Power Quality


Good morning!

POWER QUALITY ISSUES IN POWER SYSTEMS

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Organized by

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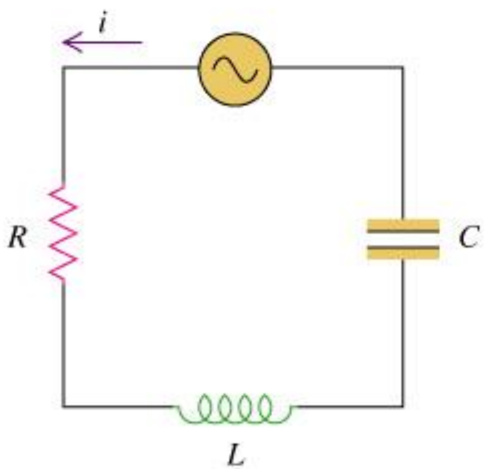
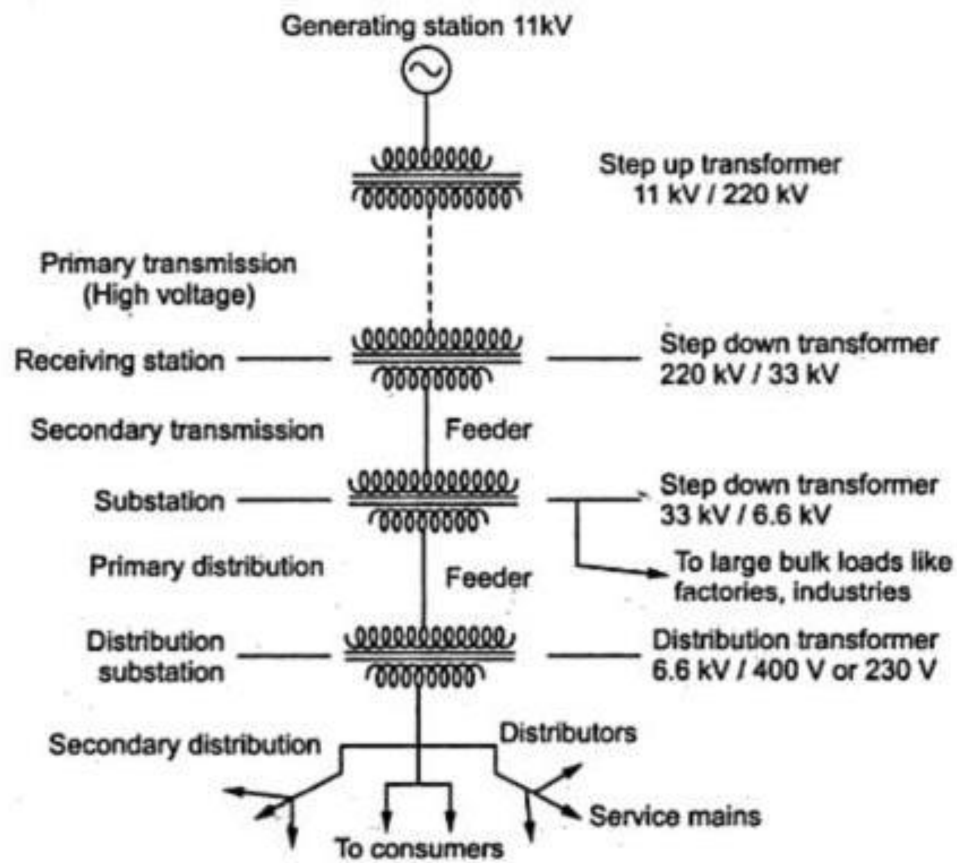
Power Quality

- Power quality determines the fitness of electrical power to consumer devices.
- Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life.
- The term is used to describe electric power that drives an electrical load and the load's ability to function properly.
- Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all.
- There are many ways in which electric power can be of poor quality and many more causes of such poor quality power.

Power Quality





What is a power quality problem?

- A Power Quality Problem is:

  Any occurrence manifested in voltage, current or frequency which results in failure or mis-operation of end-use equipment

Importance of Power Quality

- Load Equipment Sensitivity (microprocessor-based)
- Process Automation
- Networks
- Power Electronics

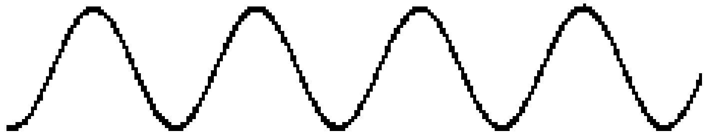
PQ is a Business Problem

•Power Quality issues cause business problems such as:

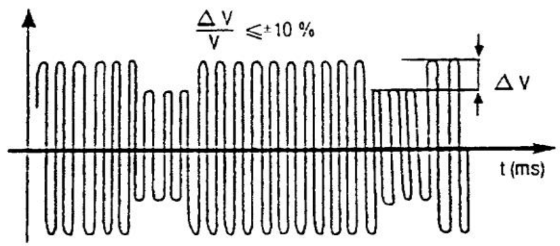
- Lost productivity, idle people and equipment
- Lost orders, good will, customers and profits
- Lost transactions and orders not being processed
- Revenue and accounting problems
- Customer and/or management dissatisfaction
- Overtime required to make up for lost work time

According to Electric Light and Power Magazine, 30 to 40 Percent of All Business Downtime Is Related to Power Quality Problems.

Power Quality Parameters

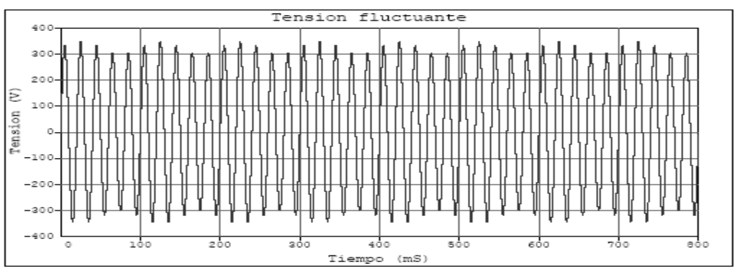


Frequency



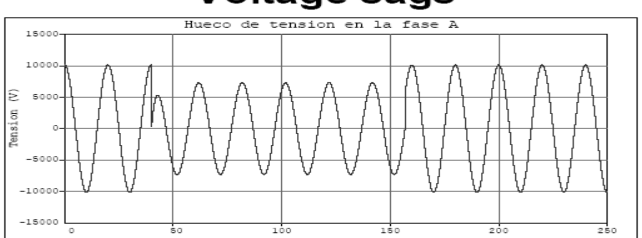
Voltage Variations

Flicker



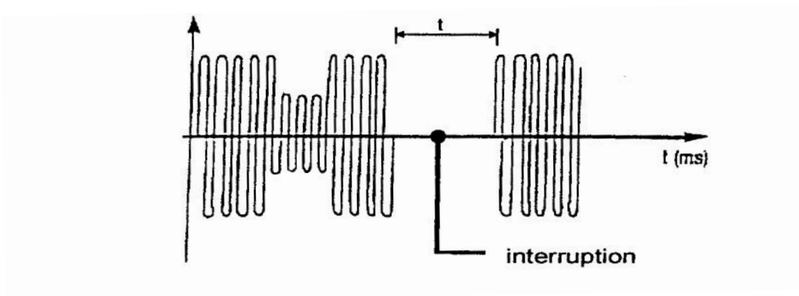
Voltage Flicker

Voltage sags

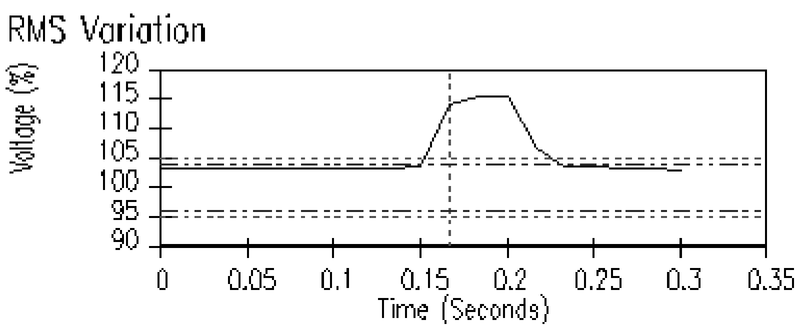


Voltage Dip

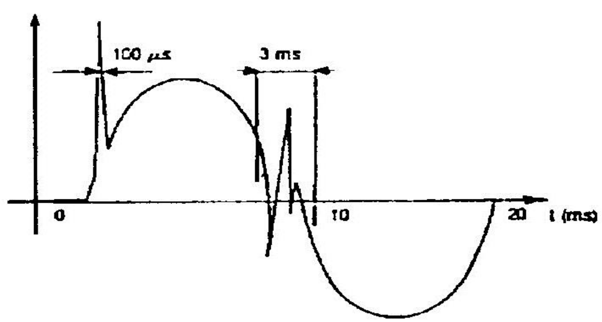
Power Quality Parameters



Interruptions

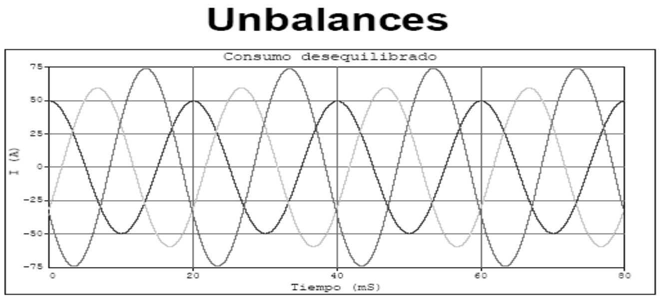


Temporary Overvoltage

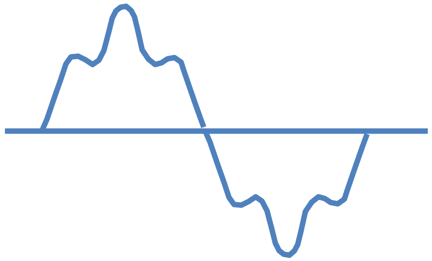


Transients

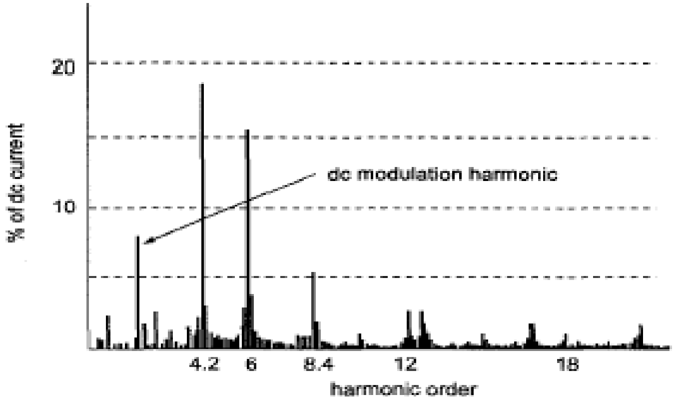
Power Quality Parameters



Unbalance



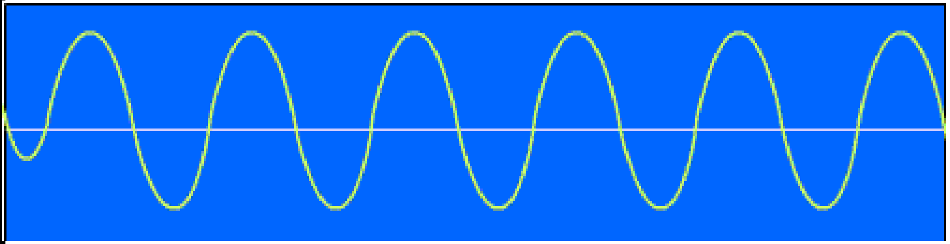
Harmonics



Interharmonics

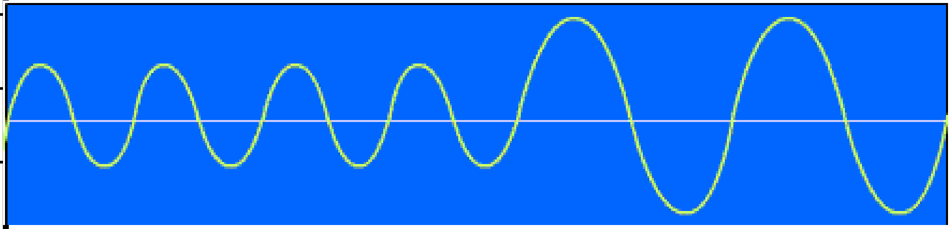
PQ Definitions

IEEE Categories Std 1159-1995	
Short Duration Variations	**Typical Duration**
Instantaneous Sag	0.5 – 30 cycles
Momentary Sag	30 cycles – 3 sec
Temporary Sag	3 sec – 1 min



PQ Definitions

IEEE Categories Std 1159-1995	
Short Duration Variations	**Typical Duration**
Instantaneous Sag	0.5 – 30 cycles
Momentary Sag	30 cycles – 3 sec.
Temporary Sag	3 sec – 1 min.
Instantaneous Swell	0.5 – 30 cycles
Momentary Swell	30 cycles – 3 sec.
Temporary Swell	3 sec – 1 min.



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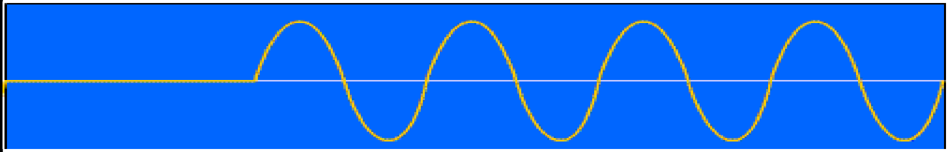
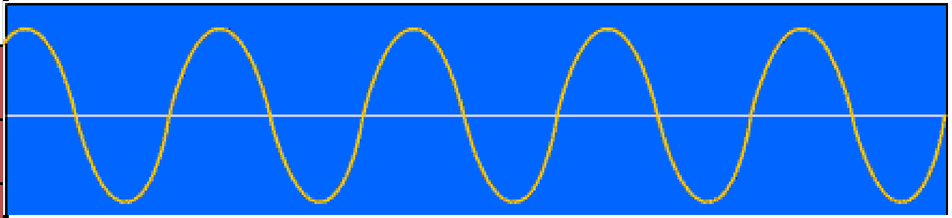
Short Duration Variations	**Typical Duration**
Instantaneous Sag	0.5 – 30 cycles
Momentary Sag	30 cycles – 3 sec.
Temporary Sag	3 sec – 1 min.
Instantaneous Swell	0.5 – 30 cycles
Momentary Swell	30 cycles – 3 sec.
Temporary Swell	3 sec – 1 min.
Momentary Interruptions	0.5 – 30 cycles
Temporary Interruptions	30 cycles – 3 sec.



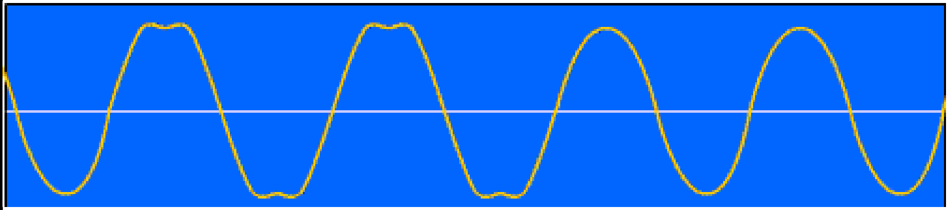
PQ Definitions

IEEE Categories Std 1159-1995	
Long Duration Variations	**Typical Duration**
Sustained interruptions	> 1 min
Under voltages	> 1 min
Over voltages	> 1 min



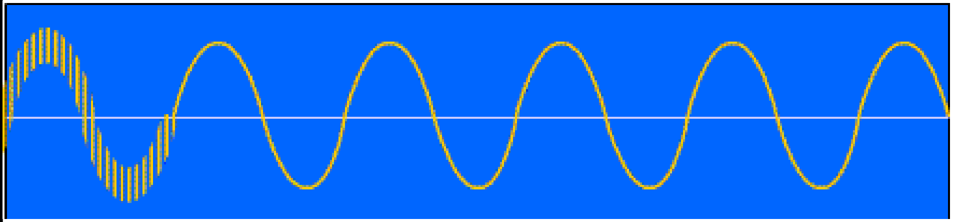
PQ Definitions

IEEE Categories Std 1159-1995	
Long Duration Variations	**Typical Duration**
Sustained interruptions	> 1 min
Under voltages	> 1 min
Over voltages	> 1 min
Voltage imbalance	Steady state
Waveform Distortion	



PQ Definitions

IEEE Categories Std 1159-1995	
Long Duration Variations	**Typical Duration**
Sustained interruptions	> 1 min
Under voltages	> 1 min
Over voltages	> 1 min
Voltage imbalance	Steady state
Waveform Distortion	
DC offset	Steady state
Harmonics	Steady state
Inter harmonics	Steady state



For Electric Utilities Control of Voltage and Prevention of Outages is Power Quality

IEEE1159-EN50160 Levels

	IEEE 1159				EN50160
No.	Categories	Typical Spectral Content	Typical Duration	Typical Voltage Magnitude	
	Short Duration Variations				
	Instantaneous				
7	Sag		0.5-30 Cycles	0.1-0.9 pu	<1 sec
8	Swell		0.5-30 Cycles	1.1-1.8 pu	No
	Momentary				
9	Interruption		0.5 Cycles-3s	<0.1 pu	<1 sec
10	Sag		30 Cycles-3s	0.1-0.9 pu	No
11	Swell		30 Cycles-3s	1.1-1.4 pu	No
	Temporary				
12	Interruption		3 s-1 min	<0.1 pu	No
13	Sag		3 s-1 min	0.1-0.9 pu	No
14	Swell		3 s-1 min	1.1-1.2 pu	No
	Long Duration Variations				
15	Interruption, Sustained		>1 min	0.0 pu	Yes
16	Undervoltages		>1 min	0.8-0.9 pu	Yes 10 min
17	Overvoltages		>1 min	1.1-1.2 pu	Yes 10 min

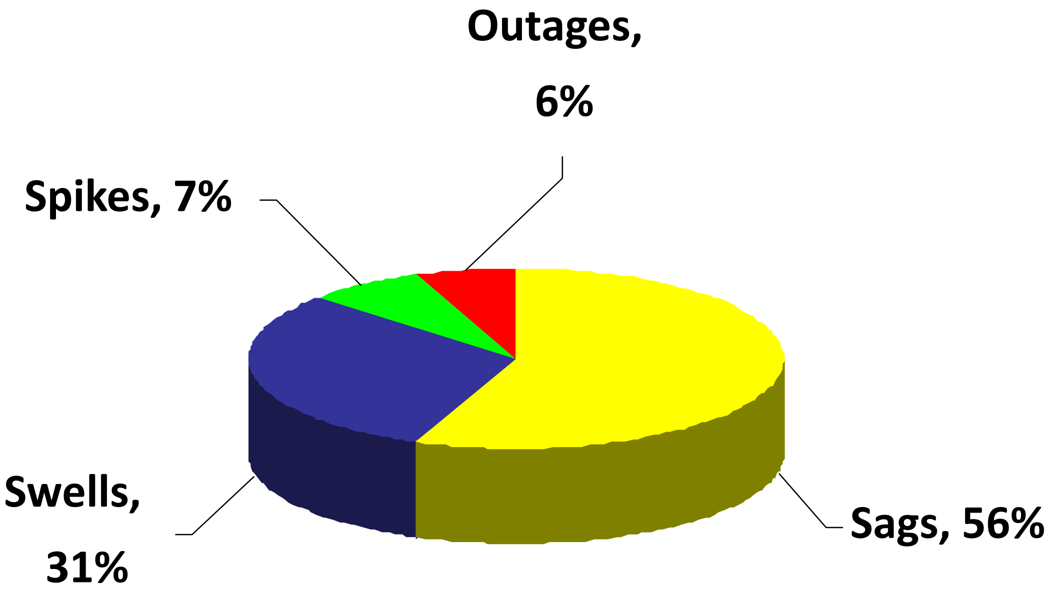
Sources of PQ Problems

- Utility Sources
  - Lightning
  - PF Correction Equipment
  - Faults
  - Switching

Internal Sources

- Individual Loads –Lighting, Elevators, Coolers, HVAC
- Uninterruptible Power Supplies
- Variable Frequency Drives
- Battery Chargers
- Large Motors During Startup
- Electronic Dimming Systems
- Lighting Ballasts (esp. Electronic)
- Arc Welders, and Other Arc Devices
- Medical Equipment, e.g. MRIs and X-Ray Machines
- Office Equipment and Computers
- Wiring

Major PQ Problems



Source: EPRI, 1994

Swells

System fault conditions

Switching on a large capacitor bank

Switching off a large load

Sags (Dips)

Associated with system faults

Switching of heavy loads

Starting of large motors

Should we Care about Power Quality?

Comprehensive Research in Europe in 1400 sites at 8 countries reports that 20% experience the following:

- Computer lockouts (20%)
- Light flickering (22%)
- Electronic card failures (18%)
- Power Factor correction system failures (17%)
- Failures in high load switching (16%)
- Neutral conductor overheating (12%)
- Unexpected breaker operation (11%)
- Power meters inaccurate readings (6%)

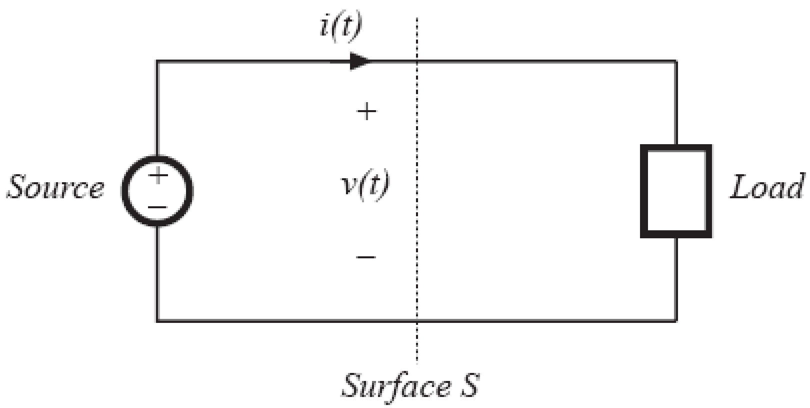
And of course excess losses and downtime

Causes and Solutions

PQ Problem	Major Sources	Solutions
Frequency	The Utility	
Voltage variations	Load changing	Sync. loads, Fast PF correction
Voltage flicker	Load changing, mainly welding	Fast PF correction
Voltage dip	Motor and other load startups	Motor starters, VFD, Fast PF correction
Interruptions	The Utility	
Overvoltage	Over PF compensation	Fast PF correction
Transients	Connections, Switching	Controlled switches
Unbalance	Unbalanced loads, transformer phase shift	Balance the loads
Harmonics	Non linear loads, resonance	Active/passive filtration, detuned capacitors, Improved VFD operation

Power And Harmonics in Nonsinusoidal Systems

- Average power



$$v(t) = V_0 + \sum_{n=1}^{\infty} V_n \cos\left(n\omega t - \varphi_n\right)$$

$$i(t) = I_0 + \sum_{n=1}^{\infty} I_n \cos\left(n\omega t - \theta_n\right)$$

$$P_{av} = \frac{W_{cycle}}{T} = \frac{1}{T}\int_0^T v(t)i(t)dt$$

$$P_{av} = V_0 I_0 + \sum_{n=1}^{\infty} \frac{V_n I_n}{2} \cos\left(\varphi_n - \theta_n\right)$$

Example 1

$$v(t) = 1.2 \cos(\omega t) + 0.33 \cos(3\omega t) + 0.2 \cos(5\omega t)$$
$$i(t) = 0.6 \cos(\omega t + 30°) + 0.1 \cos(5\omega t + 45°) + 0.1 \cos(7\omega t + 60°)$$

Ans: $P_{av} = 0.32$

Root-mean-square (RMS) value of a waveform, in terms of Fourier series

$$(\text{rms value}) = \sqrt{V_0^2 + \sum_{n=1}^{\infty} \frac{V_n^2}{2}}$$

- Similar expression for current
- Harmonics always increase rms value
- Harmonics do not necessarily increase average power
- Increased rms values mean increased losses

Power factor

- Power factor is a figure of merit that measures how efficiently energy is transmitted.

$$\text{power factor} = \frac{\text{(average power)}}{\text{(rms voltage) (rms current)}}$$

$$P_{av} = \frac{V_1 I_1}{2} \cos\left(\varphi_1 - \theta_1\right)$$

$$\text{(rms current)} = \sqrt{I_0^2 + \sum_{n=1}^{\infty} \frac{I_n^2}{2}}$$

Power Factor Cotd...

$$\text{(power factor)} = \left(\frac{\frac{I_1}{\sqrt{2}}}{\sqrt{I_0^2 + \sum_{n=1}^{\infty} \frac{I_n^2}{2}}} \right) \left(\cos\left(\varphi_1 - \theta_1\right) \right)$$

$$= \text{(distortion factor)}\ \text{(displacement factor)}$$

THD-Total Harmonic Distortion

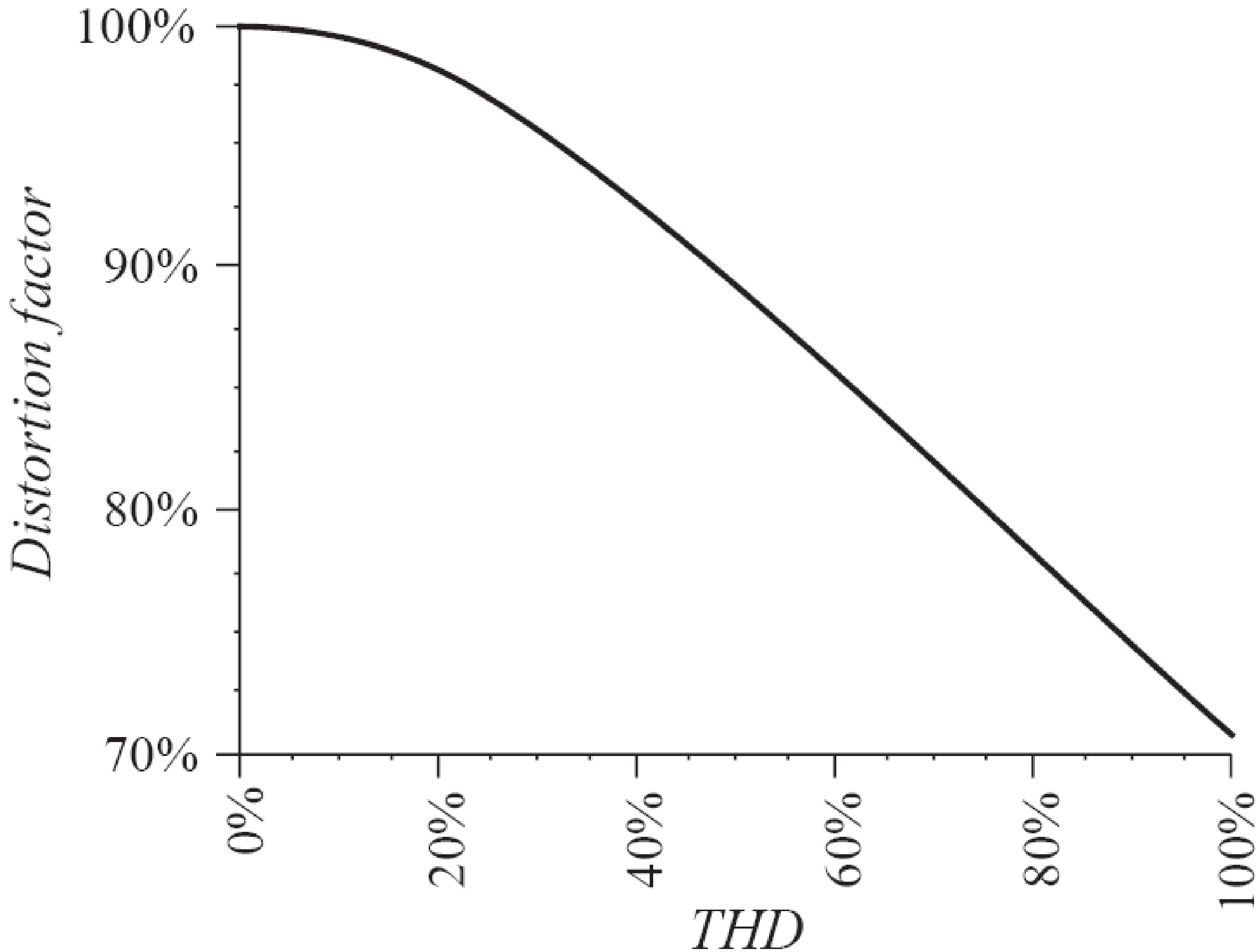
$$THD(V) = \frac{100\sqrt{(V_2^{\;2} + V_3^{\;2} + \ldots.. + V_n^{\;2})}}{V_1}(\%)$$

$$THD(I) = \frac{100\sqrt{(I_2^{\;2} + I_3^{\;2} + \ldots.. + I_n^{\;2})}}{I_1}(\%)$$

I_N, V_N – Individual Harmonics of order N

$$(\text{distortion factor}) = \frac{1}{\sqrt{1 + (\text{THD})^2}}$$

Distortion factor vs. THD



Problem 1

Signal	Fund. Voltage	Harmonic Voltages (V)							
		5	7	11	13	17	19	23	25
1	444.9	70.9	50.0	39.1	25.0	20.0	10.0	2.1	10.1
2	440.9	71.0	12.9	6.2	5.2	0.9	1.5	57.2	36.9
3	440.9	12.3	12.8	5.9	5.1	10.1	8.3	20.0	55.7
4	439.7	13.0	8.5	5.7	5.1	0.8	1.7	17.8	49.7

Power Quality Indices

Index	Definition	Main applications
Total harmonic distortion (THD)	$\left(\sqrt{\sum_{i=2}^{\infty} I_i}\right) / I_1$	General purpose; standards
Power factor (PF)	$P_{tot} / \lvert V_{rms} \rvert \lvert I_{rms} \rvert$	Potentially in revenue metering
Telephone influence factor	$\left(\sqrt{\sum_{i=2}^{\infty} w_i^2 I_i}\right) / I_{rms}$	Audio circuit interference
C message index	$\left(\sqrt{\sum_{i=2}^{\infty} c_i^2 I_i}\right) / I_{rms}$	Communications interference
IT product	$\sqrt{\sum_{i=1}^{\infty} w_i^2 I_i^2}$	Audio circuit interference; shunt capacitor stress
VT product	$\sqrt{\sum_{i=1}^{\infty} w_i^2 V_i^2}$	Voltage distortion index
K factor	$\left(\sum_{h=1}^{\infty} h^2 I_h^2\right) / \sum_{h=1}^{\infty} I_h^2$	Transformer derating
Crest factor	V_{peak} / V_{rms}	Dielectric stress
Unbalance factor	$\lvert V_- \rvert / \lvert V_+ \rvert$	Three phase circuit balance
Flicker factor	$\Delta V / \lvert V \rvert$	Incandescent lamp operation; bus voltage regulation; sufficiency of short circuit capacity

Example 2

RMS	60 Hz	180 Hz	420 Hz
V	$1\angle 0^o$	$0.2\angle 20^o$	$0.5\ \angle 10^o$
I	$1\angle -30^o$	$0.2\angle 80^o$	$0.15\ \angle -20^o$

Find V_{rms}, I_{rms}, P_{av}, S, TPF, DF,VTHD, ITHD

Ans: 1.021, 1.031, 1,052, 0.848, 0.866 (lag)m 20.62%, 25%

THD - ANOTHER EXAMPLE

f	$\|V\|$	$\|I\|$
60	1.00	1.00
180	0.01	0.31
300	0.04	0.15
420	0.03	0.07
540	0.02	0.03
660	0.01	0.02

$$VTHD^2 = 0.01^2 + 0.04^2 + 0.03^2 + 0.02^2 + 0.01^2$$

$$VTHD = 5.57\%$$

$$ITHD = 35.33\%$$

Standards for Harmonics Limitation IEEE/IEC

- **IEEE 519-1992 Standard: Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems (Current Distortion Limits for 120v-69kv DS)**

Table 1: Current Harmonic Limits [4]

Ratio Iscc / Iload	Harmonic odd numbers (<11)	Harmonic odd numbers (>35)	THD-i
< 20	4.0 %	0.3 %	5.0 %
20 - 50	7.0 %	0.5 %	8.0 %
50 - 100	10.0 %	0.7 %	12.0 %
>100	15.0 %	1.4 %	20.0 %

Standard of Harmonics Limitation

- **IEEE 519-1992 Standard: Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems (Voltage Distortion Limits)**

Table 2: Voltage Harmonic Limits [4]

Bus Voltage	Voltage Harmonic limit as (%) of Fundamental	THD-v (%)
<= 69kV	3.0	5.0
69 – 161kV	1.5	2.5
>= 161 kV	1.0	1.5

SMPS

SMPS

- Electrical energy is use to drive the computer system. This is in the form of a SMPS or source is SMPS.
- The basic function of the power supply is to convert the type of electrical power available at the wall socket to the type the computer circuitry can use.
- The power supply in a conventional desktop system is designed to convert either 120-volt (nominal) 60Hz AC (alternating current) or 240V (nominal) 50Hz AC power into +3.3V, +5V, and +12V DC (direct current) power.

