4 x 4ch	4 x 4 ch	4 x 4ch	4 x 4ch
Temperature Sensor	Optional	Optional	Optional	Optional	Optional	Optional	Optional	Optional	Optional	Optional
CAN	FlexCAN	FlexCAN	FlexCAN	FlexCAN	FlexCAN	FlexCAN	FlexCAN	FlexCAN (2)	FlexCAN (2)	FlexCAN (2)
SCI (UART)	2	2	2	2	2	2	2	2	2	2
SPI (Synchronous)	2	2	2	2	2	2	2	2	2	2
GPIO (Ded./Shrd/Tot)	21 / 28 / 49	21/ 28 / 49	0 / 62 / 62	0 / 76 / 76	21 / 28 / 49	0 / 62 / 62	0 / 76 / 76	21 / 28 / 49	0 / 62 / 62	0 / 76 / 76
JTAG/EOnCE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Package	128LQFP	128LQFP	144LQFP	160LQFP	128LQFP	144LQFP	160LQFP	128LQFP	144LQFP	160LQFP

All devices are 60 MHz, (-40, +125)°C

56F8300 Pin Compatibility



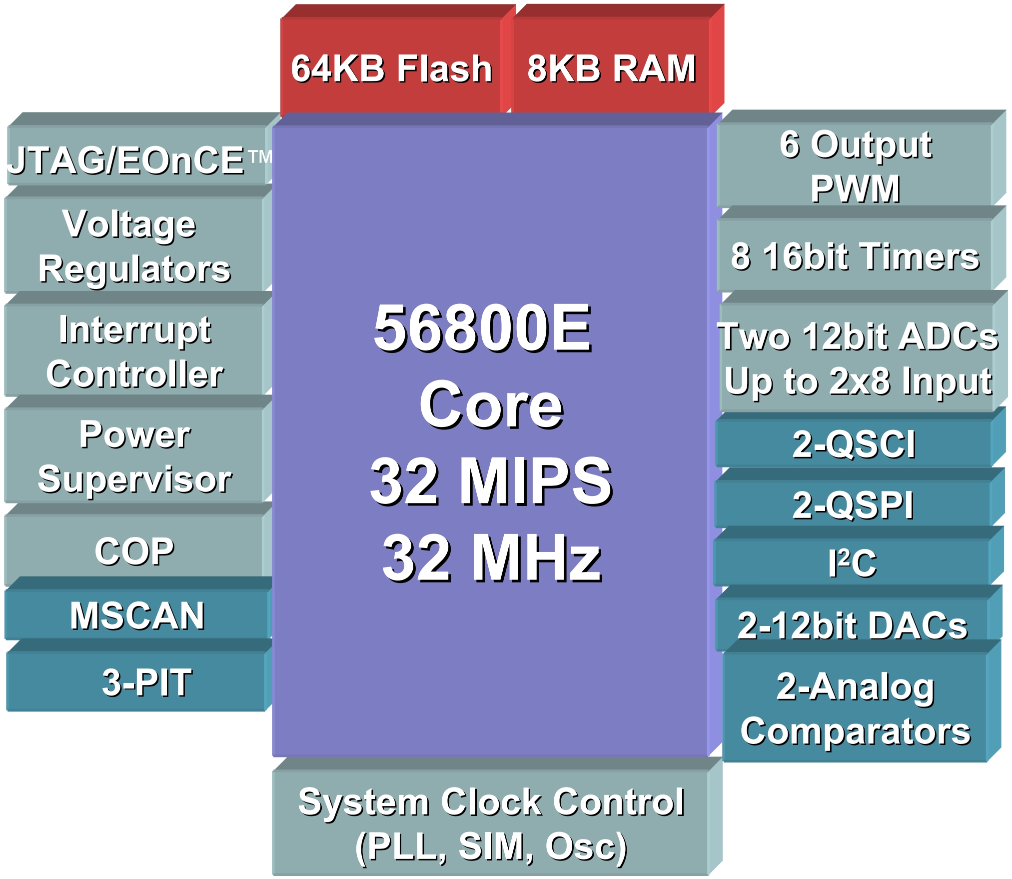
Cost Effective 56F8000 Solutions 56F8011/56F8013/56F8014



- 32 MIPS Performance
- 16 K Bytes Program FLASH
- 4 K Bytes Program/Data RAM
- Tunable Internal Relaxation Oscillator
- Software Programmable Phase Locked Loop
- **Up to 96 MHz Peripherals – Timers and PWMs**
- Up to 6-Output PWM Module with up to 4 Programmable Fault Inputs
- **Selectable PWM frequency for each complementary PWM signal pair**
- **Two 12-bit ADCs with up to 8 Inputs , 1.125us conversion rate**
- Synchronization between PWM and ADC
- Four 16-bit General Purpose Programmable Timers
- Computer Operating Properly Timer
- Serial Ports: SCI, SPI, I2C
- **Up to 26 GPIOs – Versatile pin usage**
- Low Power Consumption – 59mA Max and .026mA Min
- JTAG/EOnCE™ Debug Port
- **MSRP starting at $2.92 for 1K units**