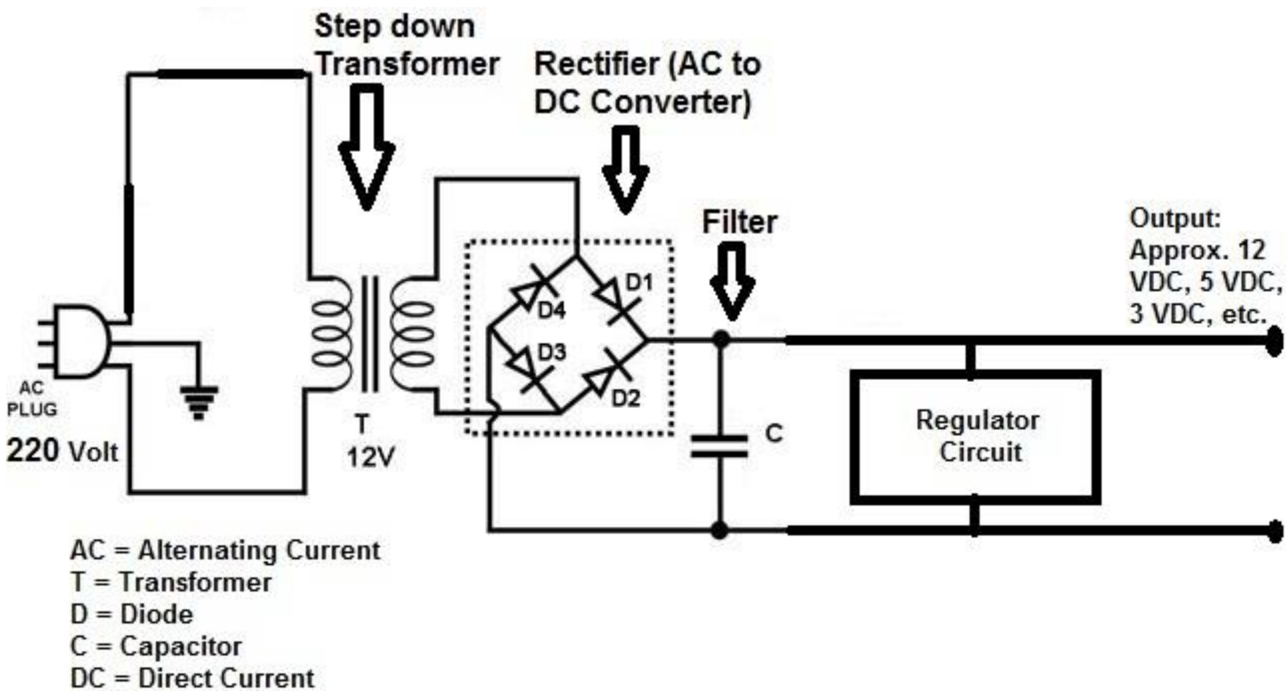
SMPS

- Power supplies, often referred to as "switching power supplies", use switcher technology to convert the AC input to lower DC voltages. The typical voltages supplied are:
- 3.3 volts - used by digital circuits
- 5 volts - used by digital circuits
- 12 volts - run motors in disk drives and fans.

Some Power Consumption Values

PC Item	Watts
Accelerated Graphics Port (AGP) card	20 to 30W
Peripheral Component Interconnect (PCI) card	5W
small computer system interface (SCSI) PCI card	20 to 25W
floppy disk drive	5W
network interface card	4W
50X CD-ROM drive	10 to 25W
RAM	10W per 128M
5200 RPM Integrated Drive Electronics (IDE) hard disk drive	5 to 11W
7200 RPM IDE hard disk drive	5 to 15W
Motherboard (without CPU or RAM)	20 to 30W
550 MHz Pentium III	30W
733 MHz Pentium III	23.5W
300 MHz Celeron	18W
600 MHz Athlon	45W

SMPS – Circuit Diagram



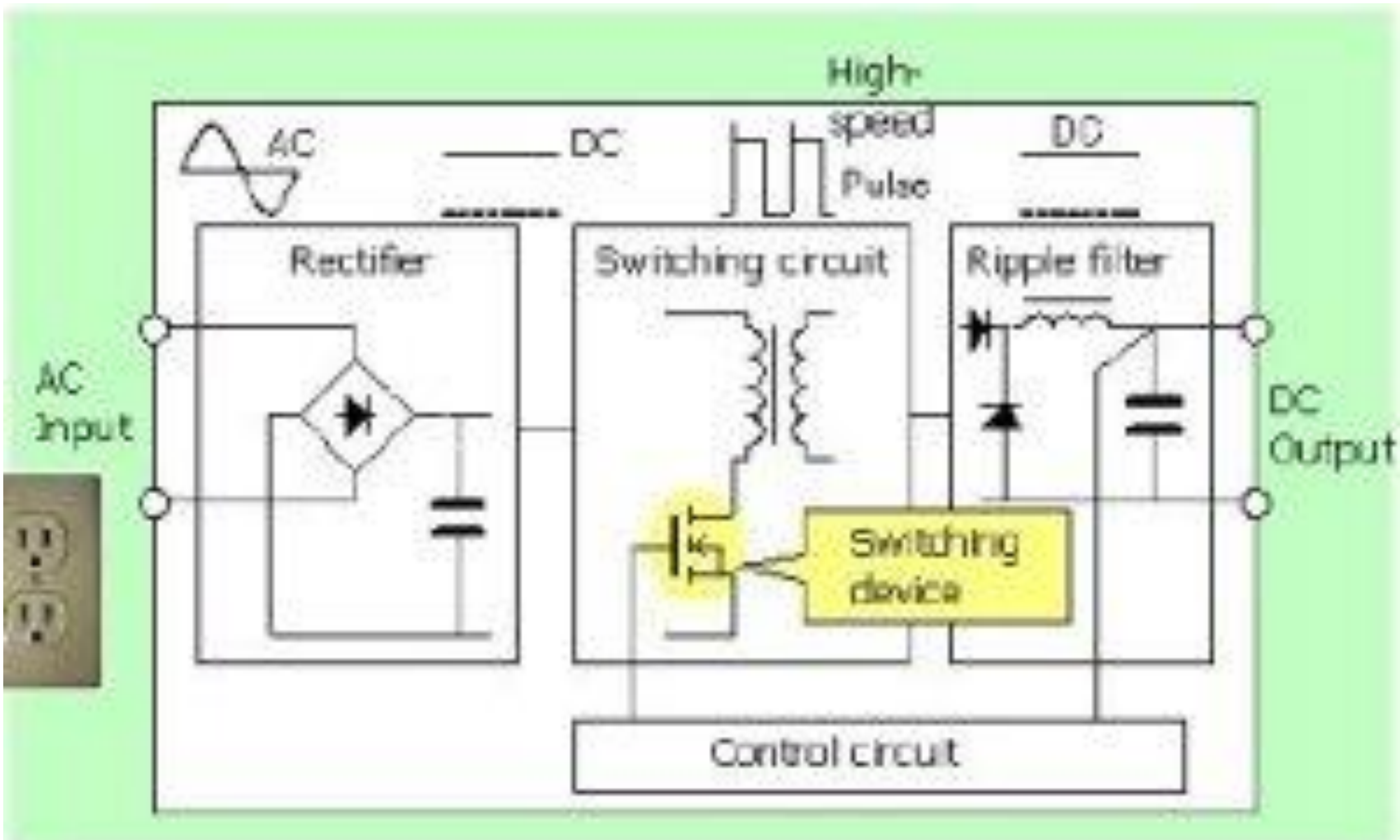
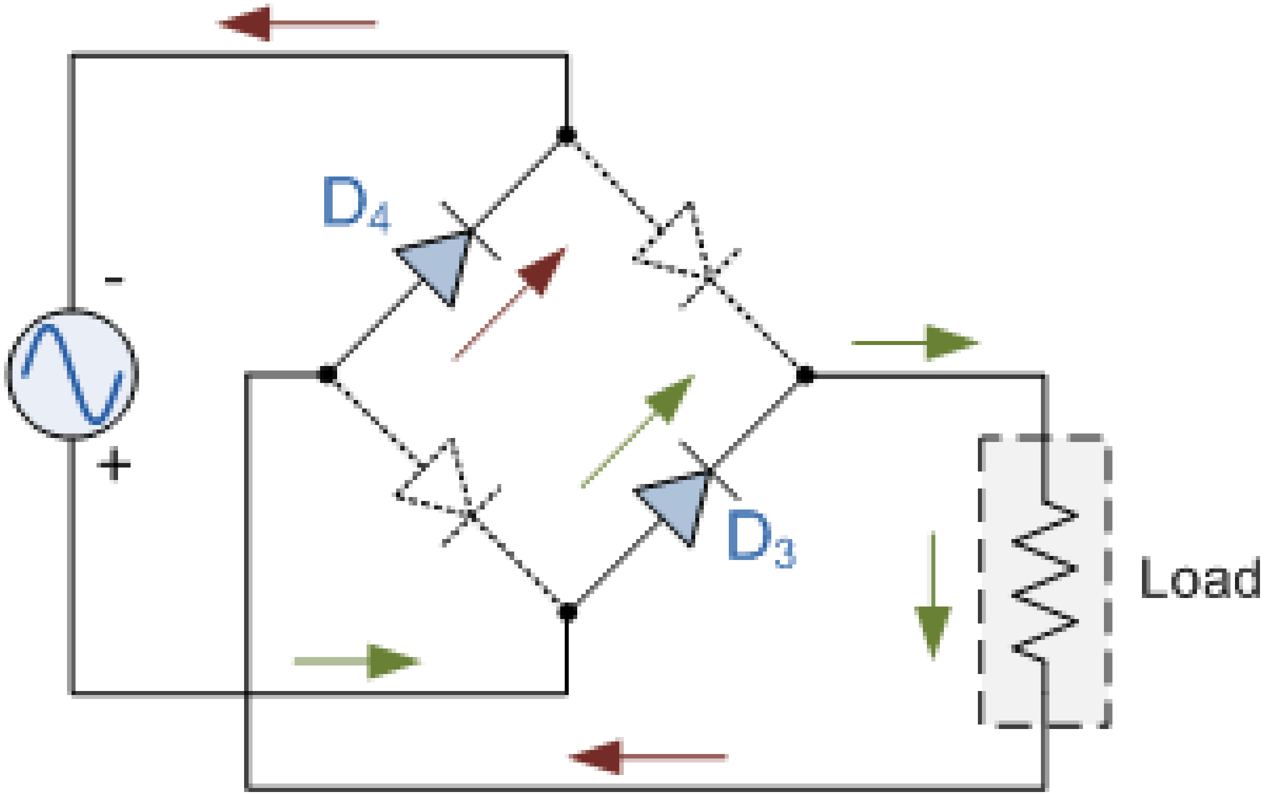


Figure 3> Outline Drawing of a Switching Power Supply

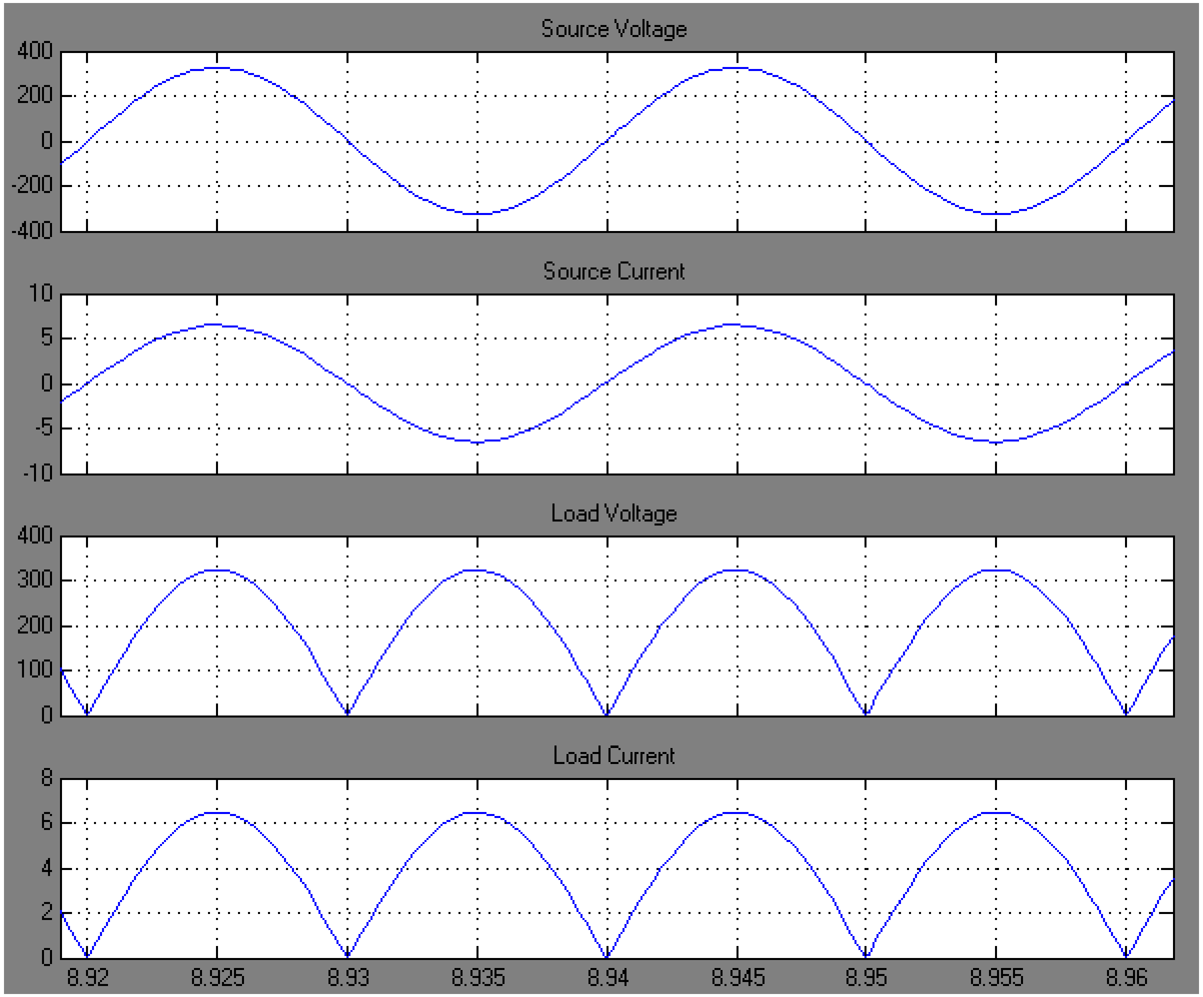
SMPS

- **Step Down Transformer:** Step down transformers are designed to reduce electrical voltage. Their primary voltage is greater than their secondary voltage. This kind of transformer "steps down" the voltage applied to it. Step down transformers convert electrical voltage from one level to a lower level.
- **Rectifier:** A **rectifier** is an electrical device that converts alternating current (AC) to direct current (DC), also known as **rectification**.
- **Filter:** To further reduce the ripple in DC Voltage, filter is used.
- **Regulator Circuit:** A **voltage regulator** is an electrical regulator designed to automatically maintain a constant voltage level.

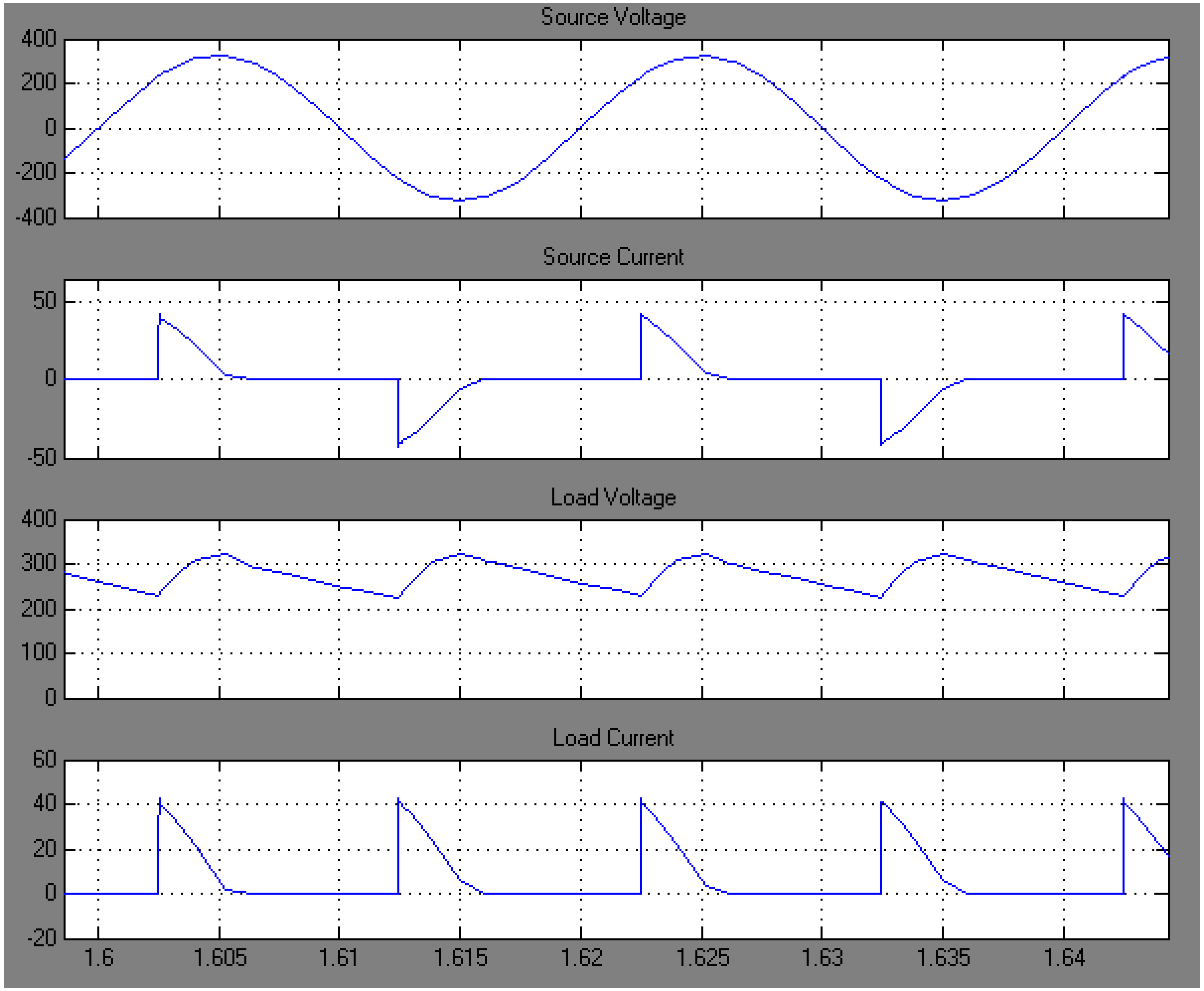
Rectifier Load



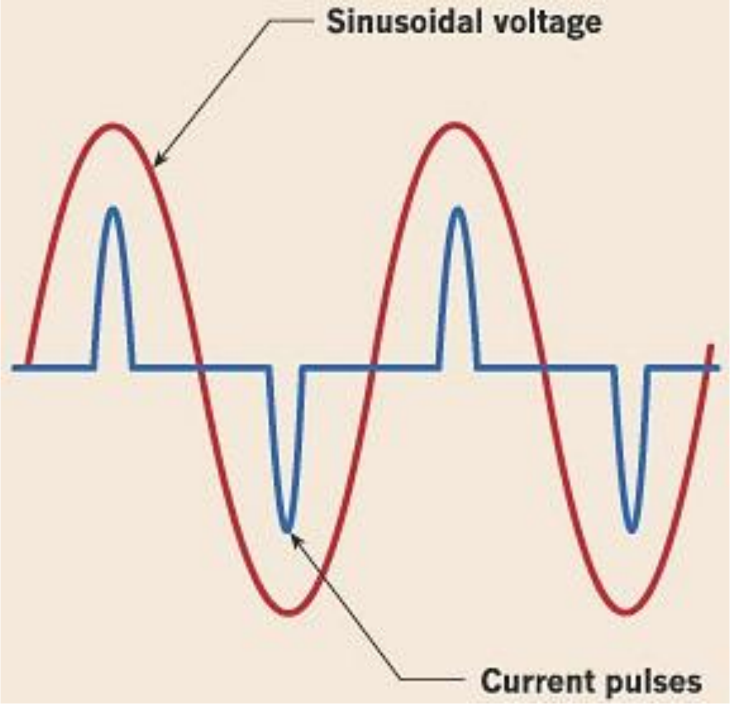
Rectifier without Filter

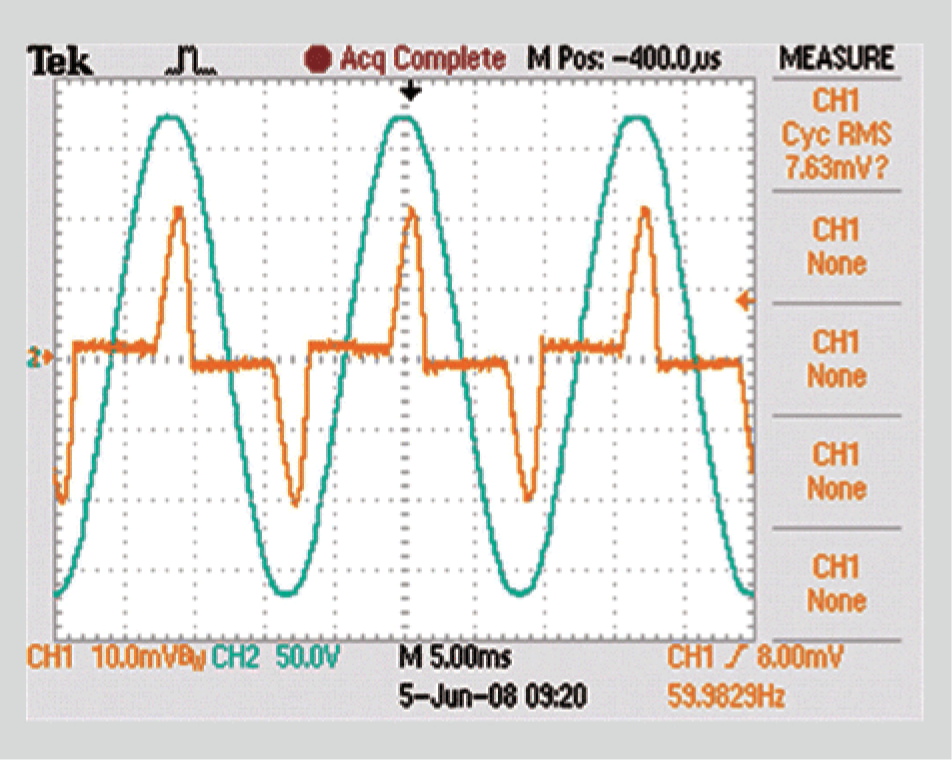


Rectifier with Filter

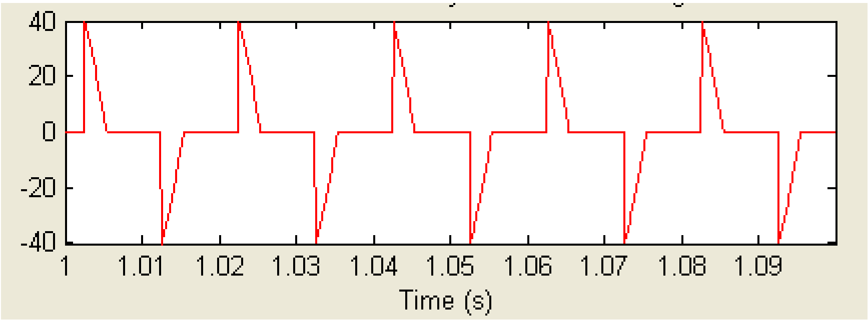


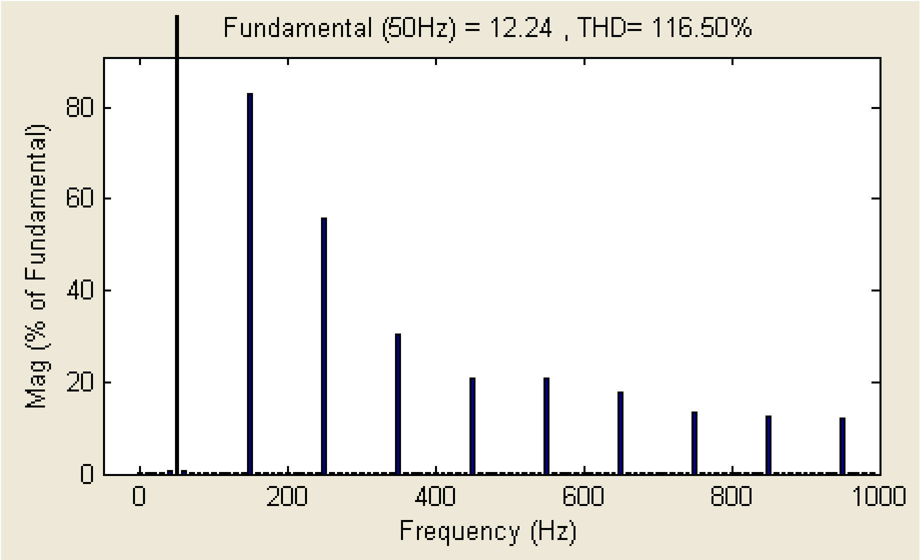
Waveform


Sinusoidal voltage
Current pulses

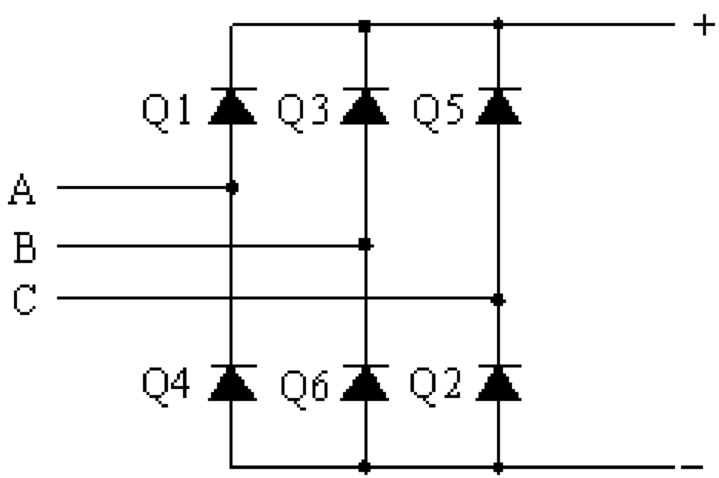

Tek
Acq Complete
M Pos: -400.0µs
MEASURE
CH1
Cyc RMS
7.63mV?
CH1
None
CH1
None
CH1
None
CH1
None
CH1 10.0mV
CH2 50.0V
M 5.00ms
5-Jun-08 03:20
CH1 8.00mV
59.9829Hz

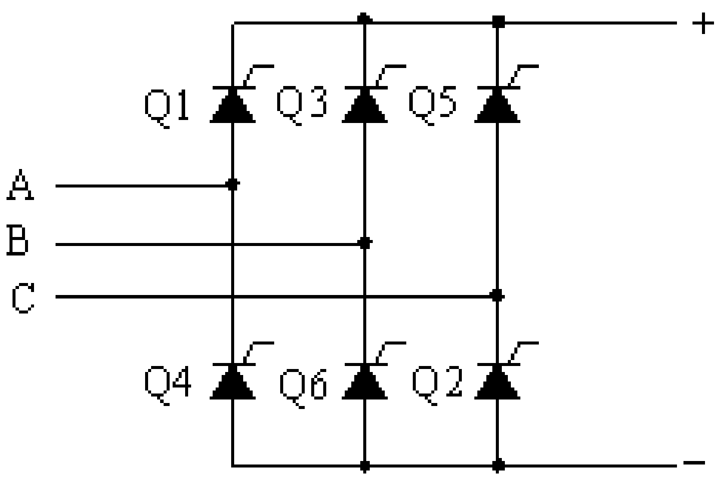
THD Analysis of Input Current



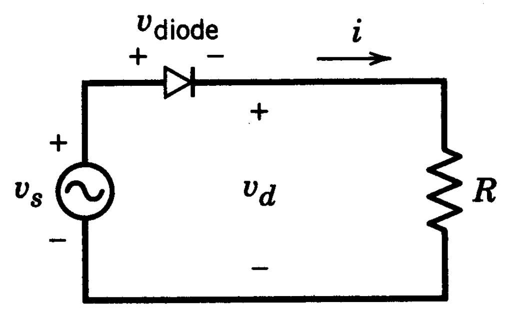


Three Phase Power Converters

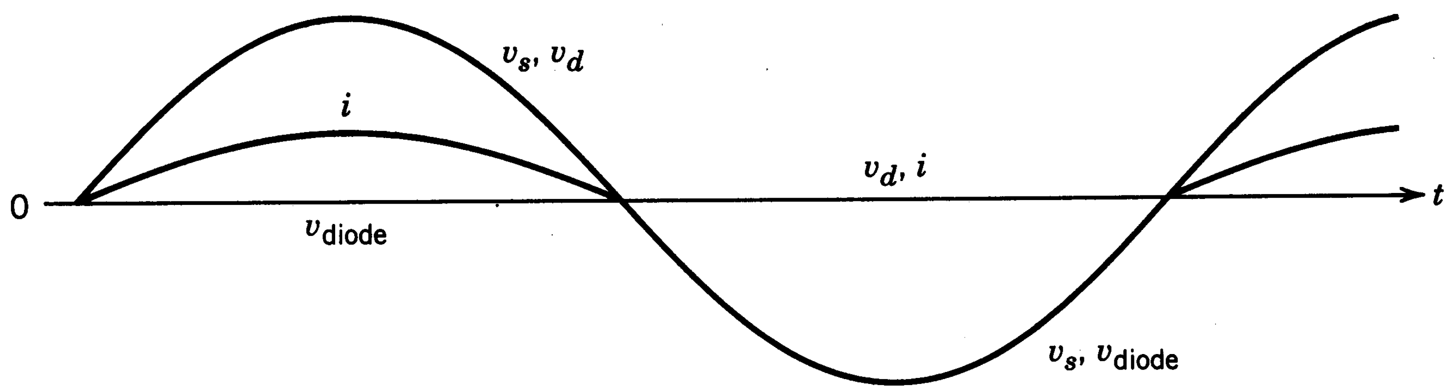




A Simple Diode Circuit with a Pure Resistive Load



(a)



(b)

Figure 5-2 Basic rectifier with a load resistance.

- The load voltage v_d and the current i have an average component

Diode-Rectifier Bridge Analysis

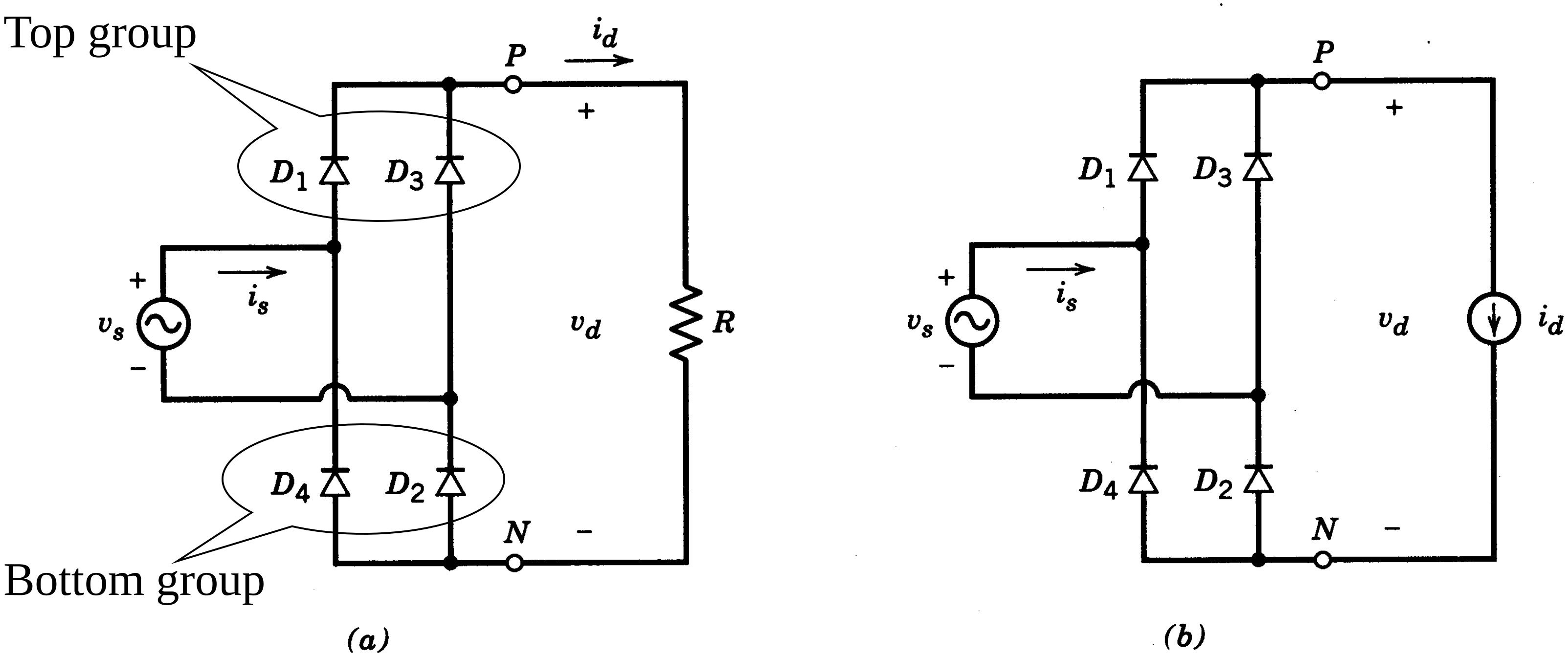


Figure 5-6 Idealized diode bridge rectifiers with $L_s = 0$.

- It is very unlikely that a purely resistive load will be supplied
- Constant dc current is equivalent to a large inductor in series at the dc output
- Current flows continuously through one diode of the top group and one diode of the bottom group.

Redrawing Diode-Rectifier Bridge

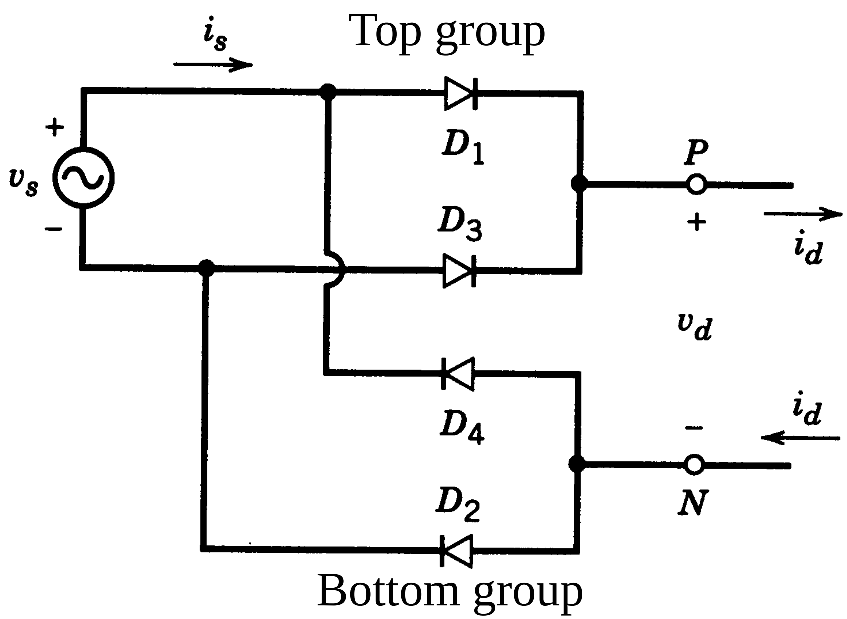


Figure 5-7 Redrawn rectifiers of Fig. 5-6.

- Current flows continuously through one diode of the top group and one diode of the bottom group.
- In the top group, cathodes of the two diodes are at the same potential. Therefore, the diode with its anode at the highest potential will conduct i_d
- When v_s goes negative, i_d instantaneously commutes to D_3 as D_1 is reversed biased.
- Similar argument could be applied to the bottom group.

Items that are worth noting:

- Waveforms with a purely resistive load and a purely dc current at the output
- When v_s is positive, D_1 and D_2 conduct

  $v_d = v_s$ and $i_d = i_s$

  When v_s is negative, D_3 and D_4 conduct

  $v_d = -v_s$ and $i_d = -i_s$
- In both cases, the dc-side voltage and current waveforms are the same
- The average value of the dc output voltage

$$V_{do} = \frac{1}{(T/2)} \int_0^{T/2} \sqrt{2} V_s \sin \omega t \, dt$$

$$= \frac{2}{\pi} \sqrt{2} V_s = 0.9 V_s$$

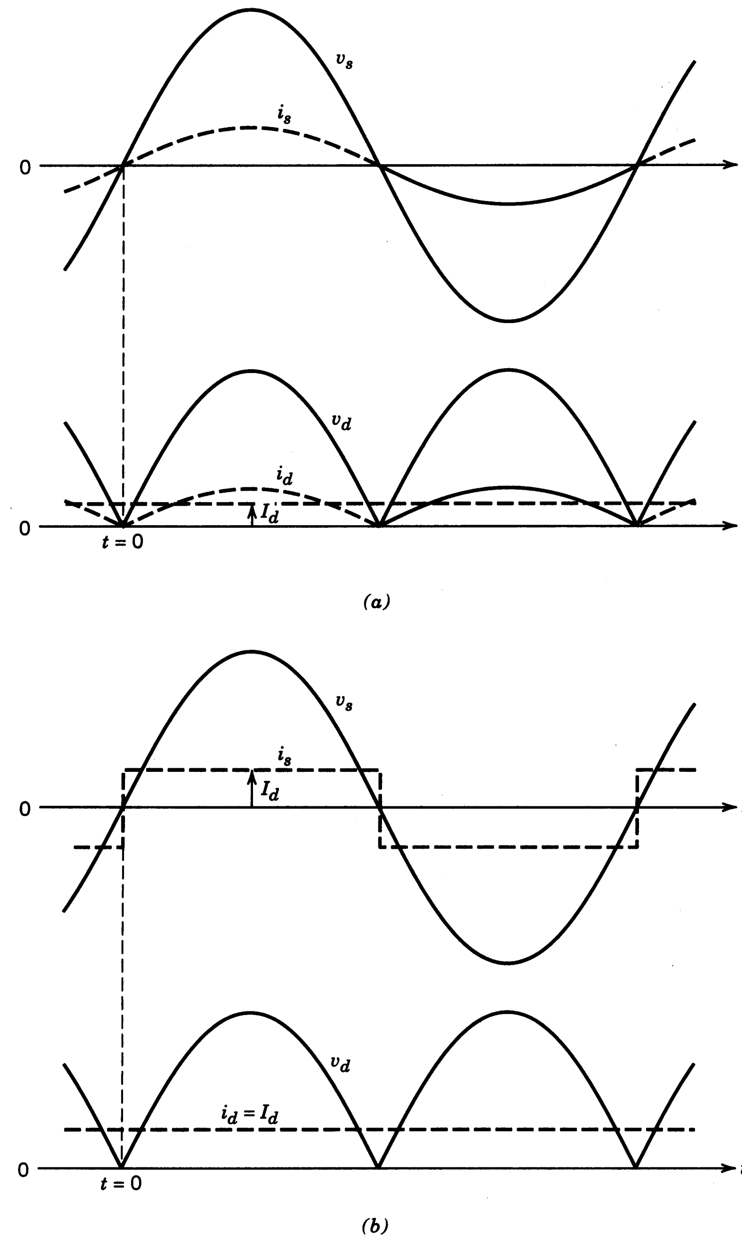


Figure 5-8 Waveforms in the rectifiers of (*a*) Fig. 5-6*a* and (*b*) Fig. 5-6*b*.

Three-Phase, Full-Bridge Rectifier

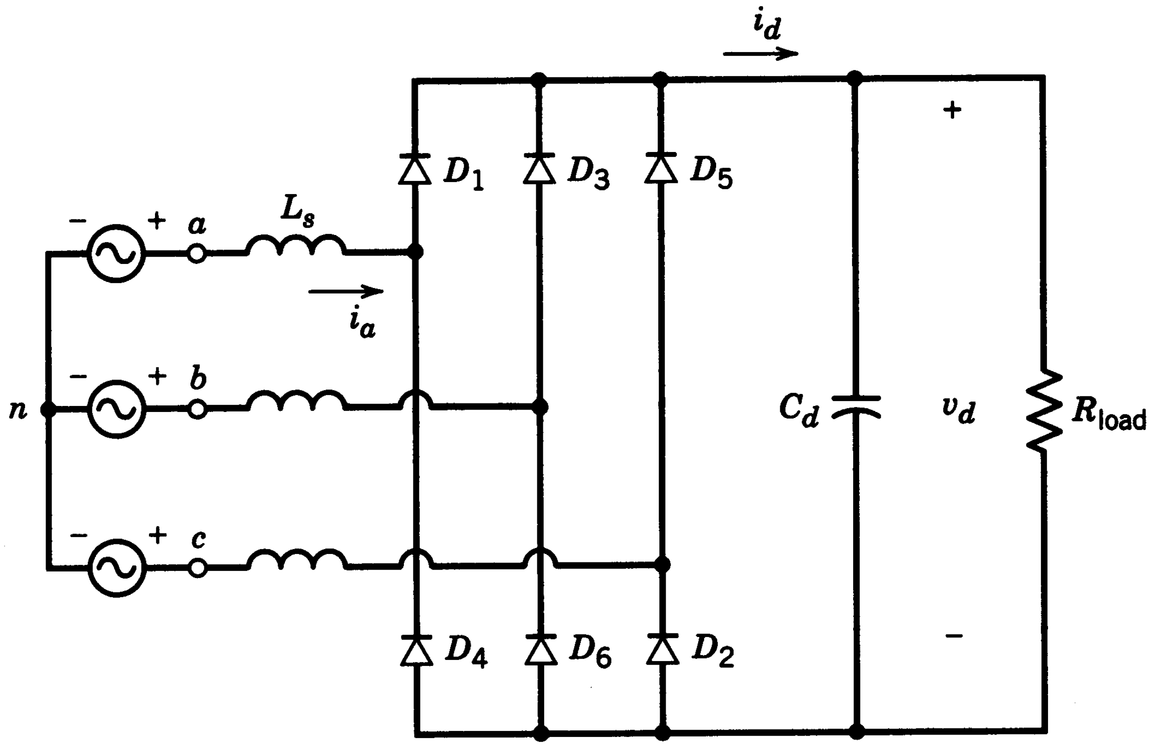


Figure 5-30 Three-phase, full-bridge rectifier.

- In industrial applications, where three-phase power is available, it is preferable to use three-phase rectifier circuits because of …
  - Higher power handling capability
  - Lower ripple content in the waveforms

Three-Phase, Full-Bridge Rectifier: Redrawn

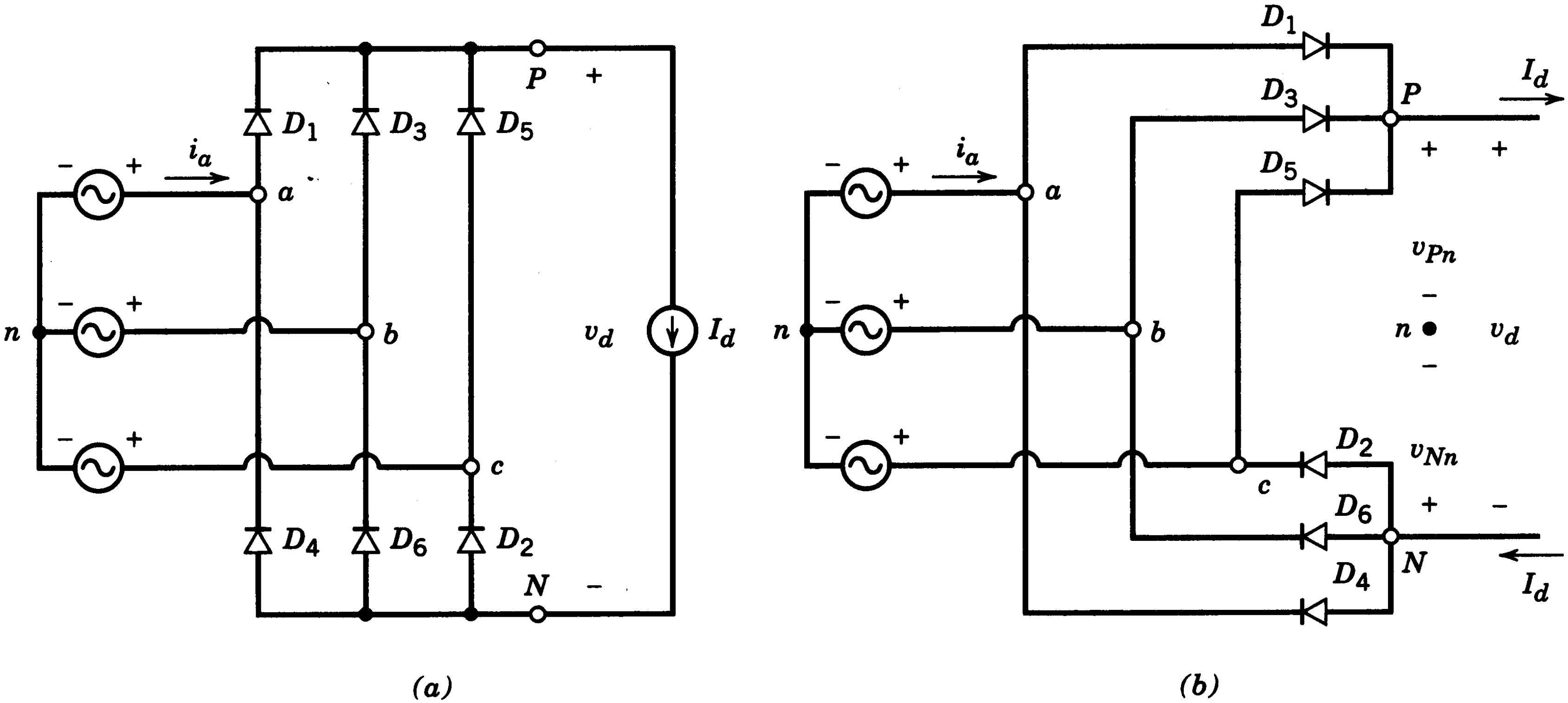


Figure 5-31 Three-phase rectifier with a constant dc current.

- Current flows through one diode from the top group and one from the bottom
- Diode with highest anode potential from the top and diode with lowest cathode potential from the bottom will conduct

Three-Phase, Full-Bridge Rectifier Waveforms

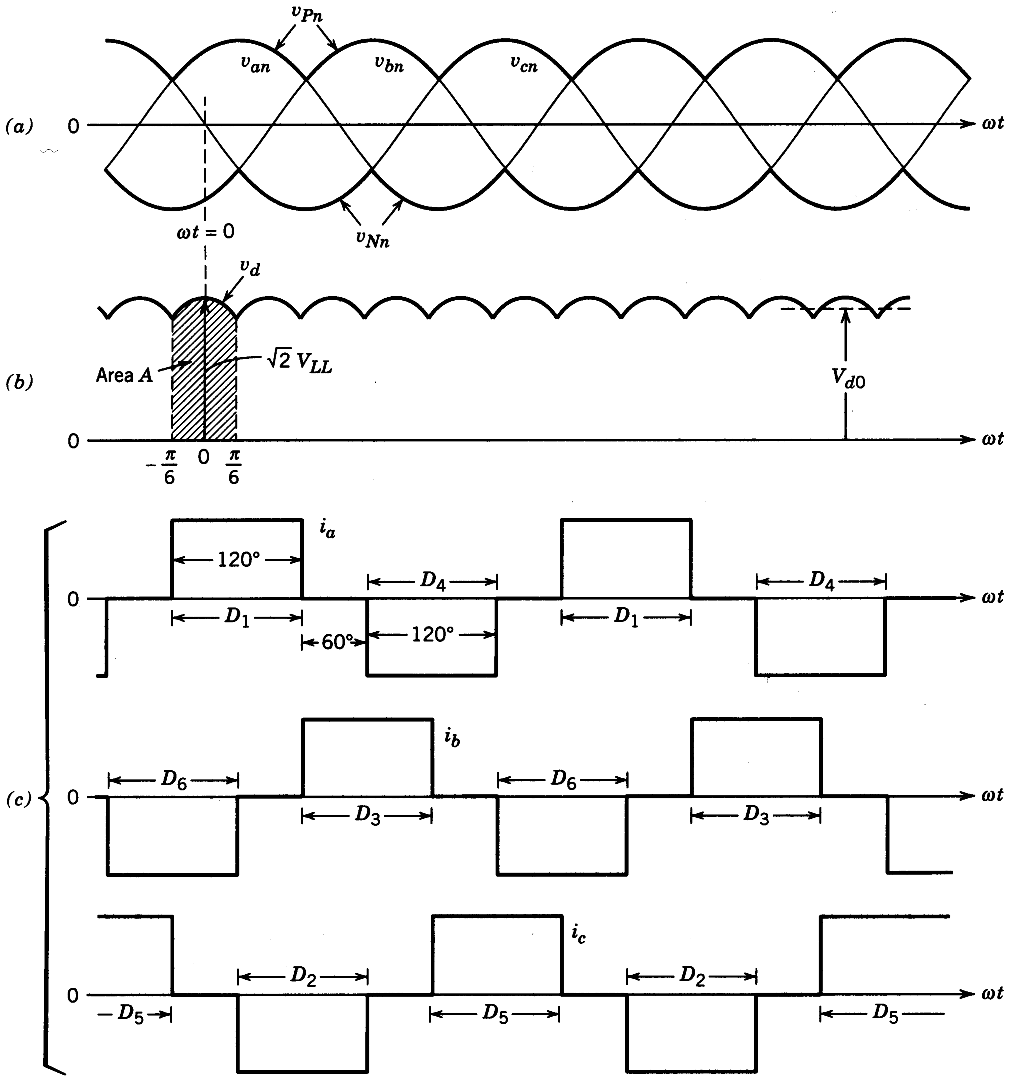


Figure 5-32 Waveforms in the circuit of Fig. 5-31.

- Six-pulse rectifier: V_d ($=V_{Pn}-V_{Nn}$) waveform consists of six segments per cycle
- Each diode conducts for 120°
- Conduct sequence: 1-2-3….
- Average dc output voltage,

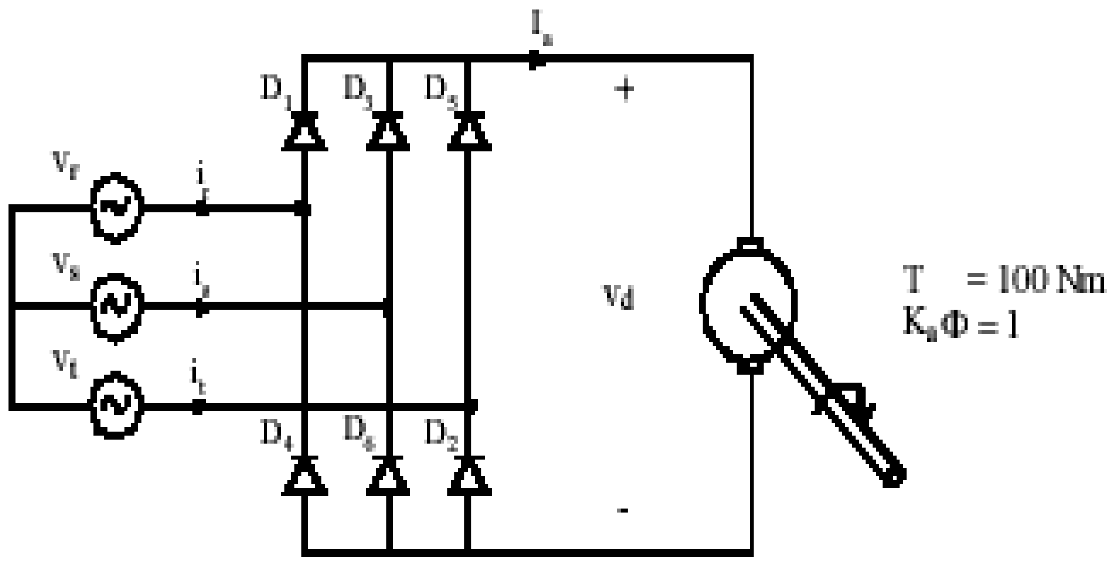
$$V_{do} = \frac{1}{(\pi/3)} \int_{-\pi/6}^{\pi/6} \sqrt{2} V_{LL} \cos\omega t \, d(\omega t)$$

$$-\frac{\pi}{6} \langle \omega t \langle \frac{\pi}{6}$$

$$= \frac{3}{\pi}\sqrt{2} V_{LL} = 1.35 V_{LL}$$

Three-phase diode rectifier.

The diode rectifier shown in the figure below, supplies a DC machine, which has a constant load torque T = 100 Nm. The flux is held constant and $K_a \cdot \phi = 1$. This gives an armature current I_a = 100 A. The armature inductance of the machine, L_a, is so large that the armature current may be considered to be constant. The line voltage of the grid, V_{LL}, is equal to 230V. Assume ideal grid, L_s=0.



(a) Sketch the armature voltage $v_d(t)$ and the line currents $i_r(t)$.
(b) Calculate the average dc voltage, V_d.
(c) Calculate the rms current in phase r, $I_{r,rms}$.
(d) List the advantages for a three-phase rectifier compared to a single-phase rectifier?

Solution: Example

a) v_d and the line currents are shown

b) $$V_{do} = \frac{6}{\pi} \int_0^{\pi/6} \sqrt{2} V_{LL} \sin(\omega t) d(\omega t) = \frac{3\sqrt{2} V_{LL}}{\pi}$$

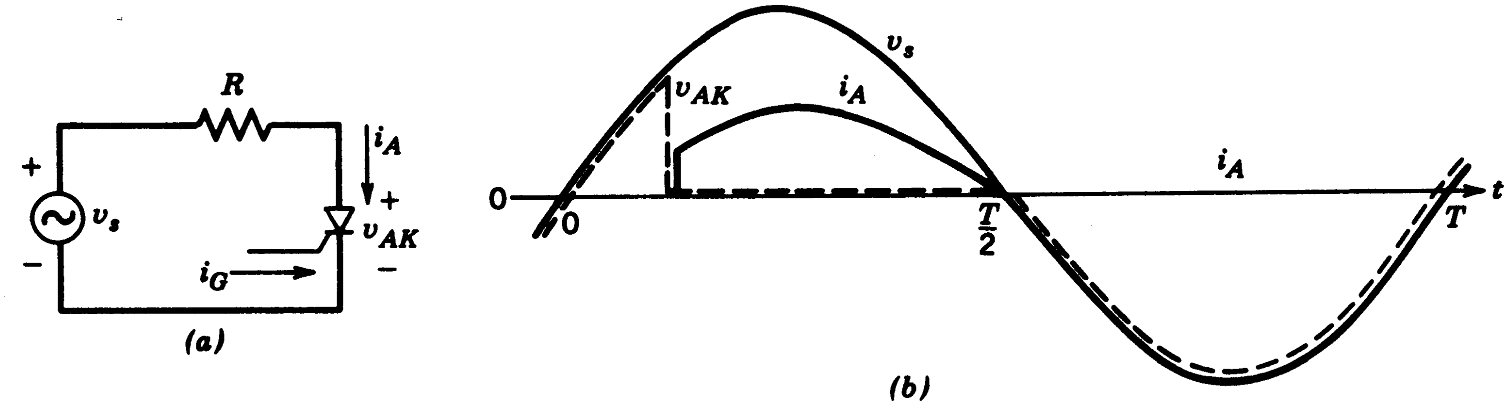
c) $$I_r = \sqrt{\frac{1}{T} \int_0^T i^2 \, dt} = \sqrt{\frac{2}{T} \int_0^{(T/2)(2/3)} I_a{}^2 \, dt} = \sqrt{\frac{2}{3}} I_a = 81.6 \text{ A}$$

d) The main advantage is a smoother dc voltage. Also the line current has less harmonic content (triple harmonics are missing).