•Packages: 32LQFP

56F8000 Family Expansion
56F8023/56F8025/56F8036/56F8037 Features

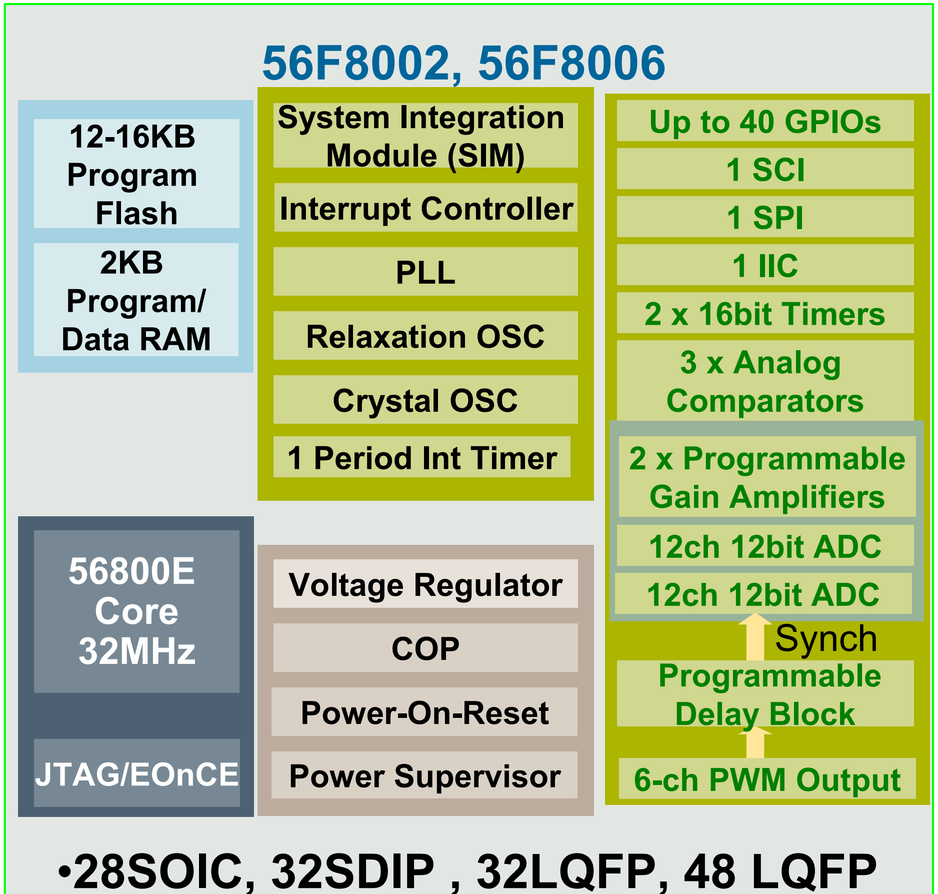


- 32 LQFP 44QFP
- 48LQFP 64LQFP

New or Improved

- 32 MHz/32 MIPS 56800E Core
- 3.0-3.6V Operation
- 32K-64K Bytes Program FLASH
- 4K-8K Bytes Program/Data RAM
- Flash security
- Tunable Internal Relaxation Oscillator
- Software Programmable Phase Locked Loop
- Up to 96 MHz Peripherals – Timers and PWMs
- 6 Output PWM Module with 4 Programmable Fault Inputs
- 2-12-bit ADCs for 6-8 Inputs w/ Int. or External Vref
- **Up to 2 12-bit Digital to Analog Converters**
- **2 - Analog Comparators**
- Synchronization between PWM and ADC
- 4 or 8 16-bit General Purpose Programmable Timers
- **1 or 3 Programmable Interval Timers**
- Computer Operating Properly Timer
- **2-Queued Serial Communications Interface**
- **2-Queued Serial Peripheral Interface**
- **Optional MSCAN**
- I²C Communications Interface
- Up to 53 GPIOs
- JTAG/EOnCE™ Debug Port
- 4 Lead Free Packages
- Up to -40 to 125C temperature range
- MSRP starting at $3.30 for 1K units

Anguilla White : Ultra Low cost Product: 56F8002, 56F8006



- 32 MHz/32 MIPS 56800E Core
- 1.8-3.6V Operation
- 12K - 16K Bytes Program FLASH with Flash security
- 2K Bytes Program/Data RAM
- Tunable Internal Relaxation Oscillator and 32KHz clock
- Phase Locked Loop (PLL)
- **Up to 96 MHz Peripherals – Timers, PWM & Hi-SCI**
- **6 Output PWM Module with 4 Programmable Fault Inputs**
  - **Programmable Dead timer insertion**
  - **Programmable PWM generation for Power supply apps**
  - **Multiple PWM Frequency outputs**
- **Two Programmable Gain Amplifiers with x2, x4, x8, x16 gains (Clocked in order to cancel input offset)**
- Two 12-bit ADCs with up to 24 Inputs , 2.5us Per conversion
- **Programmable Delay Block provides precise control of ADC/PGA sample times relative to PWM reload cycles**
- Three High Speed Analog Comparators
- 2 multiple function Programmable Timers
- Computer Operating Properly Timer
- One Periodic Interval Timer (PIT)
- 1 High Speed Serial Communication Interface (Hi-SCI)
- 1 Serial Peripheral Interface (SPI)
- I^2C Communications Interface
- Up to 40 GPIOs – Versatile pin usage
- JTAG/EOnCE™ Debug Port
- Lead Free “Green” Packages
- Industrial temp: -40C – 105C

Sampling Now!
MSRP is $1.50 in 10K quantities!