Thyristor Converters

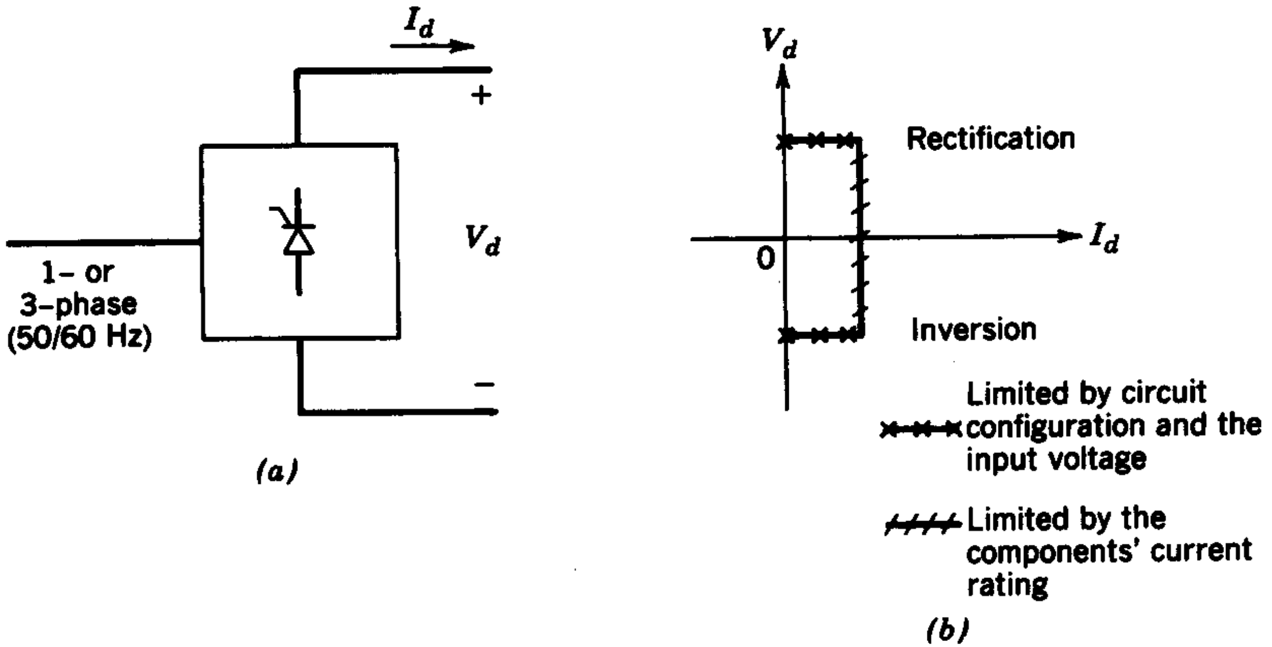
- In some applications (battery charger, some ac/dc drives), the dc voltage has to be controllable
- Thyristor converters provide controlled conversion of ac into dc
- Primarily used in three-phase, high power application
- Being replaced by better controllable switches

Thyristor in a Simple Circuit (Review Class)

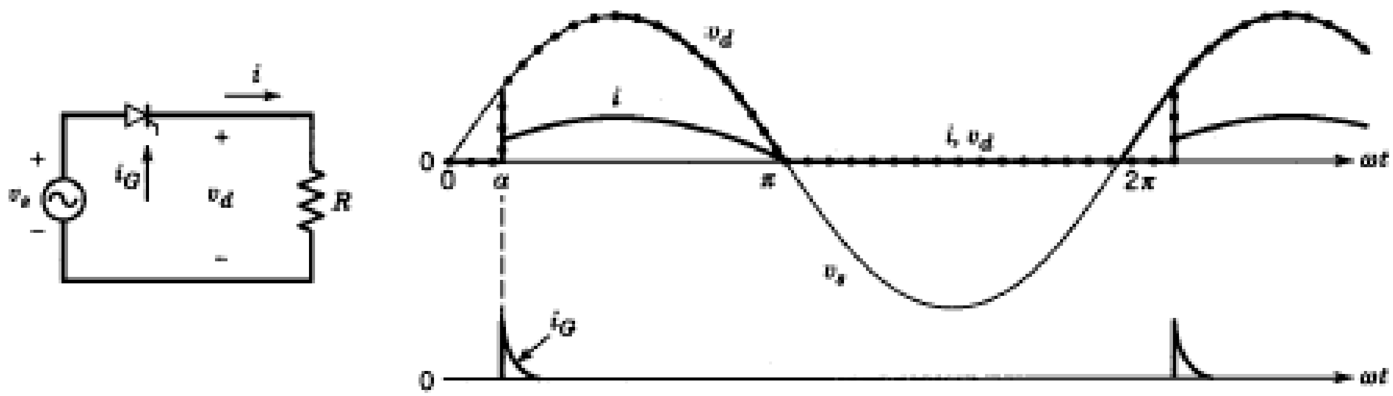


- For successful turn-off, reverse voltage required

Thyristor Converters



- Average dc voltage V_d can be controlled from a positive maximum to a negative minimum on a continuous basis
- The converter dc current I_d can not change direction
- Two-quadrant operation
- Rectification mode (power flow is from the ac to the dc side): $+V_d$ & $+I_d$
- Inverter mode (power flow is from the dc to the ac side): $-V_d$ & $+I_d$
- Inverter mode of operation on a sustained basis is only possible if a source of power, such as batteries, is present on the dc side.

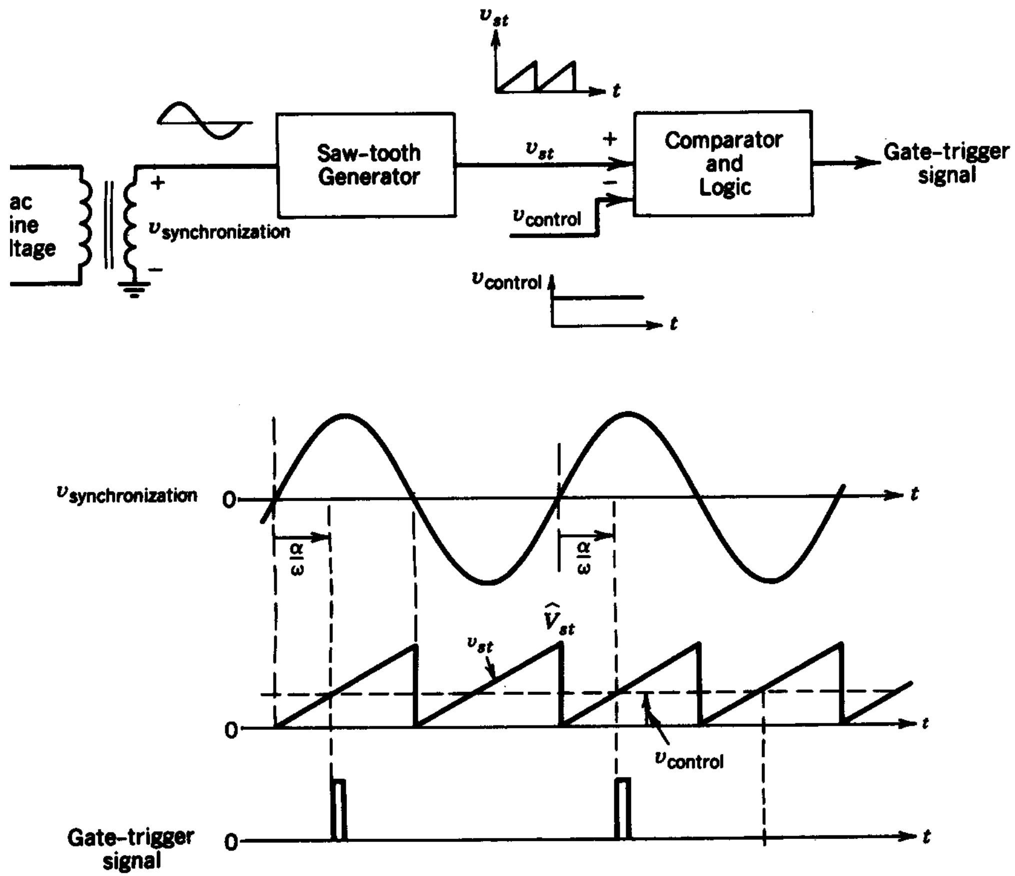


- Basic thyristor circuits: Line-frequency voltage source connected to a load resistance
- In the positive half cycle of v_s, the current is zero until $\omega t = \alpha$, at which a gate pulse of a short duration is applied
- With the thyristor conducting, $v_d = v_s$
- v_d becomes zero at $\omega t = \pi$
- By adjusting the firing angle α, the average dc voltage V_d and current I_d can be controlled

Thyristor Gate Triggering

- Generation of the firing signal
- The sawtooth waveform (synchronized to the ac input) is compared with the control signal $v_{control}$, and the delay angle α with respect to the positive zero crossing of the ac line voltage is obtained in terms of $v_{control}$ and the peak of the sawtooth waveform V_{st}.

$$\alpha^{o} = 180^{o}\left(\frac{v_{control}}{V_{st}}\right)$$



gure 6-3 Gate trigger control circuit.

Full-Bridge (Single- and Three-Phase) Thyristor Converters

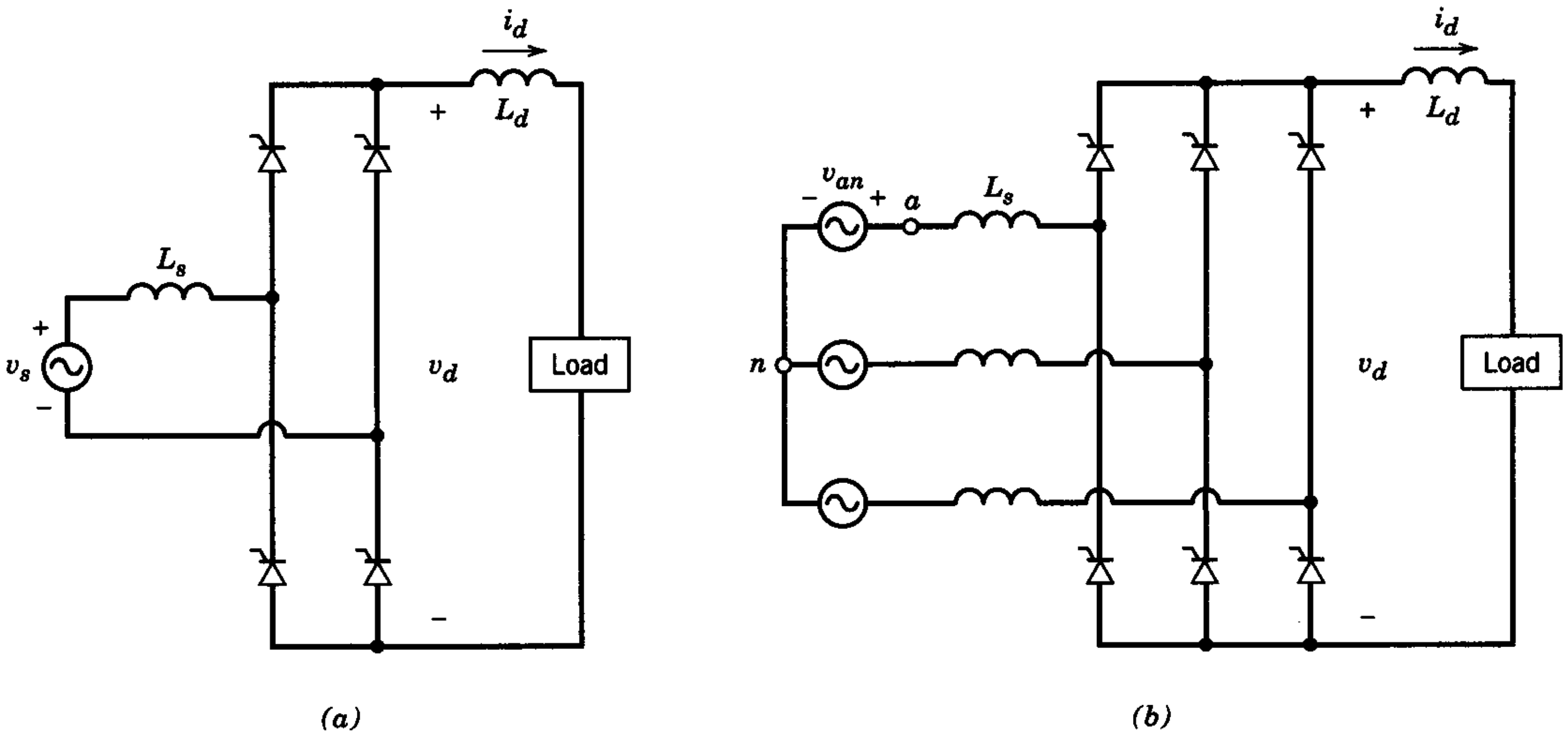


Figure 6-4 Practical thyristor converters.

Single-Phase Thyristor Converters

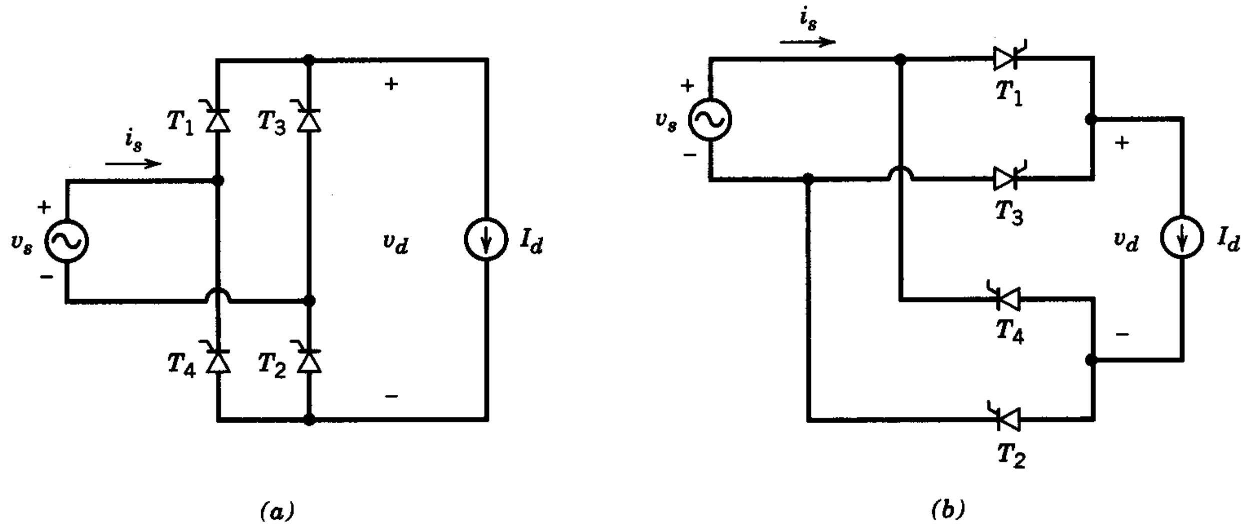
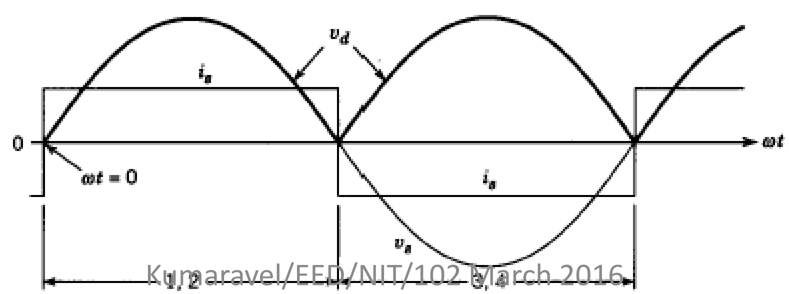


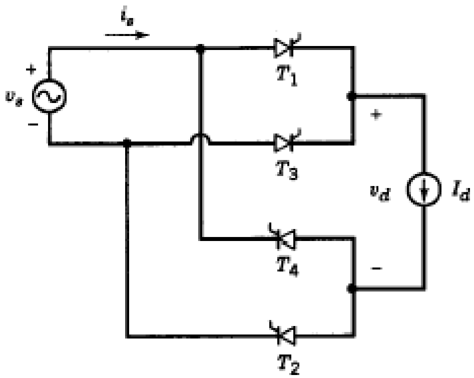
Figure 6-5 Single-phase thyristor converter with $L_s = 0$ and a constant dc current.

- One thyristor of the top group and one of the bottom group will conduct
- If a continuous gate pulse is applied then this circuit will act like a full bridge diode rectifier and the web forms are as shown below
- α=0 for 1 and 2 and $\alpha=\pi$ for thyristors 3 and 4



(a) $\alpha = 0$

1-Phase Thyristor Converter Waveforms



- Assumptions: L_s=0 and purely dc current I_d
- α: delay angle or firing angle
- Prior to ωt=0, current is flowing through 3 and 4, and $v_d = -v_s$
- Beyond ωt=0, thyristors 1 and 2 become forward biased, but cannot conduct until α.
- v_d becomes negative between 0 and α as a consequence of the delay angle
- At $\omega t=\alpha$, gate pulse applied and current commutation from thyristors 3 and 4 to 1 and 2 is instantaneous ($L_s = 0$), and $v_d = v_s$
- Thyristors 1 and 2 will keep conducting until 3 and 4 are fired

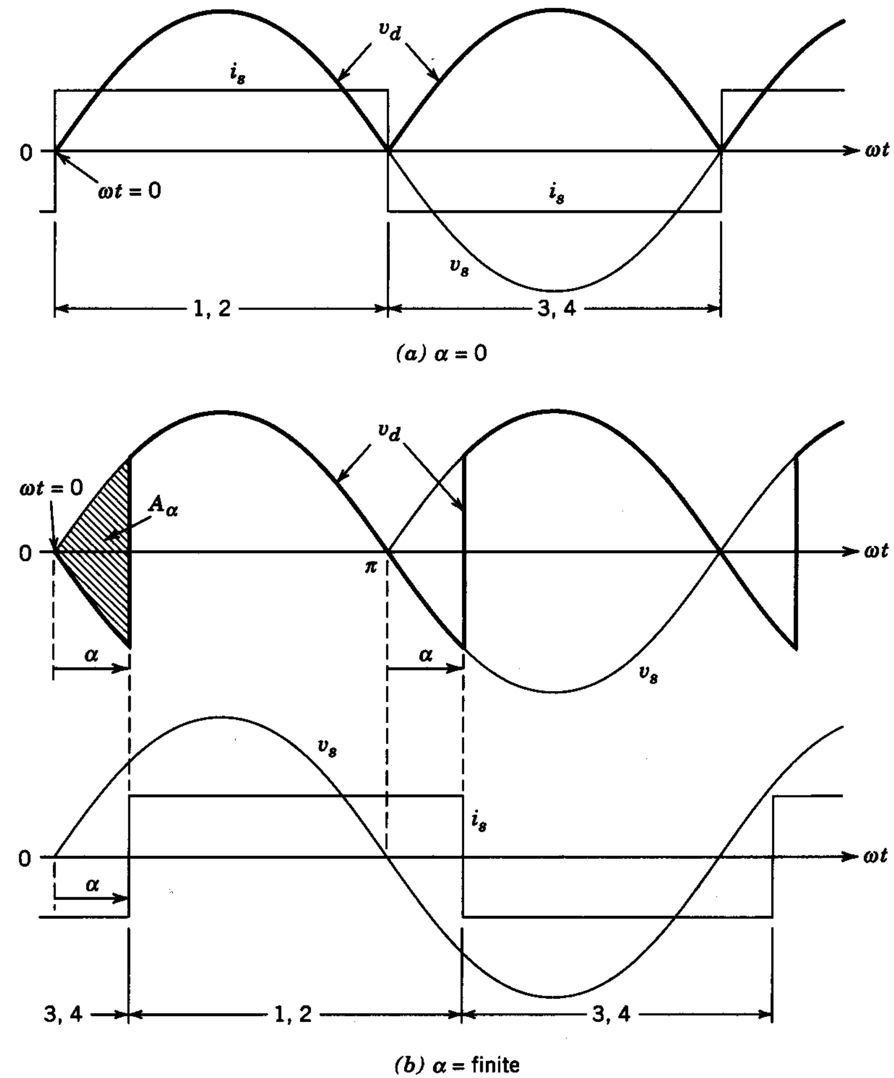


Figure 6-6 Waveforms in the converter of Fig. 6-5.

Average dc Voltage as a Function of the Delay Angle

The expression for the average voltage V_d:

$$V_{d\alpha} = \frac{1}{\pi}\int_{\alpha}^{\alpha+\pi}\sqrt{2}V_s \sin\omega t \, d(\omega t) = 0.9V_s \cos\alpha$$

Let V_{d0} be the average dc voltage with $\alpha=0$,

$$V_{d0} = \frac{1}{\pi}\int_{0}^{\pi}\sqrt{2}V_s \sin\omega t \, d(\omega t) = 0.9V_s$$

Then, drop in average voltage due to α,

$$\Delta V_{d\alpha} = V_{d0} - V_{d\alpha} = 0.9V_s(1-\cos\alpha)$$

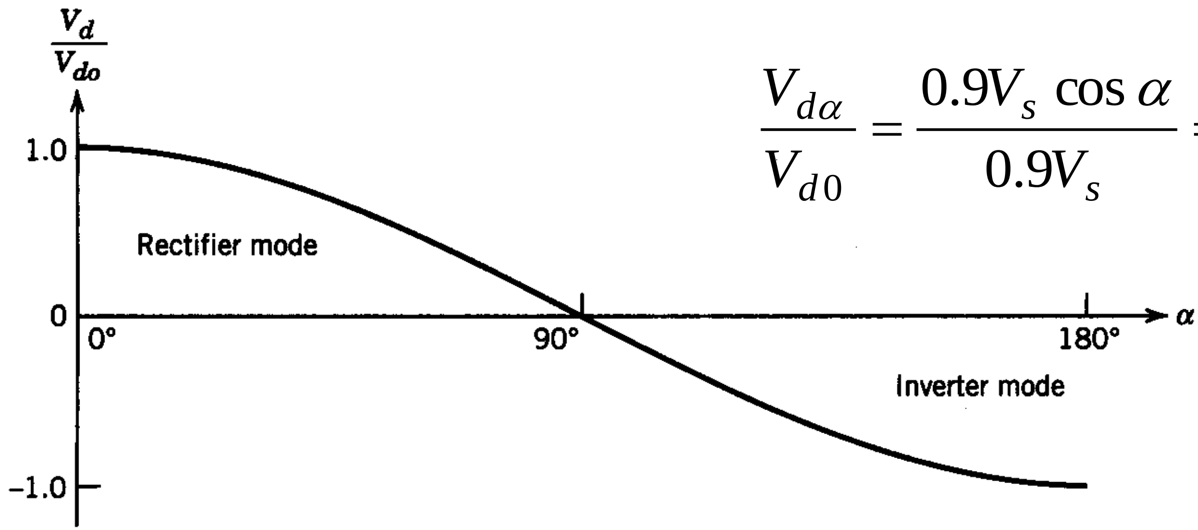
The average power through the converter,

$$P = \frac{1}{T}\int_{0}^{T} p(t)dt = \frac{1}{T}\int_{0}^{T} v_d i_d \, dt$$

With a constant dc current ($i_d=I_d$),

$$P = I_d\left[\frac{1}{T}\int_{0}^{T} v_d \, dt\right] = I_d V_d = 0.9V_s I_d \cos\alpha$$

Average dc Output Voltage



$$\frac{V_{d\alpha}}{V_{d0}} = \frac{0.9V_s \cos\alpha}{0.9V_s} = \cos\alpha$$

Figure 6-7 Normalized V_d as a function of α.

The variation of V_d as a function of α:

Average dc voltage is positive until α=90°: this region is called the rectifier mode of operation

Average dc voltage becomes negative beyond α=90°: this region is called the inverter mode of operation

Thyristor Converters: Inverter Mode (V_d is negative)

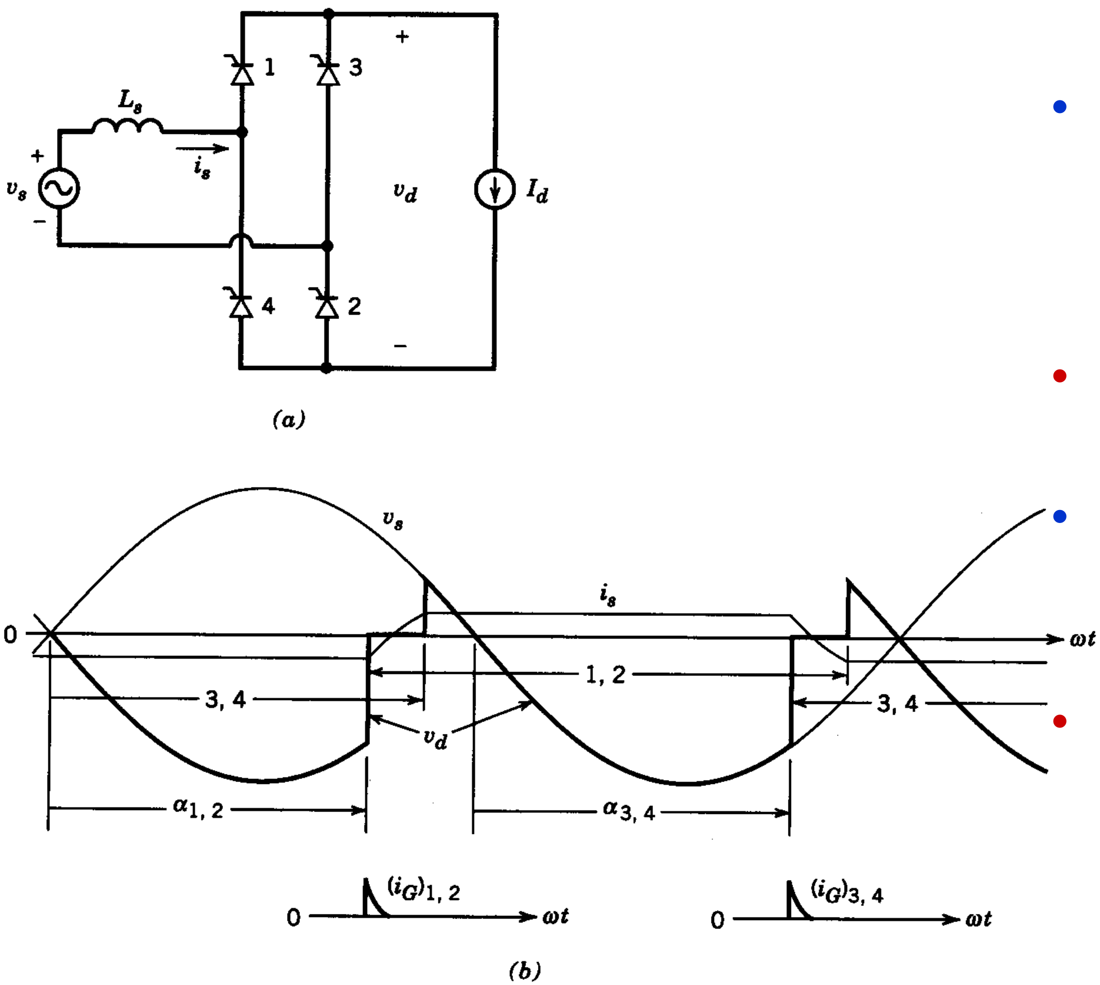


Figure 6-15 (*a*) Inverter, assuming a constant dc current. (*b*) Waveforms.

- Average value of v_d is negative for $90^o<\alpha<180^o$. Average power P_d is negative ($P_d=V_dI_d$) and thus power flows from the dc to the ac side
- On the ac side, $P_{ac}=V_sI_{s1}\cos\phi_1$ is also negative because $\phi_1>90^o$
- Inverter mode of operation is possible because there is a source of energy on the dc side
- ac side voltage source provides commutation of current from one pair of thyristors to the others

3-Phase Thyristor Converters

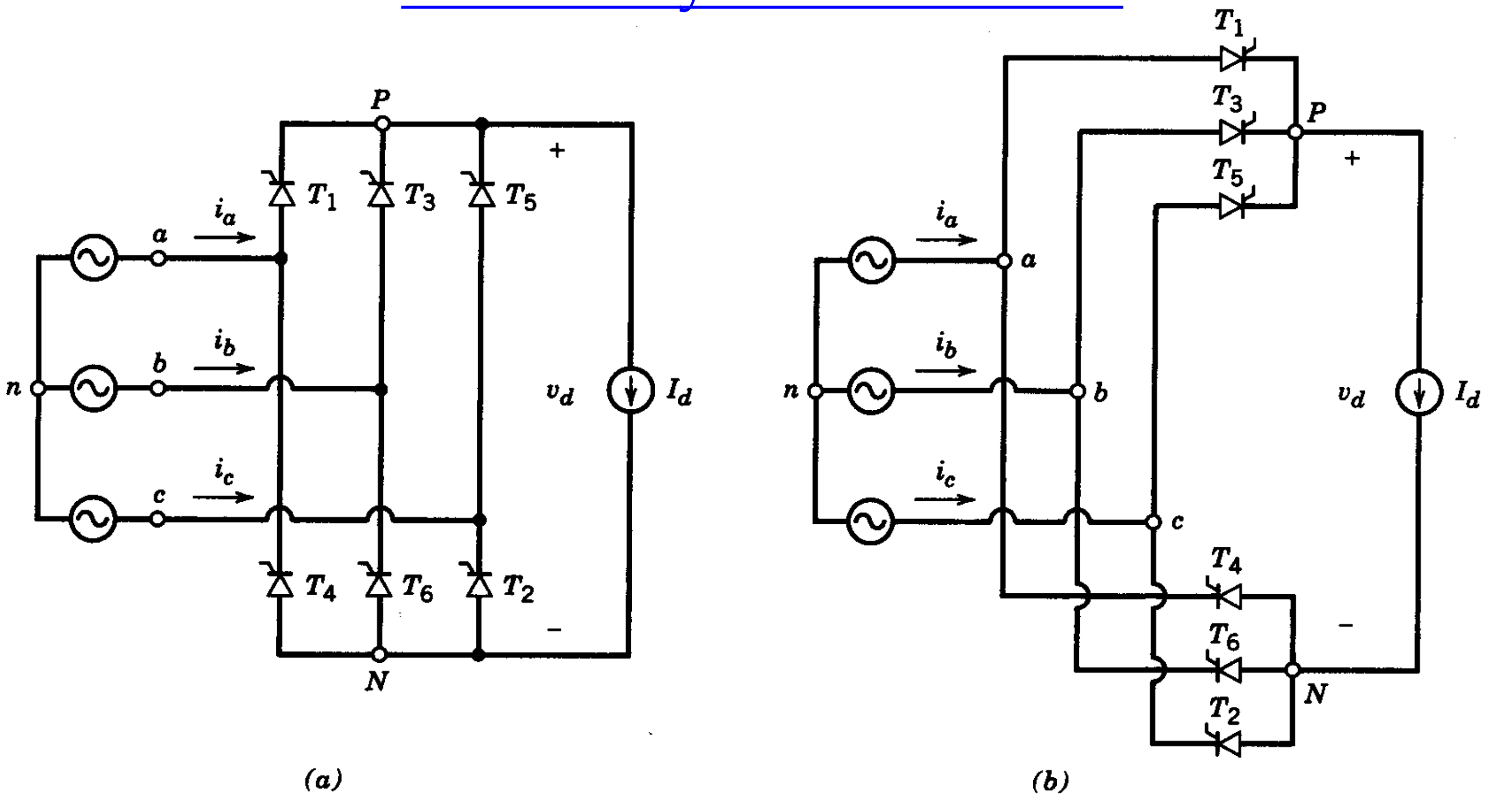


Figure 6-19 Three-phase thyristor converter with $L_s = 0$ and a constant dc current.

- Current I_d flows through the one thyristor of the top group and one of the bottom group
- If a continuous gate pulse is applied then this circuit will act like a three-phase full bridge diode rectifier and, as a result,

$$V_{d0} = 1.35 V_{LL}$$

3-Phase Thyristor Converter Waveforms

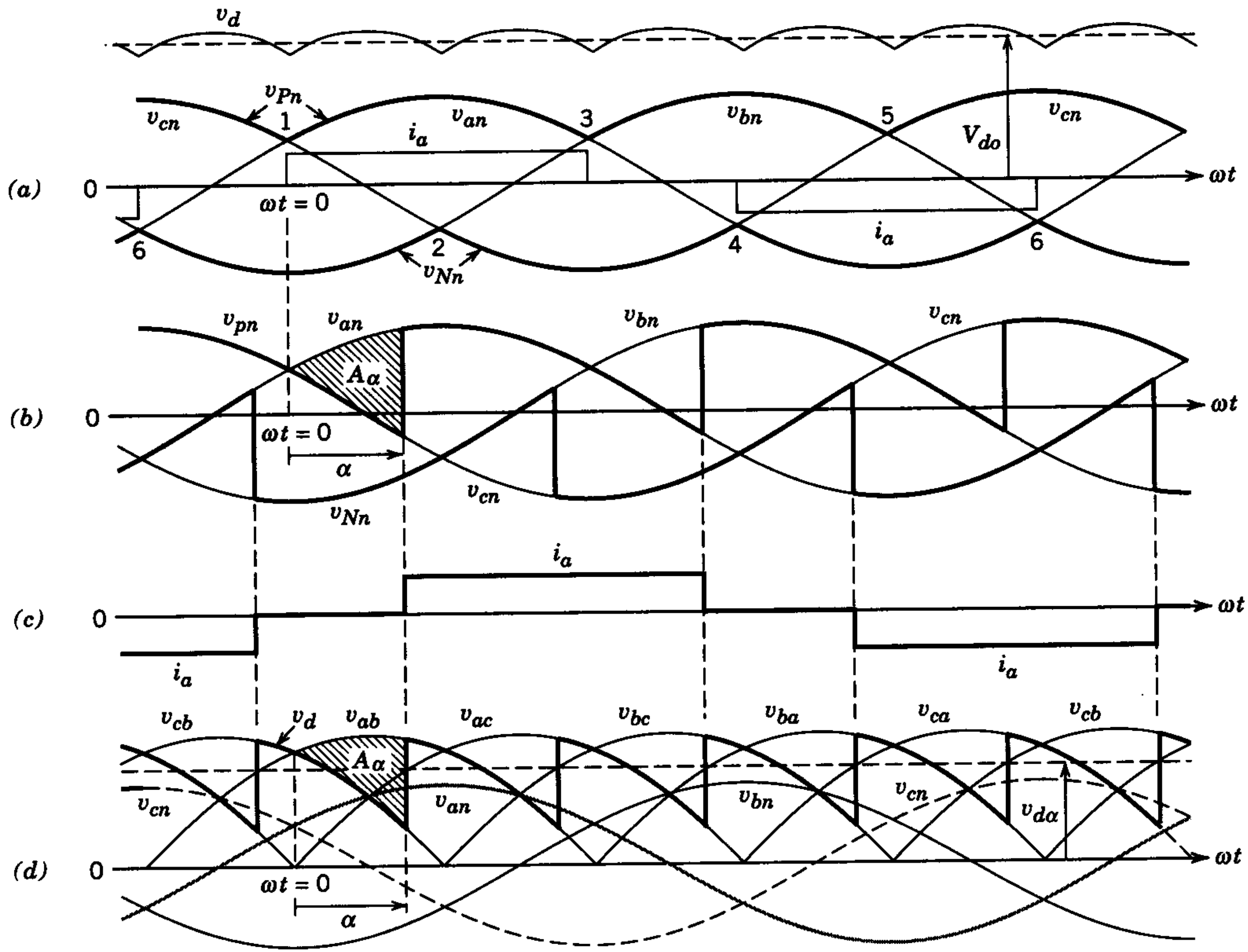


Figure 6-20 Waveforms in the converter of Fig. 6-19

Average Output DC Voltage

$$V_{d\alpha} = V_{d0} - \frac{A_\mu}{\pi/3}$$

$$V_{ac} = \sqrt{2}V_{LL}\,\sin(\omega t)$$

The reduction in the average dc voltage due to the delay angle α

$$A_\mu = \int_0^\alpha \sqrt{2}V_{LL}\,\sin(\omega t)d(\omega t) = \sqrt{2}V_{LL}(1-\cos\alpha)$$

$$\therefore \quad V_{d\alpha} = V_{d0} - \frac{A\mu}{\pi/3} = 1.35V_{LL} - \frac{\sqrt{2}V_{LL}(1-\cos\alpha)}{\pi/3}$$

$$= 1.35V_{LL}\cos\alpha = 1.35V_{d0}$$

Average Power

$$P_{d\alpha} = V_{d\alpha} I_d = 1.35V_{LL} I_d \cos\alpha$$

❖dc-side voltage waveforms as a function of α

❖V_d repeats at six times the line frequency

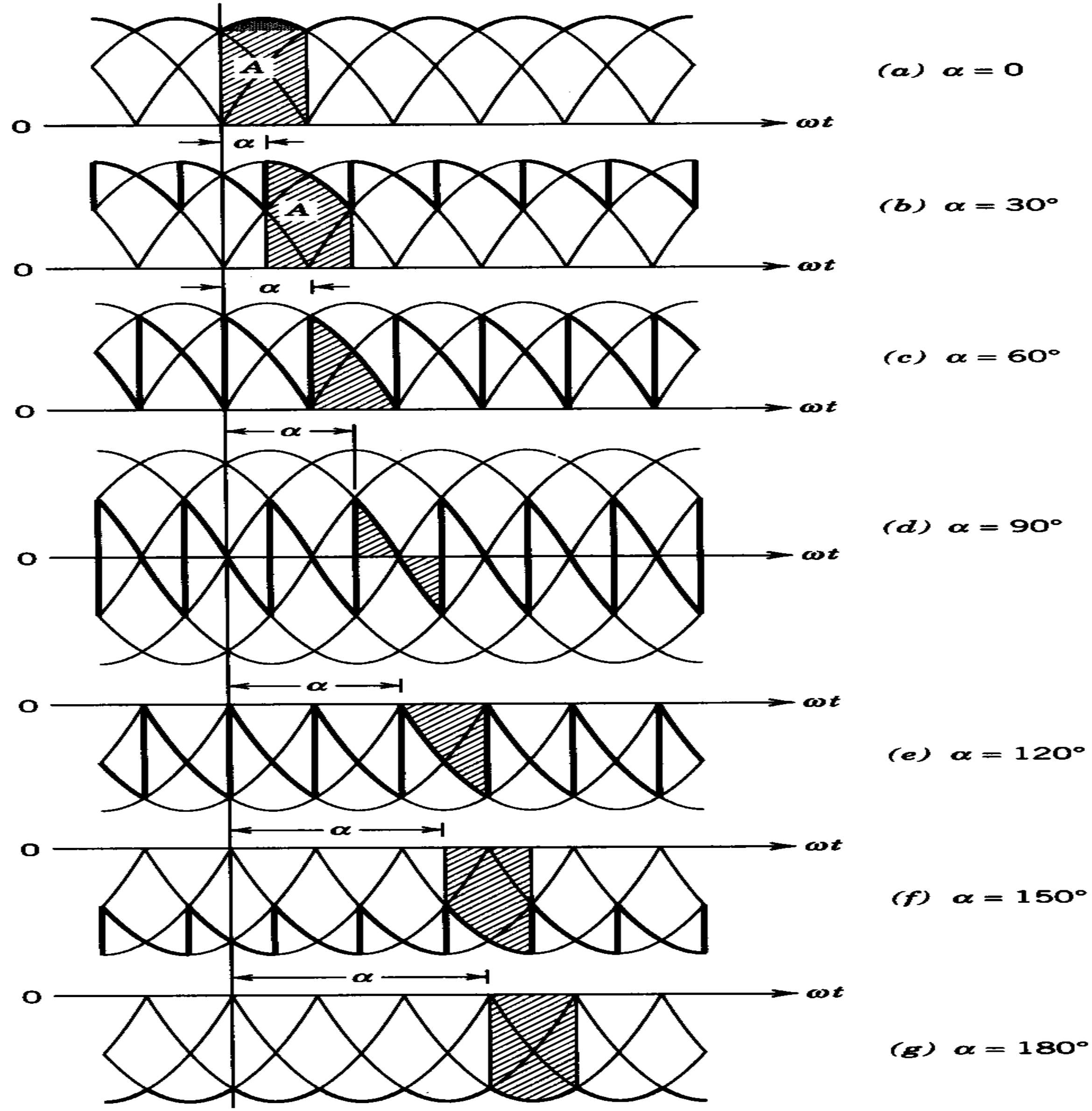
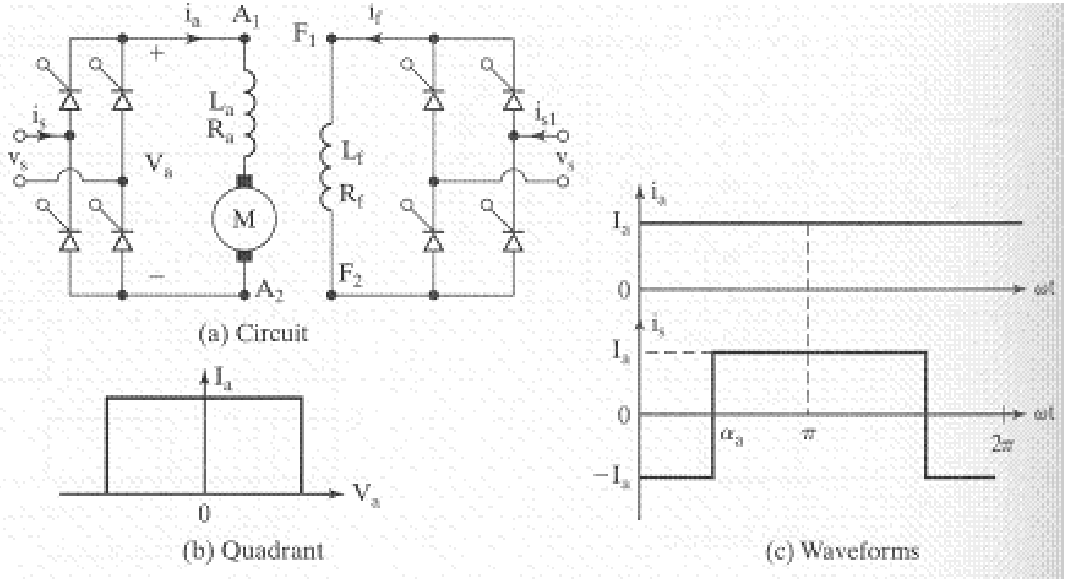


Figure 6-21 The dc-side voltage waveforms as a function of α where $V_{d\alpha}$ = A/(π/3). (From ref. 2 with permission.)

Single-Phase Full-Wave-Converter Drives

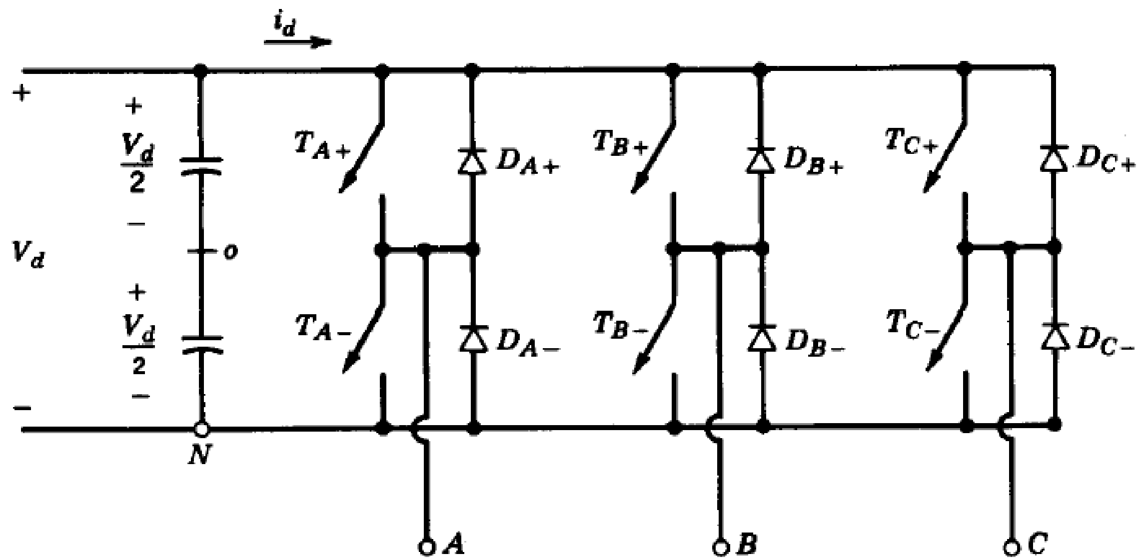
- The converter in the field circuit could be a full, or even a dual converter.
- The reversal of the armature or field allows operation in the second and third quadrants.
- The current waveforms for a highly inductive load are shown in Figure 15.13c for powering action.



Three-Phase Drives

- The armature circuit is connected to the output of a three-phase controlled rectifier.
- Three-phase drives are used for high-power applications up to megawatt power levels.
- The ripple frequency of the armature voltage is higher than that of single-phase drives and it requires less inductance in the armature circuit to reduce the armature ripple current.
- The armature current is mostly continuous, and therefore the motor performance is better compared with that of single-phase drives.

Three-Phase Inverter



- Used to supply three-phase loads
- Three single-phase inverters could be used, however, 12 switches are necessary, as a result, less efficient
- Consists of three legs, one for each phase
- One of the two switches in a leg is always ON at any instant
- Output of each leg depends on V_d and the switching status

Three-Phase Full-Wave-Converter Drives

- A three-phase full-wave-converter drive is a two-quadrant drive without any field reversal, and is limited to applications up to 1500 kW.
- During regeneration for reversing the direction of power
- However, the back emf of the motor is reversed by reversing the field excitation.
- The converter in the field circuit should be a single- or three-phase full converter.

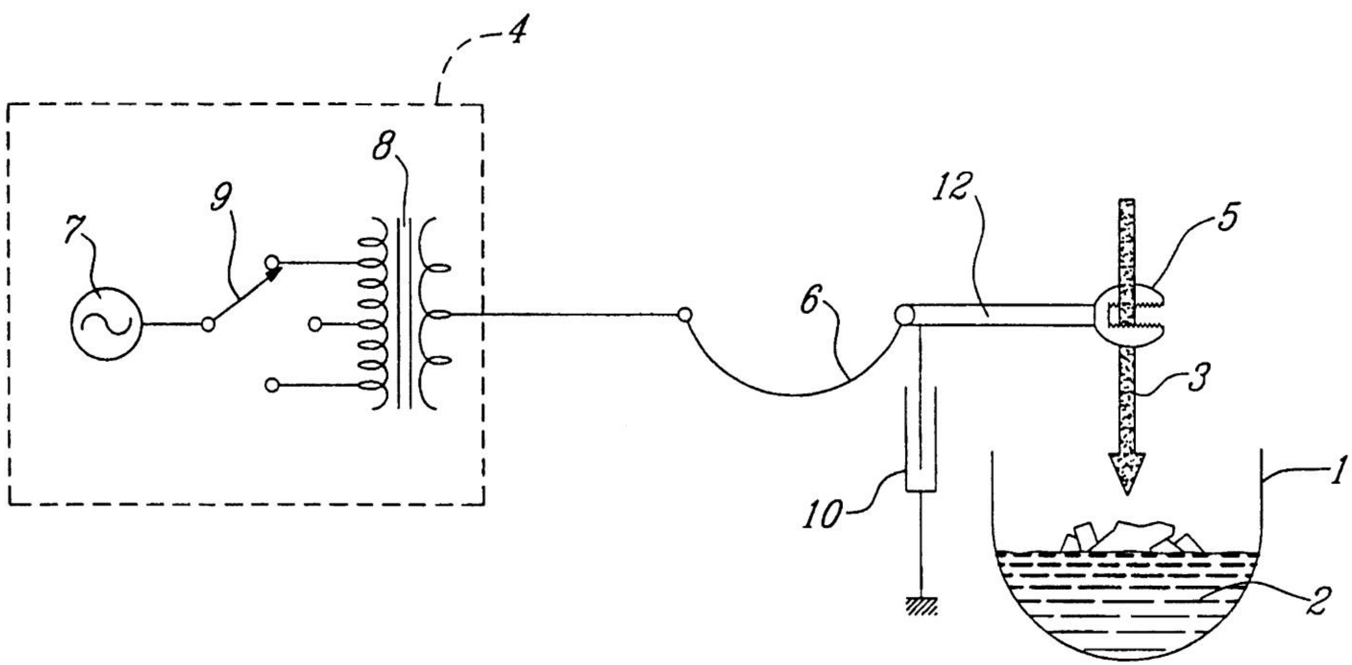
With a three-phase full-wave converter in the armature circuit, Eq. (10.25) gives the armature voltage as

$$V_a = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha_a \qquad \text{for } 0 \le \alpha_a \le \pi \qquad (15.26)$$

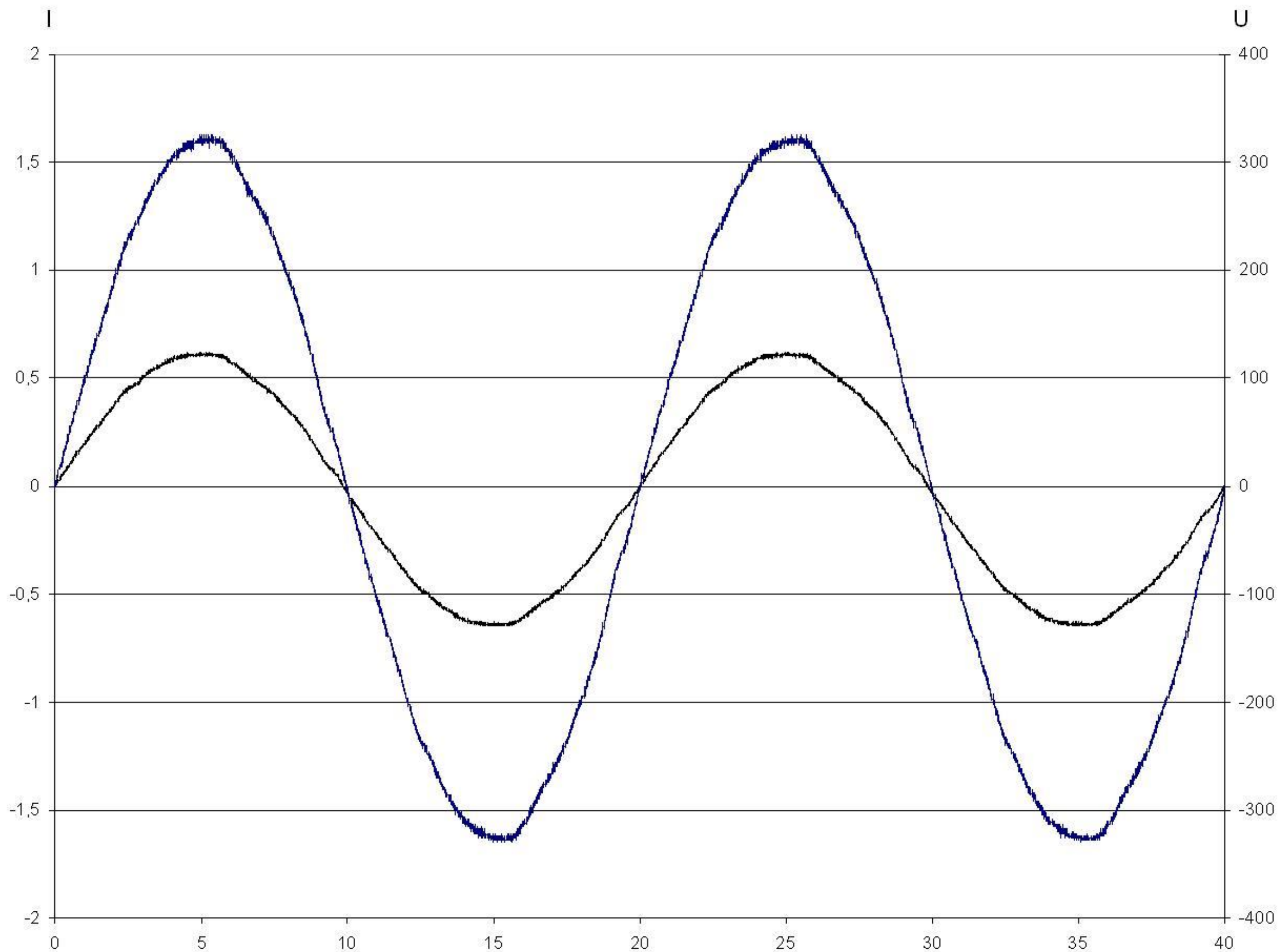
With a three-phase full converter in the field circuit, Eq. (10.25) gives the field voltage as

$$V_f = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha_f \qquad \text{for } 0 \le \alpha_f \le \pi \qquad (15.27)$$

Arc Furnace



Current drawn by a 100W incandescent lamp



Current drawn by a HF- Fluorescent Light

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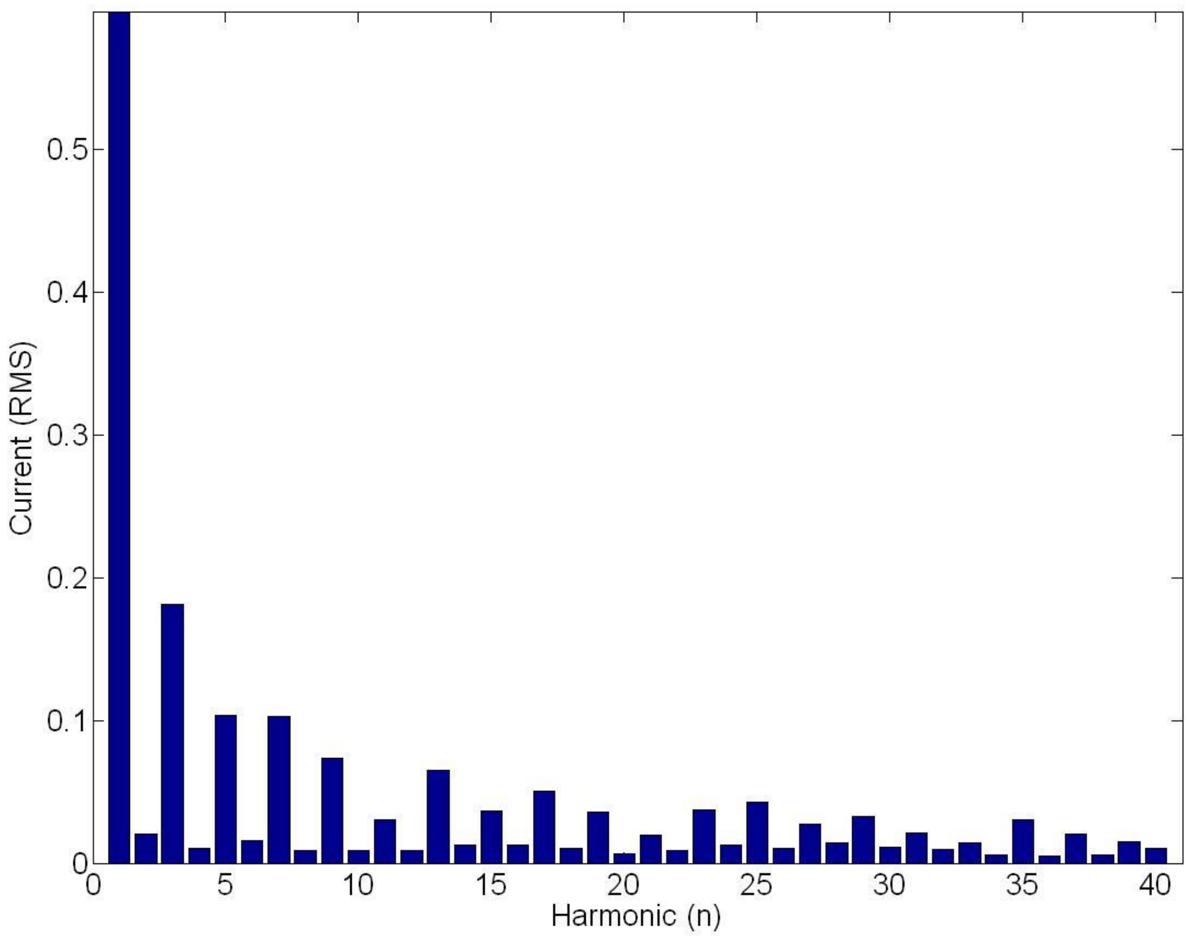
Current drawn by a HF- Fluorescent Light

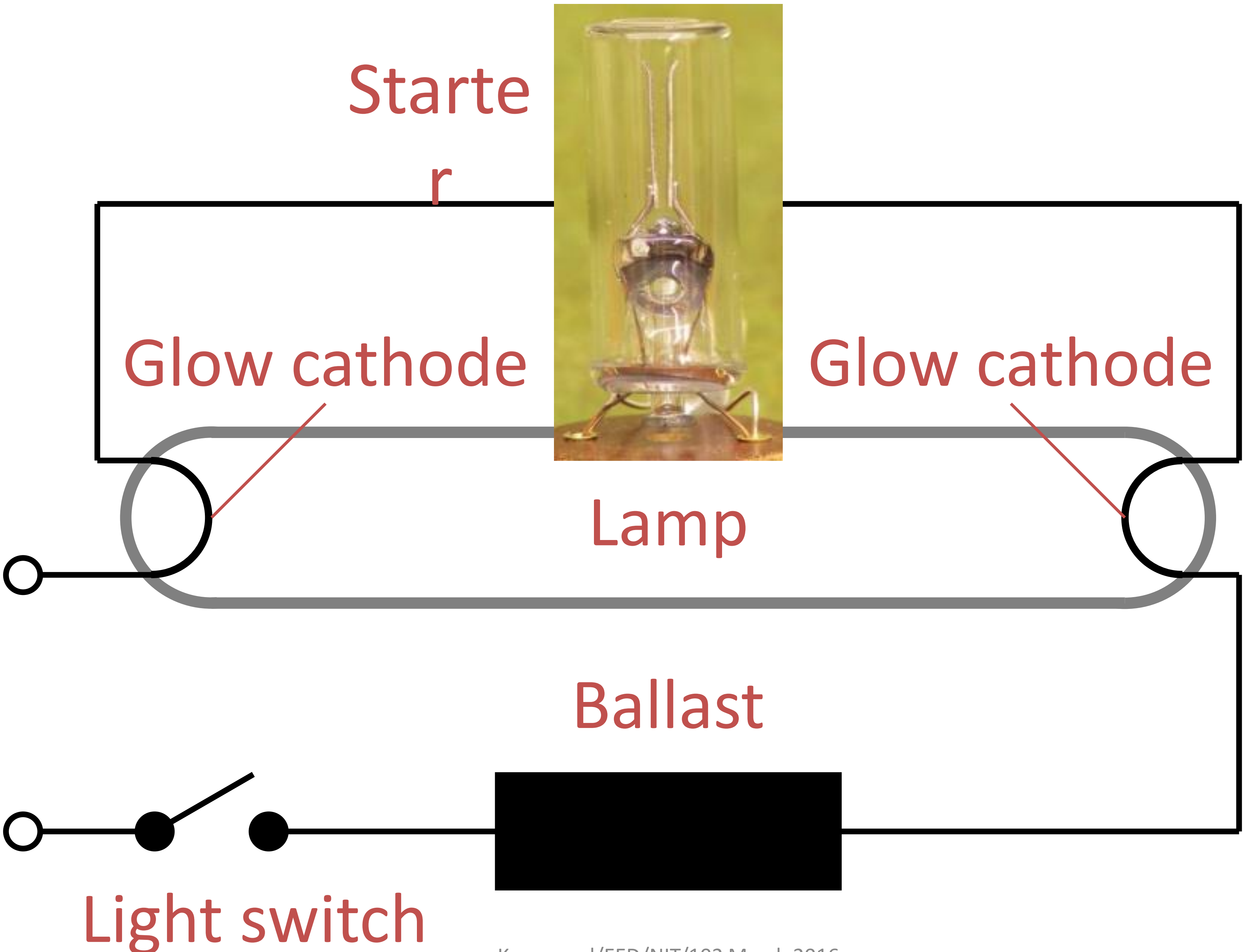


75% of all light is generated by fluorescent lamps

- These use **50%** of the share of electricity used in lighting
- (whereas lighting in total uses 11% of all electricity generation)