Pictus: MPC560xP

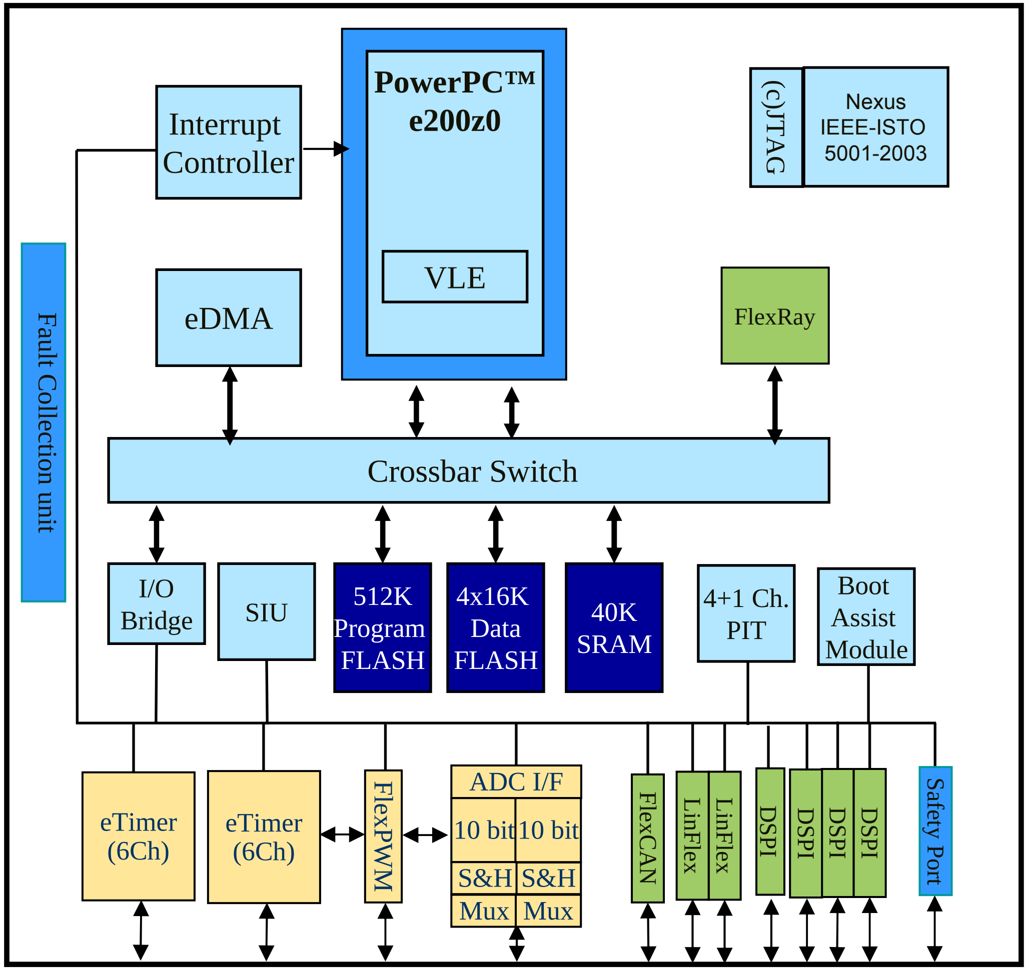
Core
- up to 60 MHz PowerPC ISA e200 zen0h core (64MHz at 105oC)

Memory
- 192k to 512k byte Program Flash with ECC
- 4x16k byte Data Flash with ECC
- 12k to 40k byte SRAM with ECC

I/O
- 1 x FlexCAN with 32MB
- 1 x Safety port (can be used as additional FlexCAN - 32MB)
- 1 x FlexRay Dual Channel with 32MB
- 2 x LinFlex
- 4 x DSPI (4 independent chip selects each)
- 1 x FlexPWM (4x3 channels with 4 Fault Inputs)
- 1 x eTimer (6 channels incl. quad decode)
- 1 x eTimer (6 channels for general purpose)
- 2 x ADC
  - 2x13 Ch.(4 shared channels), 10bit, conversion time 760 nsec (2x6ch, 4shared on 100 pin package)
- 1 x ADC triggering unit: 8 events

System
- 2 x PLL (one FM-PLL, one for Flexray)
- 16Ch eDMA
- Fault Collection Unit
- 16MHz internal RC OSC
- Junction Temperature Sensor
- JTAG (2 pin or 5 pin) / Nexus Class 2+
- 3.3V single supply (5V mask option) with external ballast transistor

  100 and 144 pins TQFP package
- 145ºC ambient temperature option with Slugdown package



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