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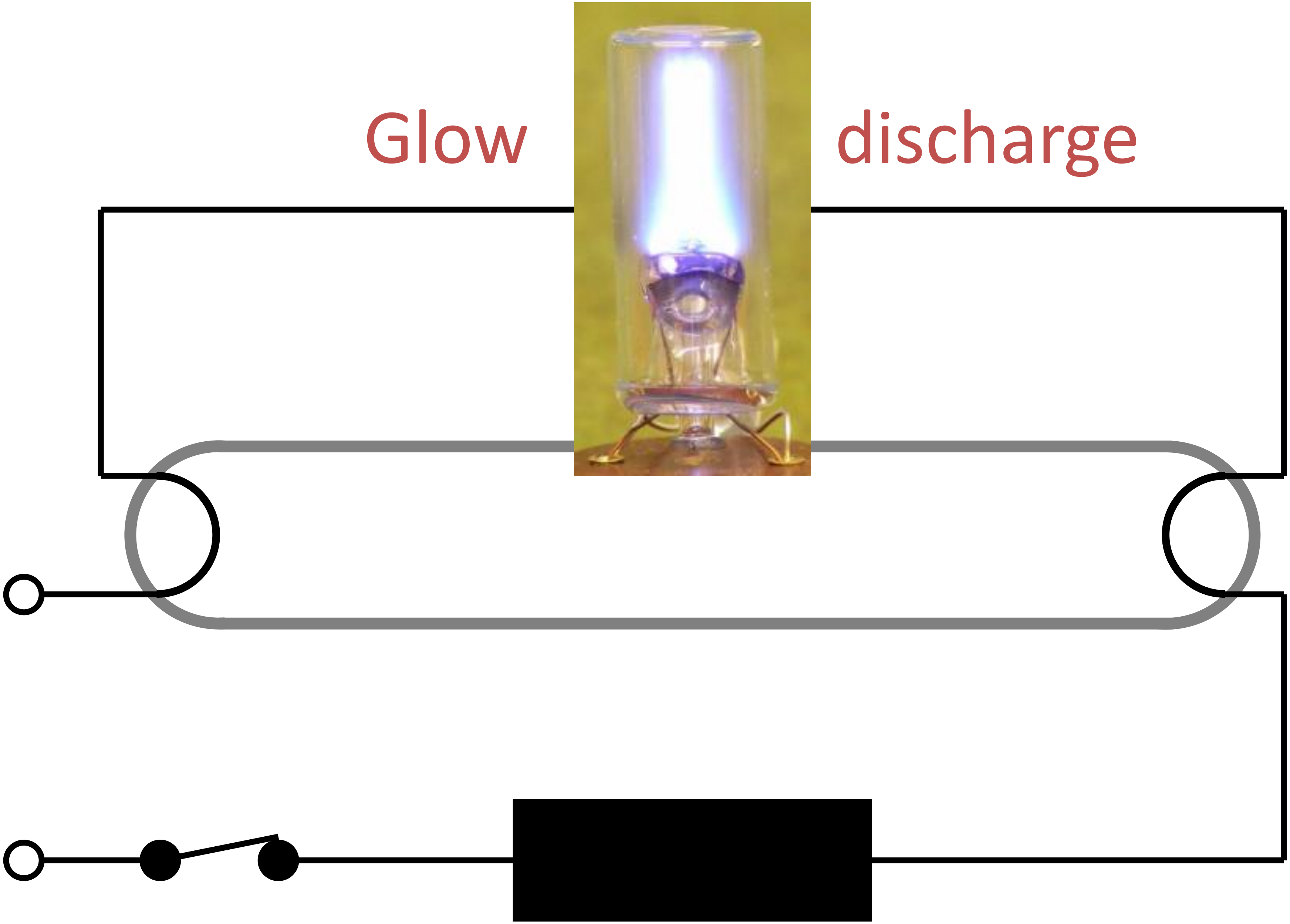
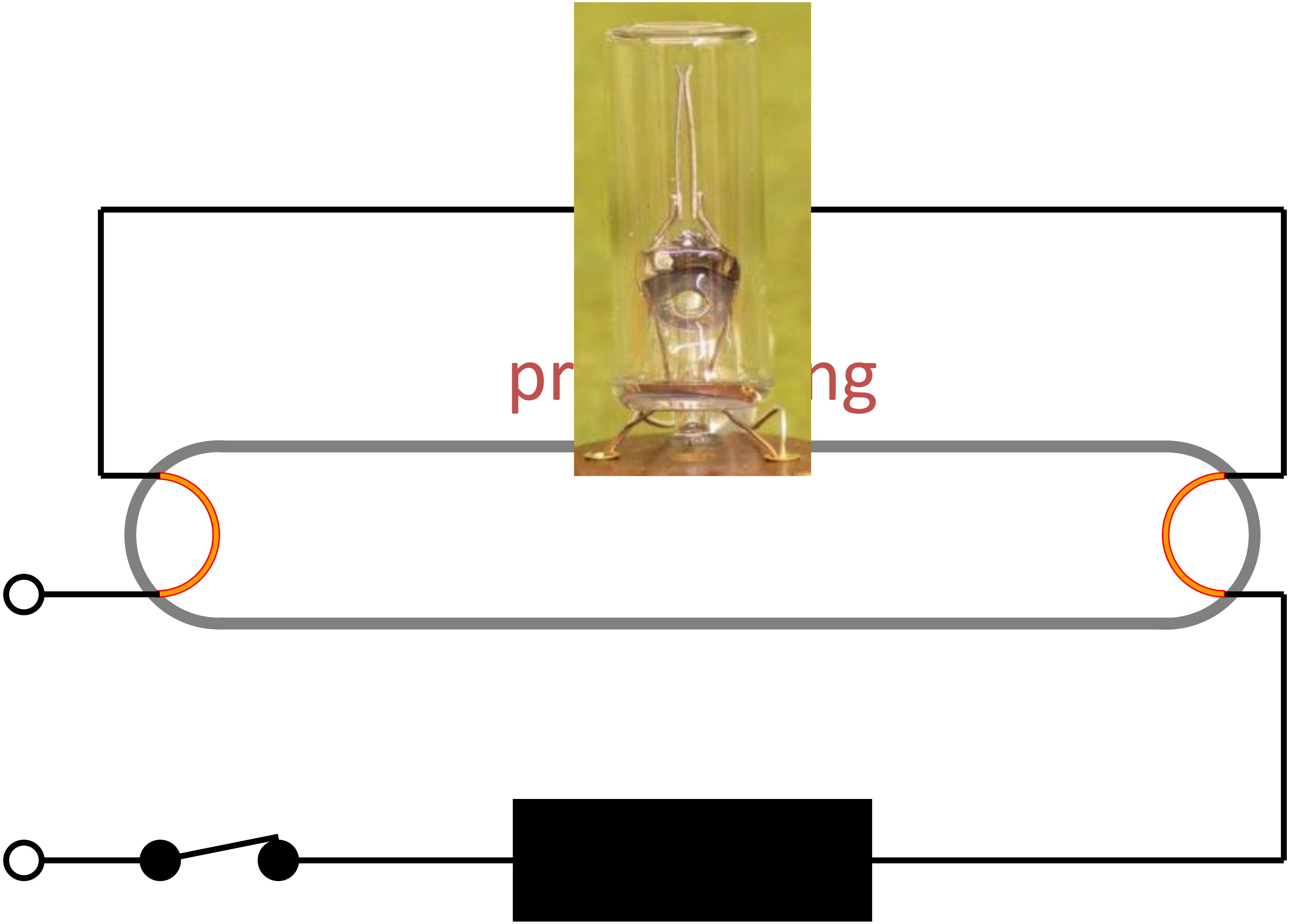
Glow cathode
Glow cathode
Lamp
Ballast
Light switch

Glow discharge

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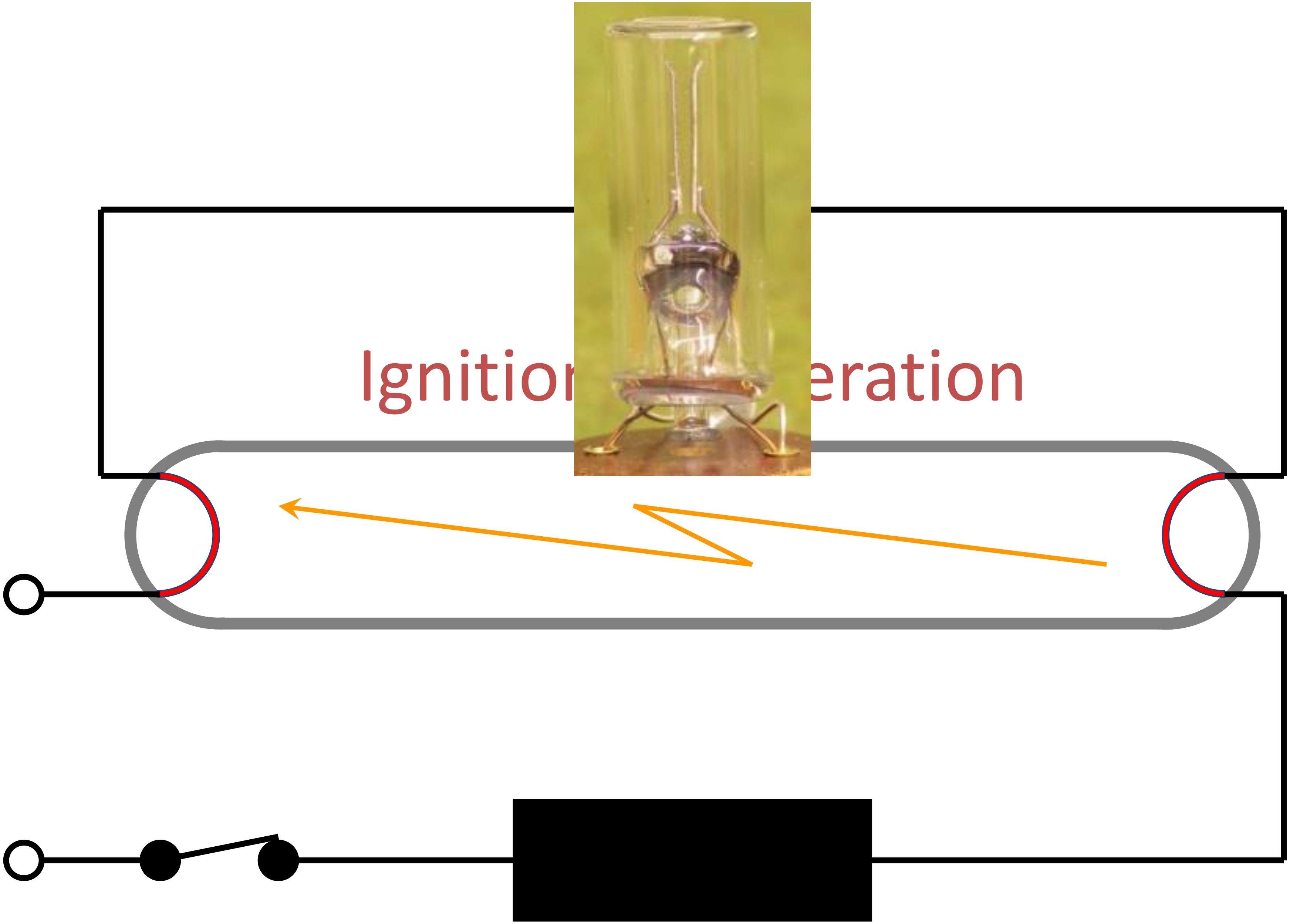
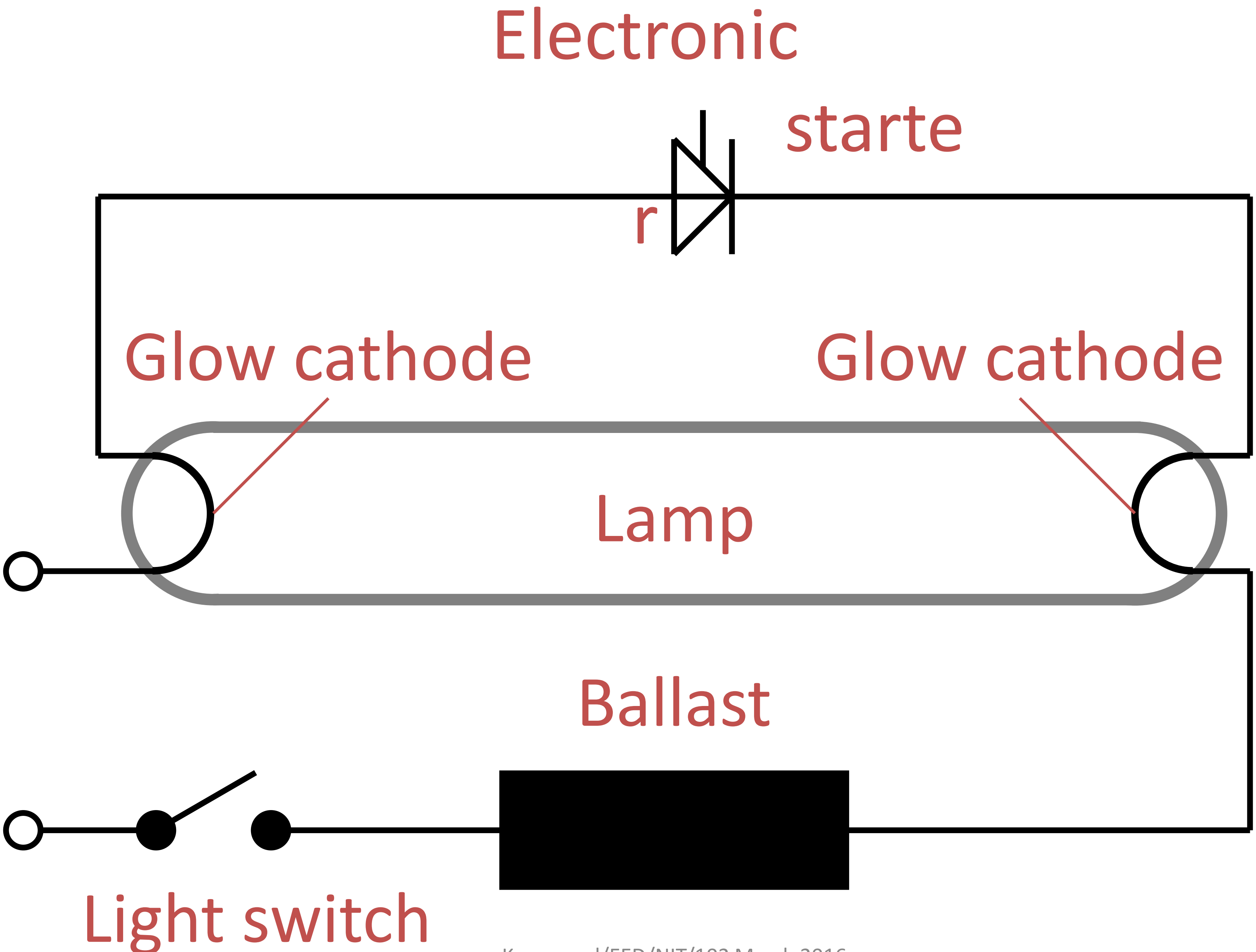
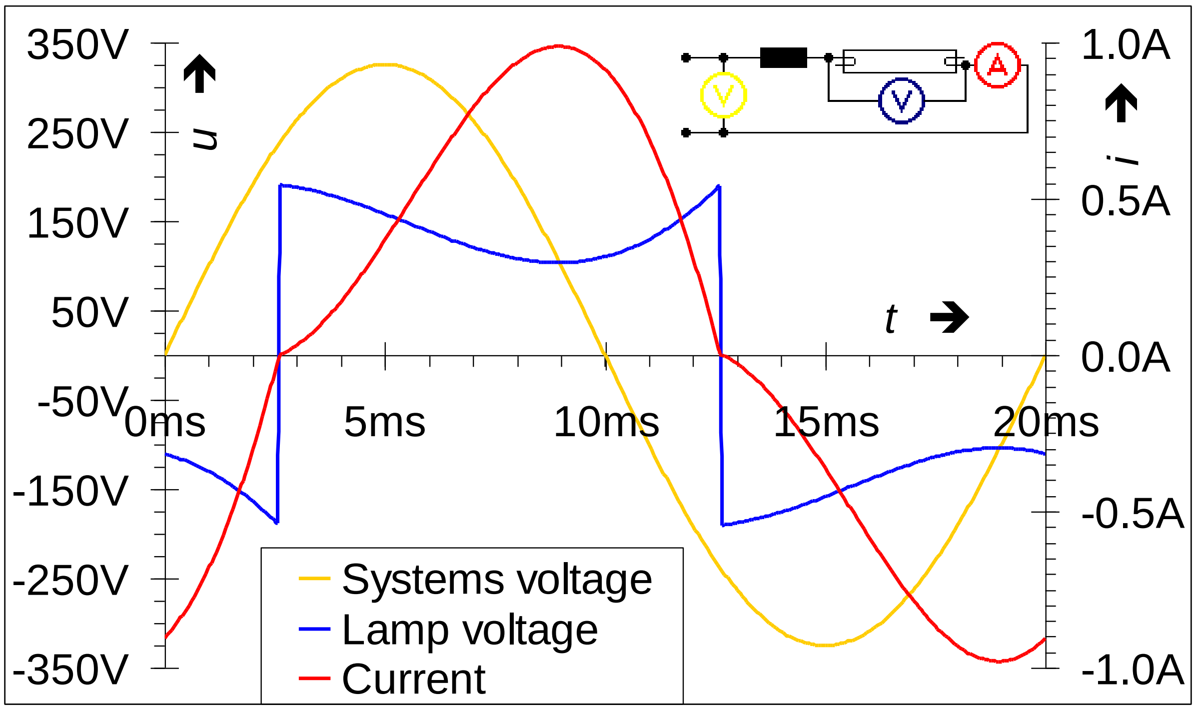


...and the less well known electronic starters

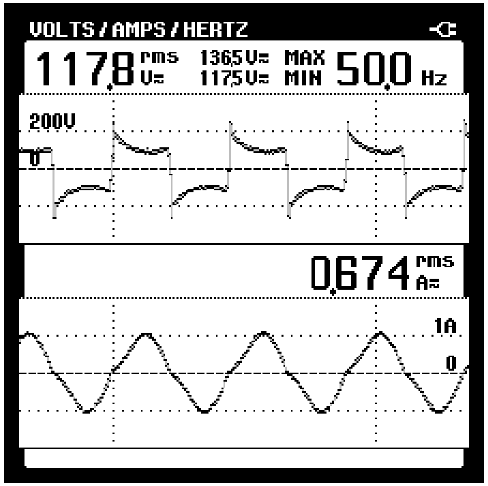

Electronic
starte
r
Glow cathode
Glow cathode
Lamp
Ballast
Light switch

Are they EMC compliant?

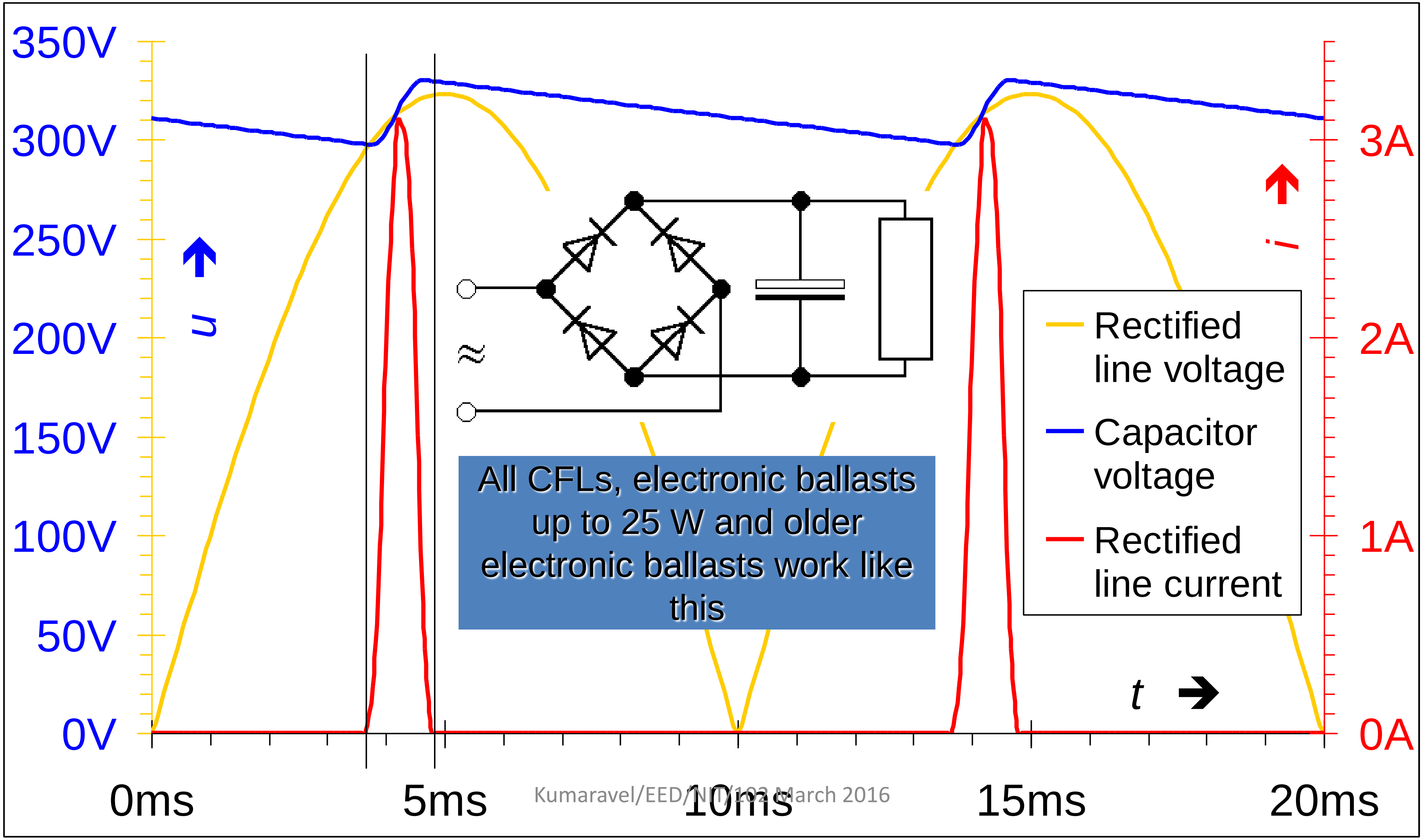
- The high inductance of a magnetic ballast suppresses current harmonics in theory…



…and in practice

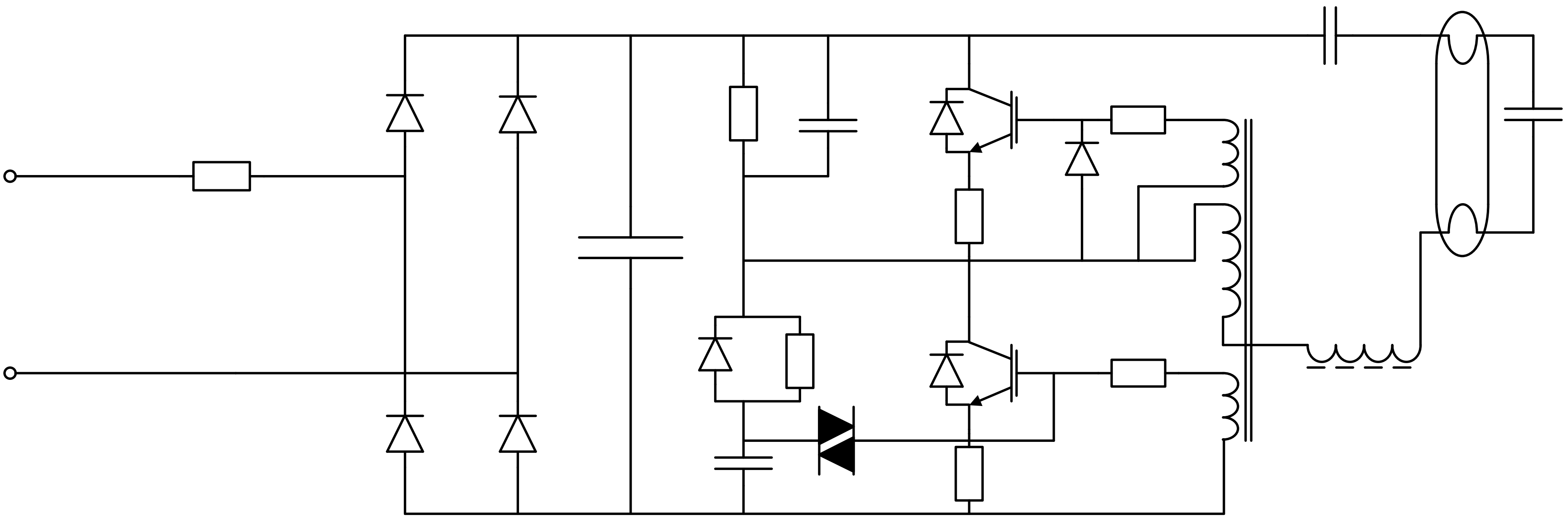


What effects do CFLs and what effects did older electronic ballasts have on the mains?

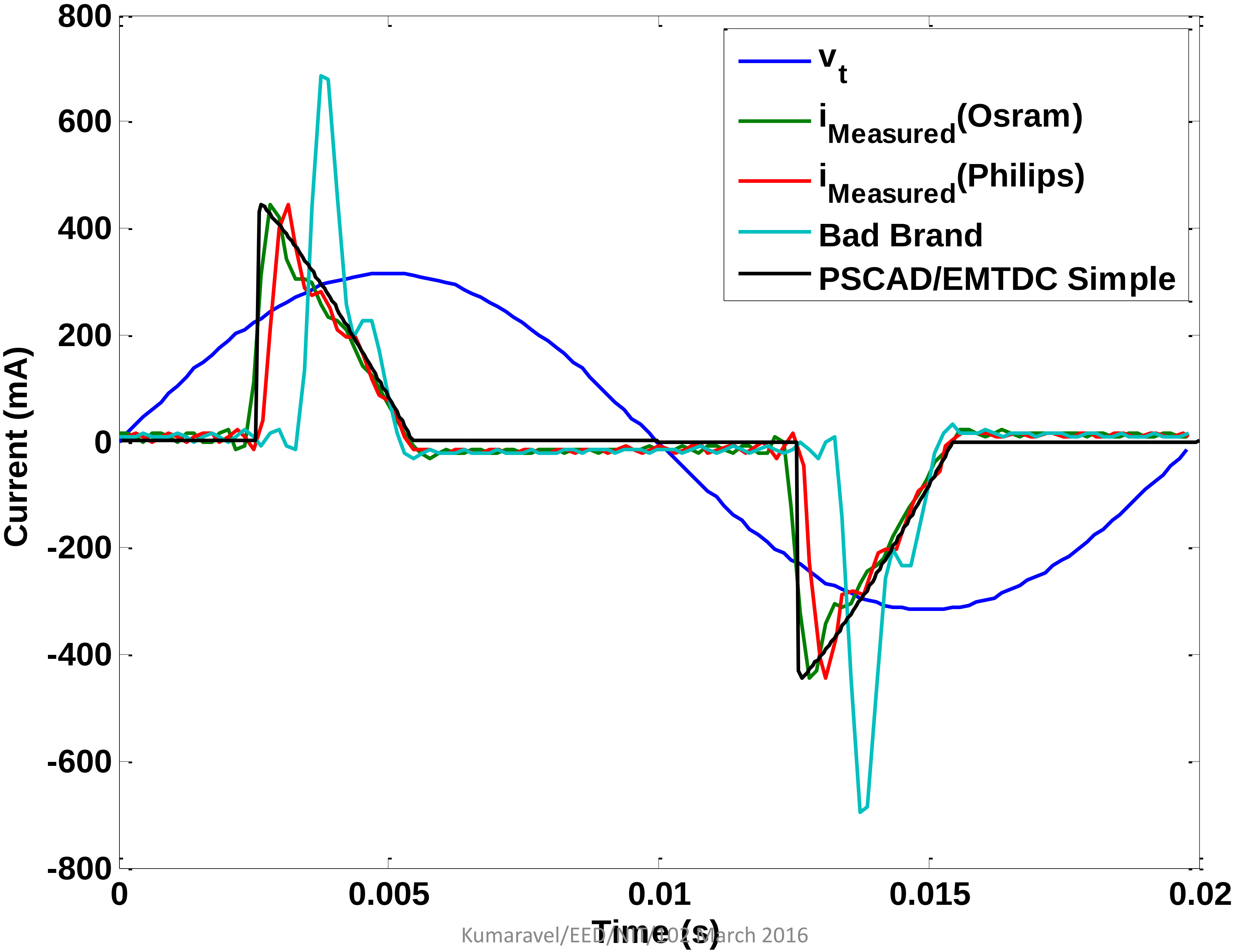


Outline

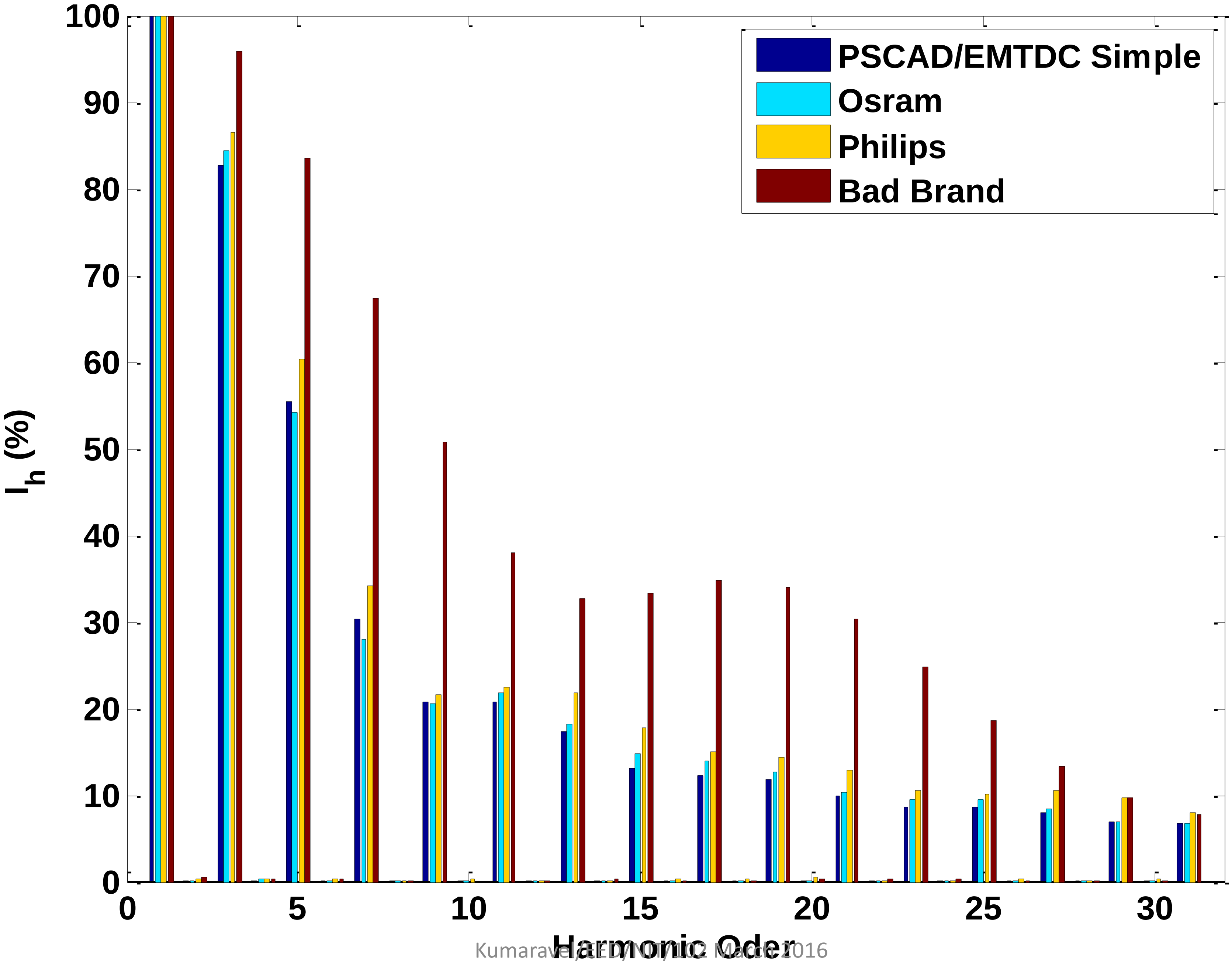
Eclipse 20W CFL



Eclipse CFL Schematic



800
600
400
200
0
-200
-400
-600
-800
Current (mA)
0
0.005
0.01
0.015
0.02
Time (s)
v_t
$i_{Measured}$(Osram)
$i_{Measured}$(Philips)
Bad Brand
PSCAD/EMTDC Simple


PSCAD/EMTDC Simple
Osram
Philips
Bad Brand
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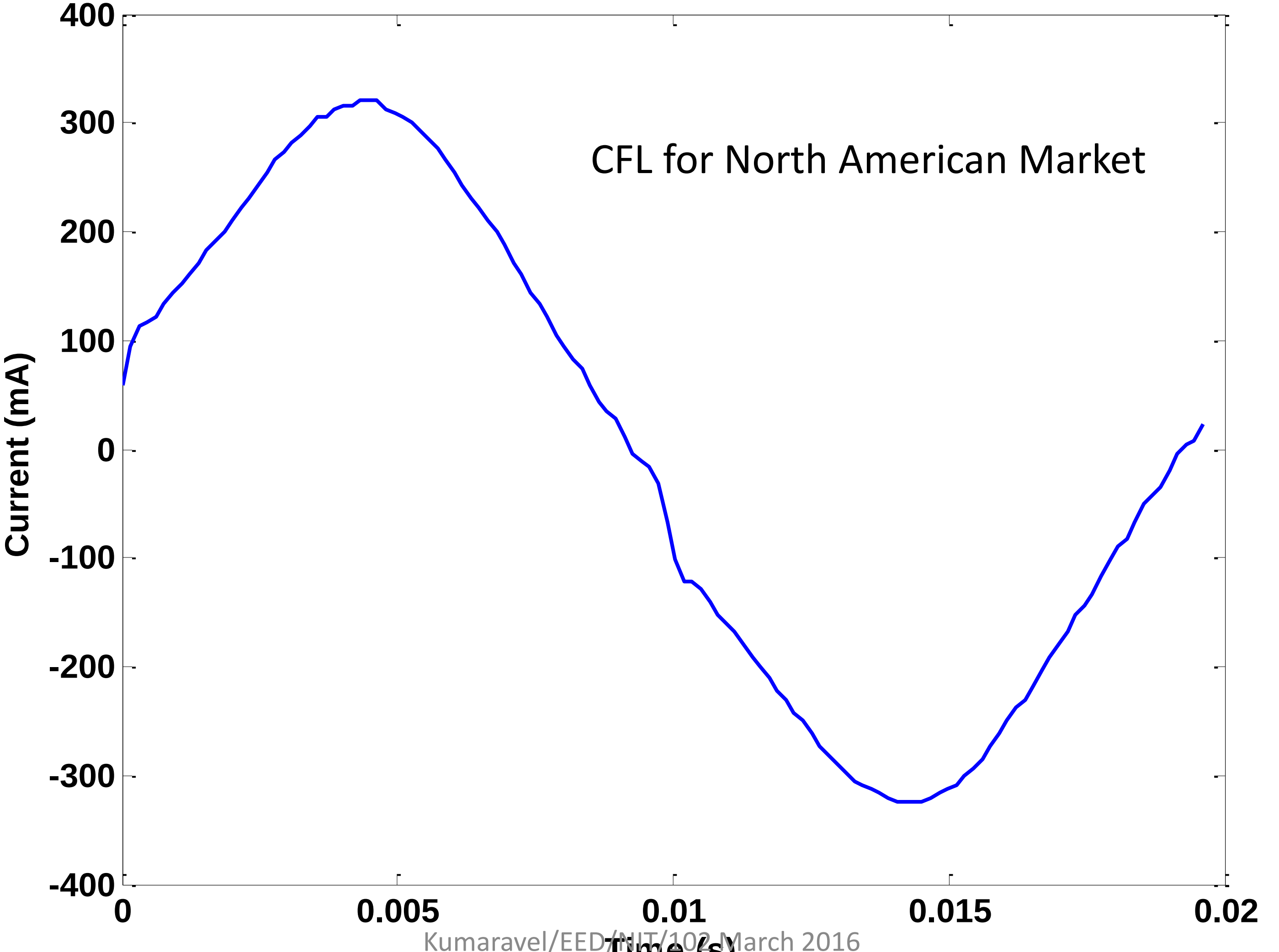
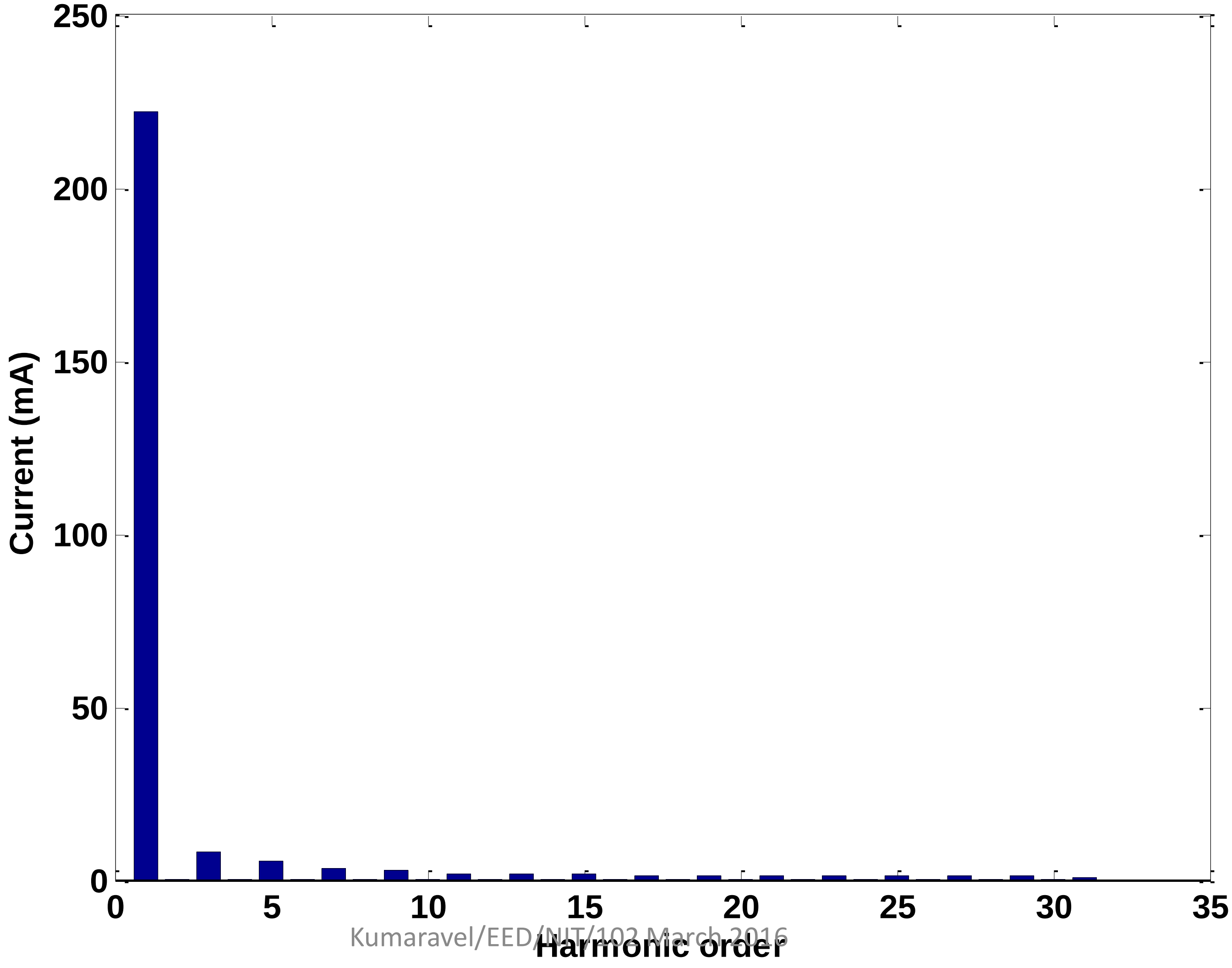
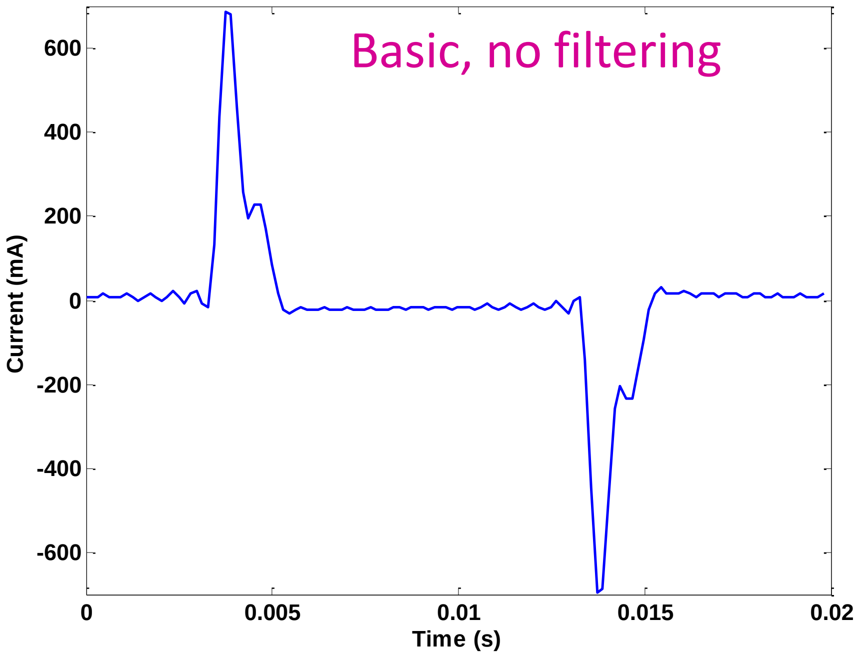
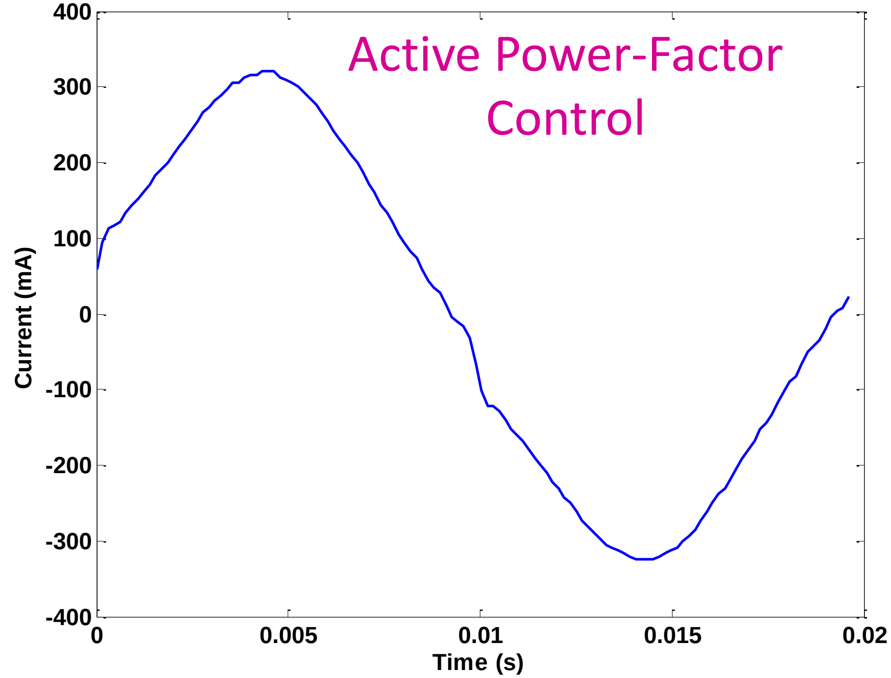
What is possible for a CFL

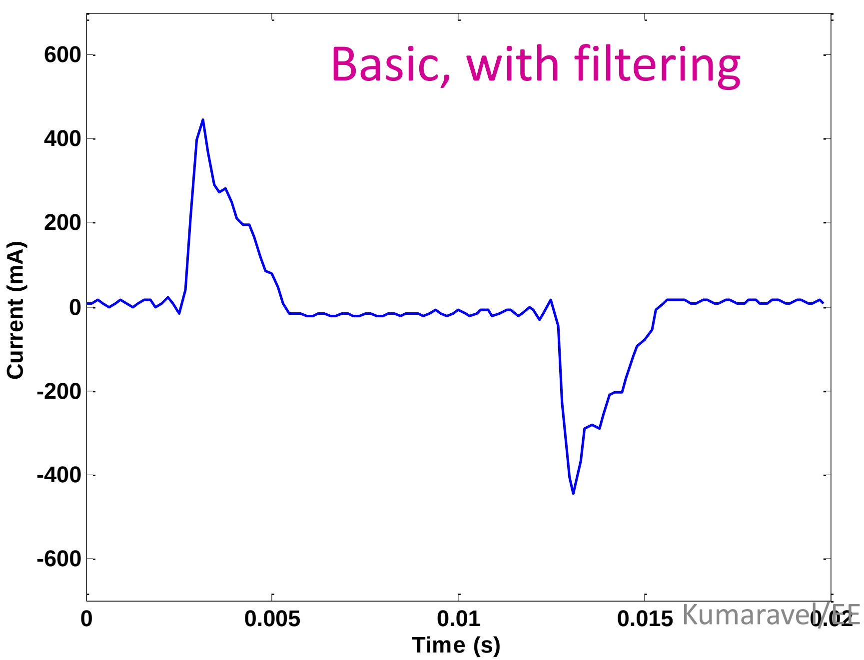


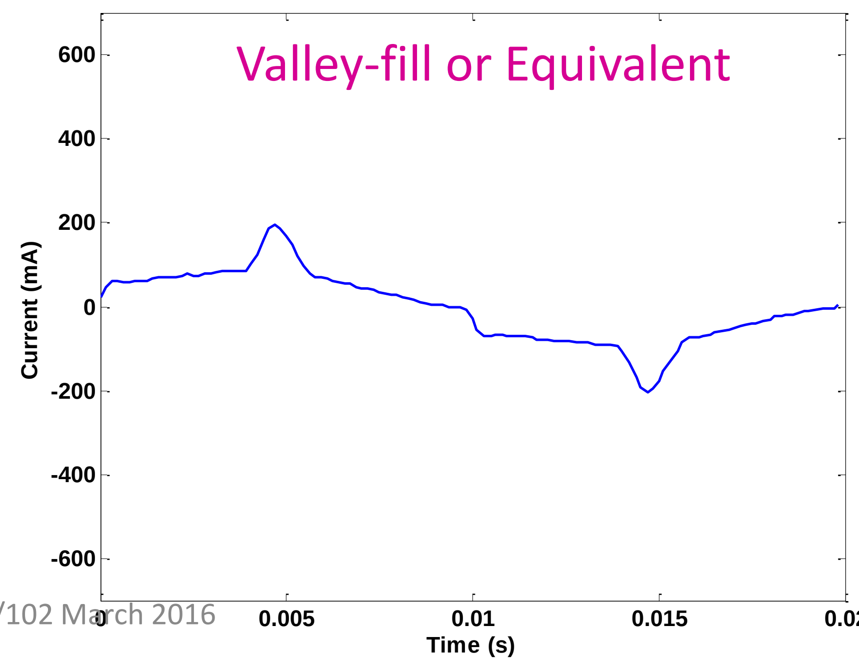
What is possible for a CFL

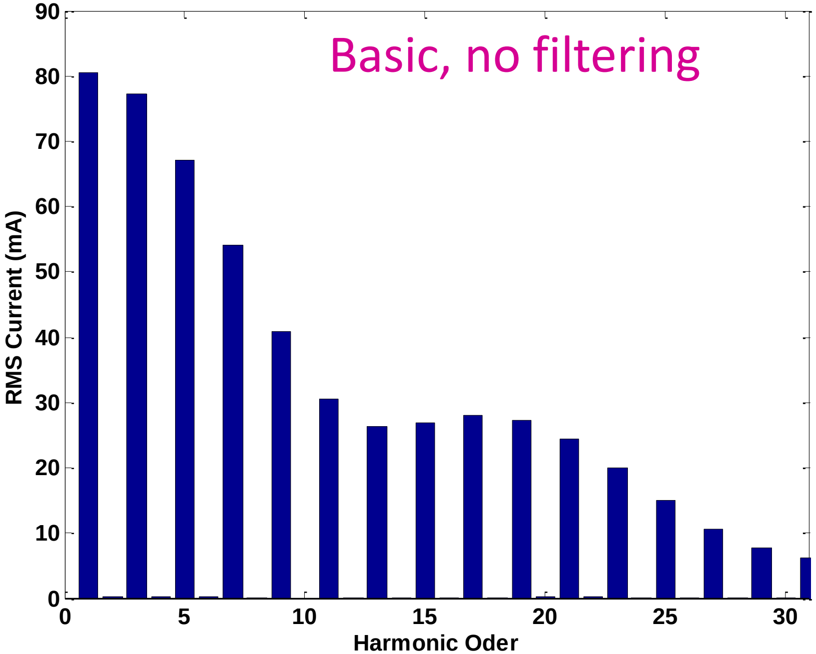


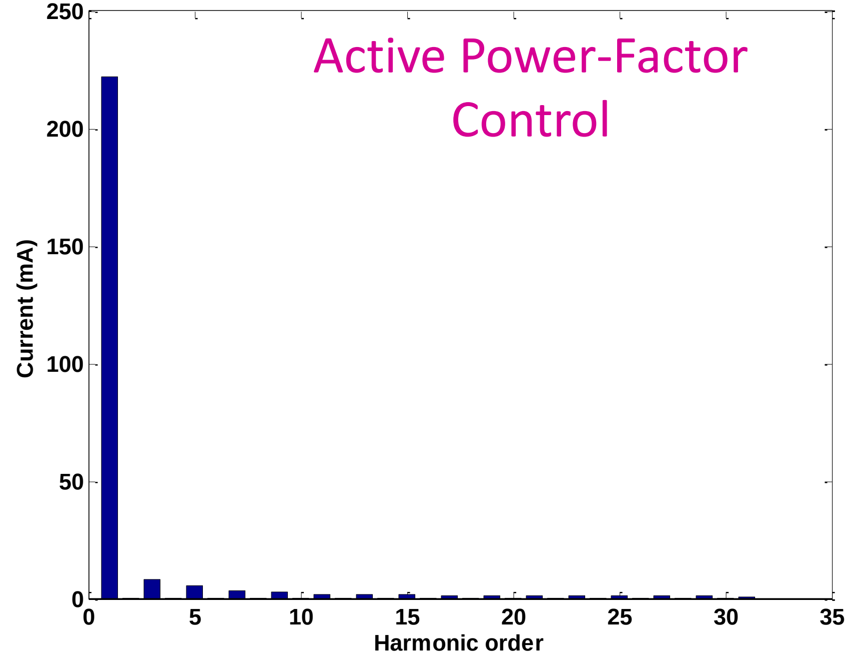

Basic, no filtering
Current (mA)
600
400
200
0
-200
-400
-600
0
0.005
0.01
0.015
0.02
Time (s)

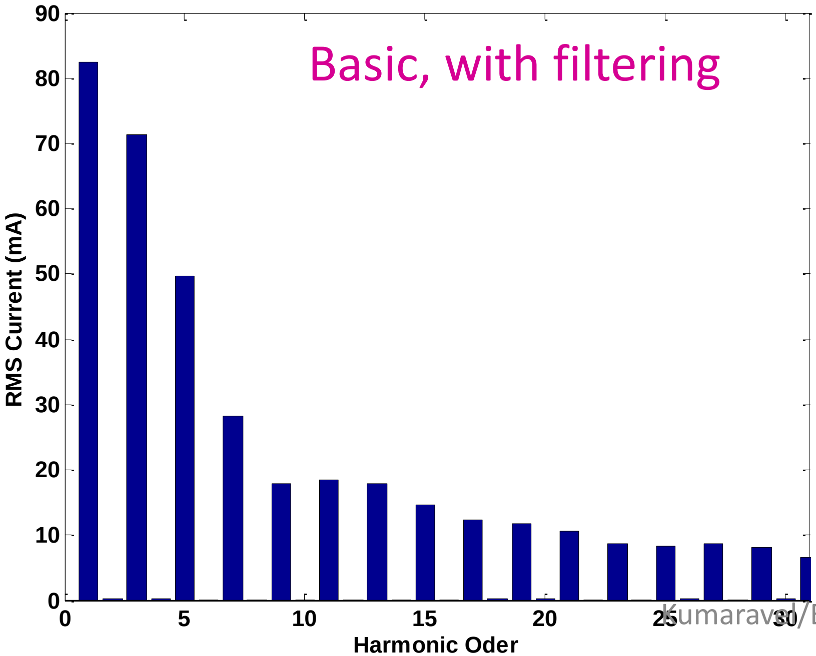

Active Power-Factor Control
Current (mA)
400
300
200
100
0
-100
-200
-300
-400
0
0.005
0.01
0.015
0.02
Time (s)

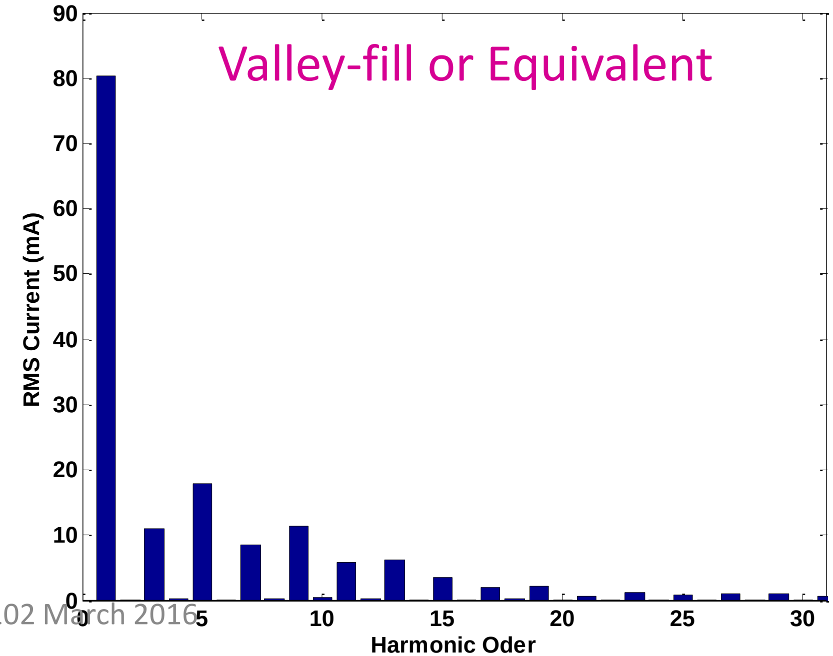

Basic, with filtering
Current (mA)
600
400
200
0
-200
-400
-600
0
0.005
0.01
0.015
0.02
Time (s)


Valley-fill or Equivalent
Current (mA)
600
400
200
0
-200
-400
-600
0
0.005
0.01
0.015
0.02
Time (s)

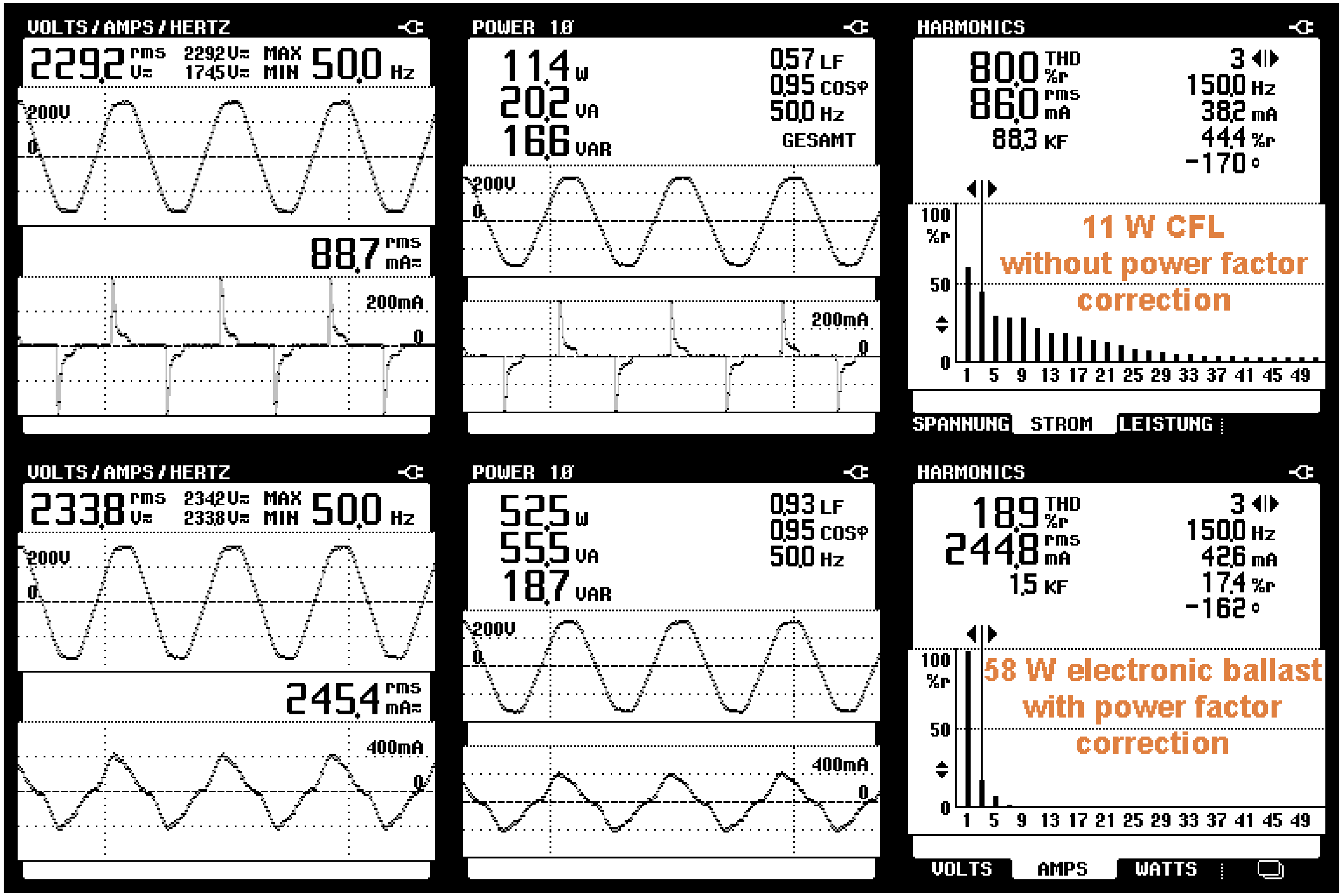

Basic, no filtering
RMS Current (mA)
Harmonic Oder
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30


Active Power-Factor Control
Current (mA)
Harmonic order
0
50
100
150
200
250
0
5
10
15
20
25
30
35


Basic, with filtering
RMS Current (mA)
Harmonic Oder
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30

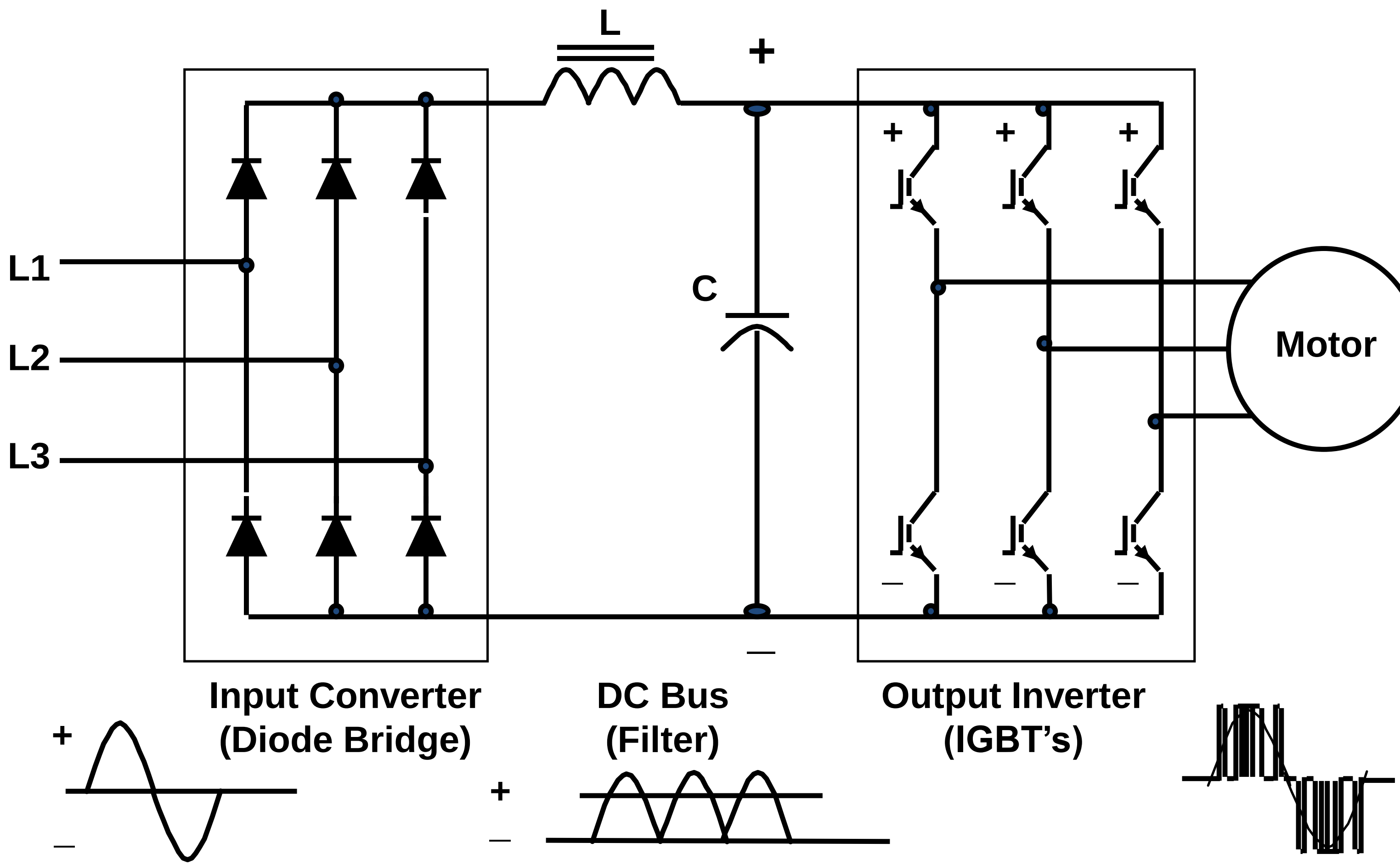

Valley-fill or Equivalent
RMS Current (mA)
Harmonic Oder
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30

How effective is power factor correction (to EN 61000-3-2)?



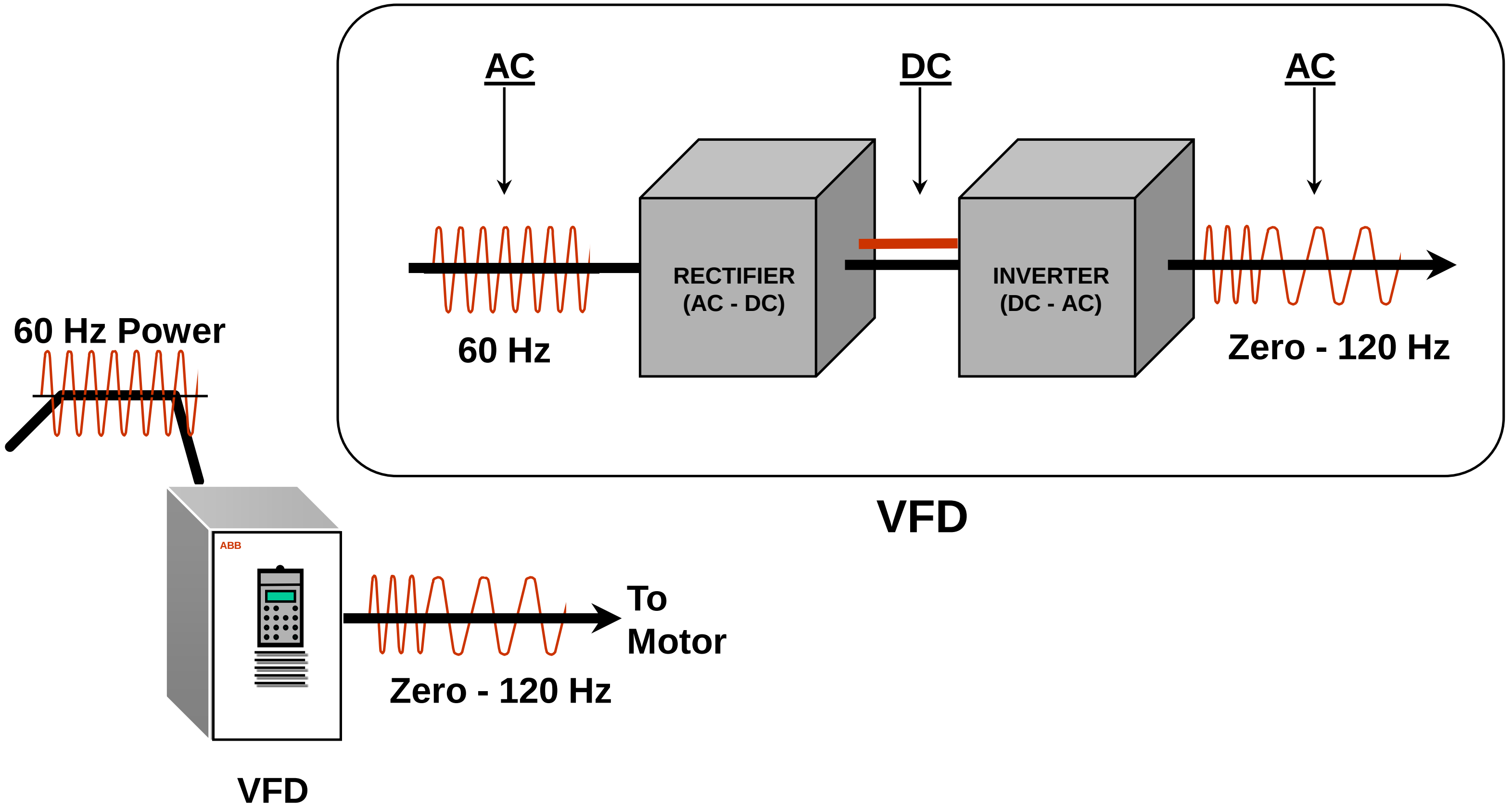

Wikipedia :
எனக்கு
எல்லாம்
தெரியும்
Facebook :
எனக்கு
எல்லாரையும்
தெரியும்
Google :
என்கிட்ட
தான்
எல்லாமே
இருக்கு
Internet :
நான்
இல்லன்னா
நீங்க 3
பேரும்
அம்பேல்தான்
!
Electricity : TNEB
என்னடா
அங்கே சத்தம்
..??

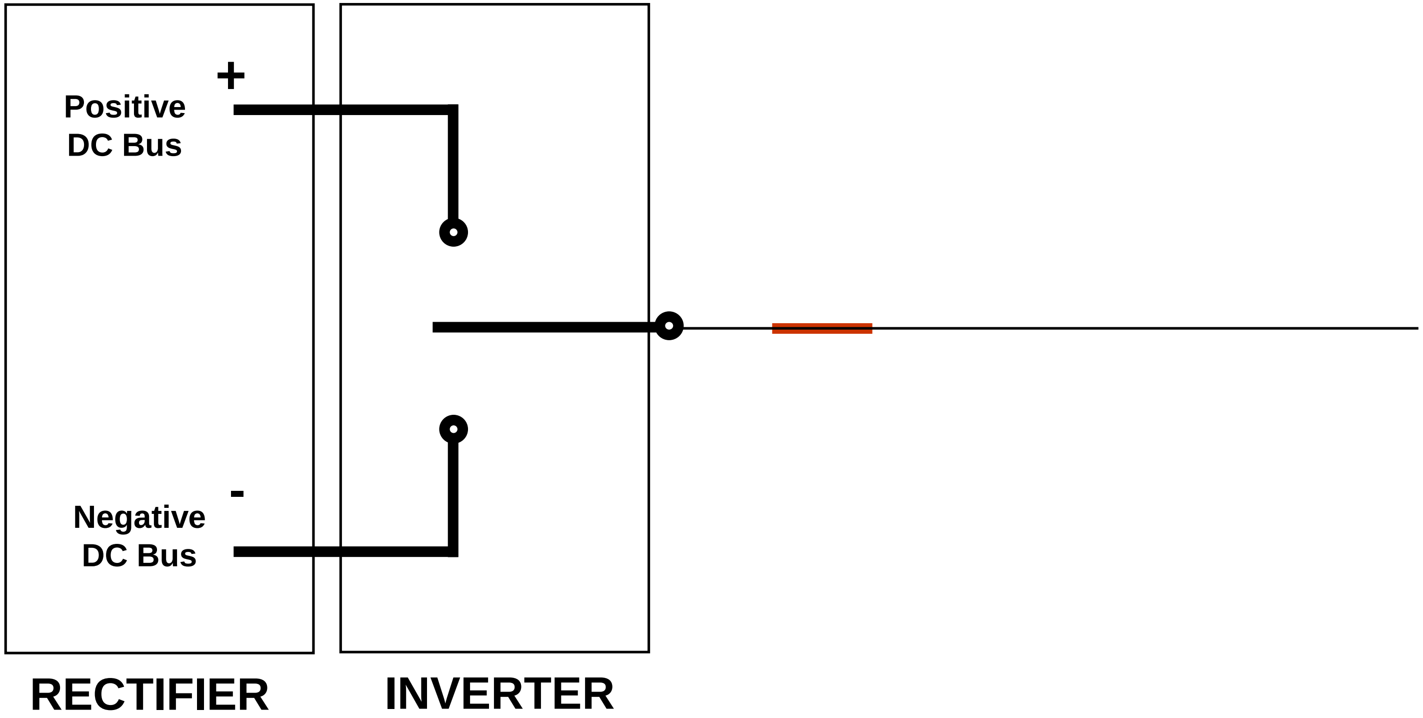
What is a Drive?

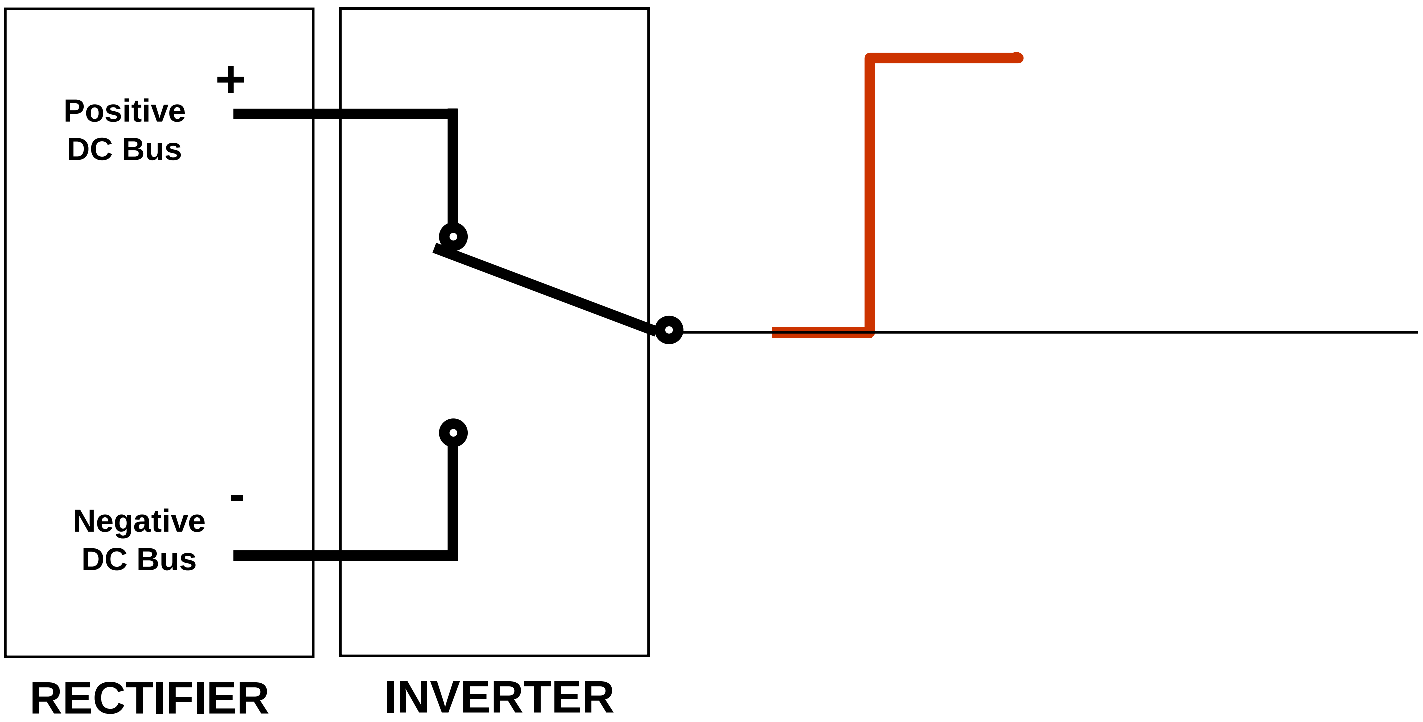


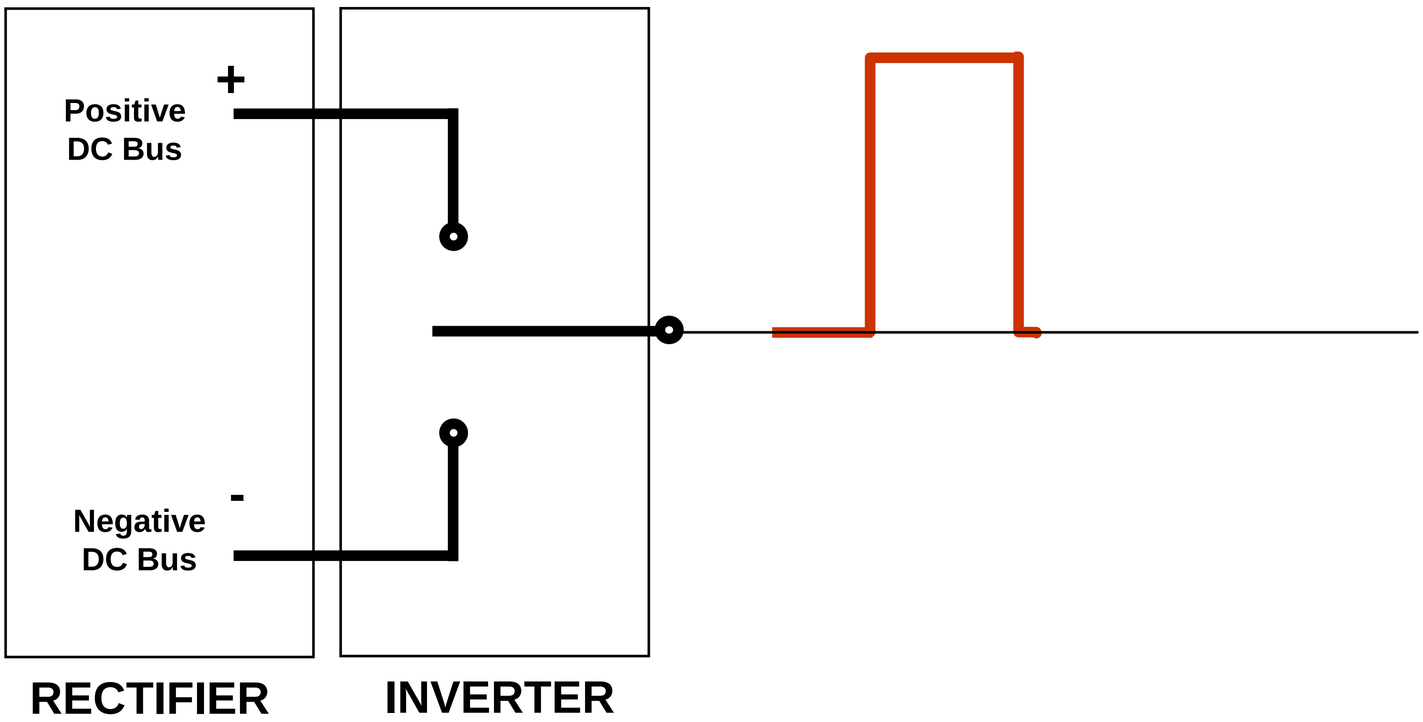
VFD Fundamentals

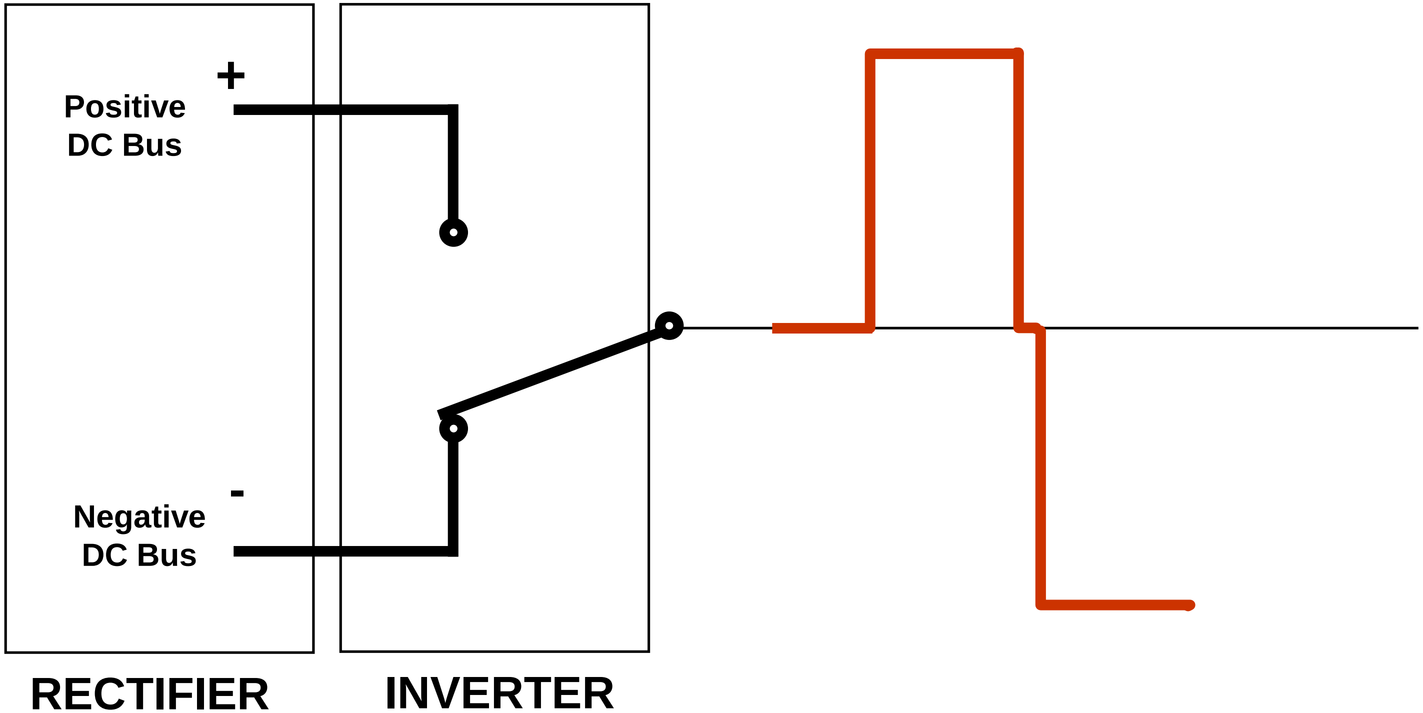
A variable frequency drive converts incoming 60 Hz utility power into DC, then converts to a simulated variable voltage, variable frequency output

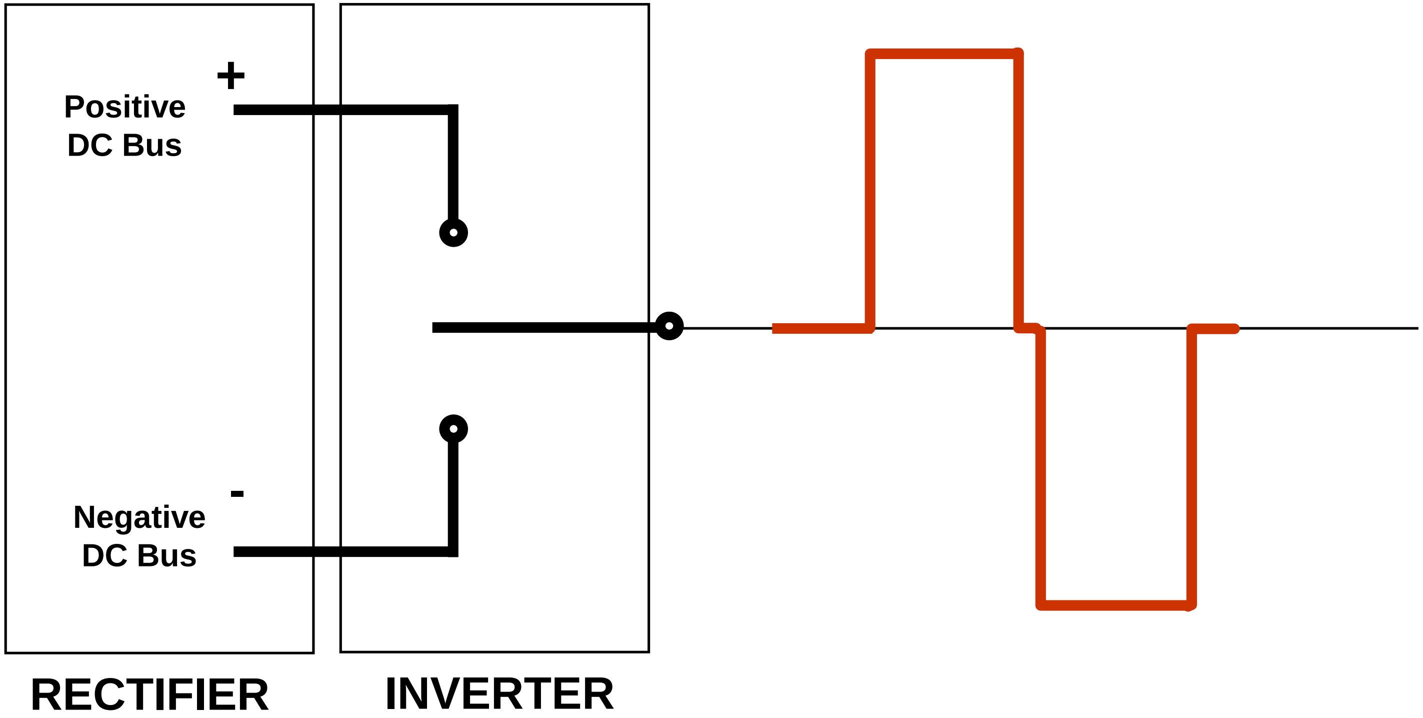


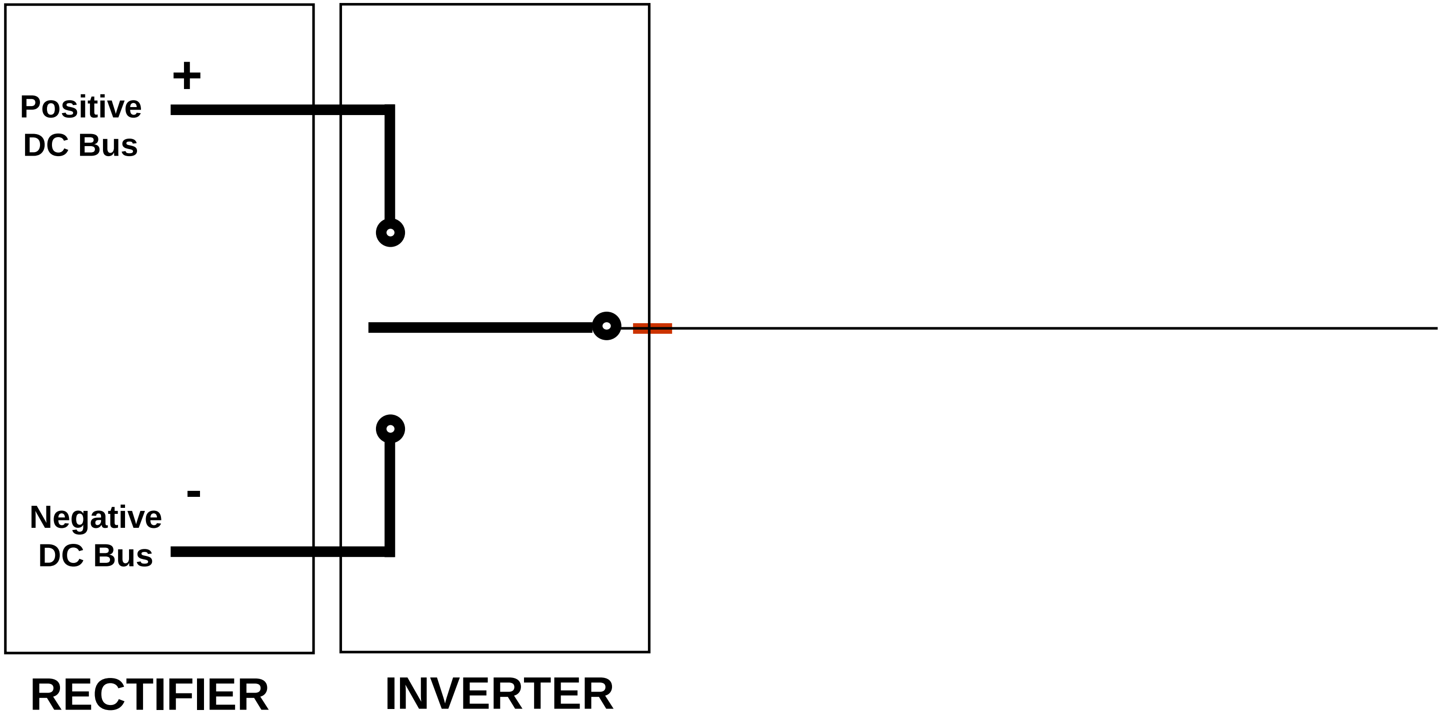

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

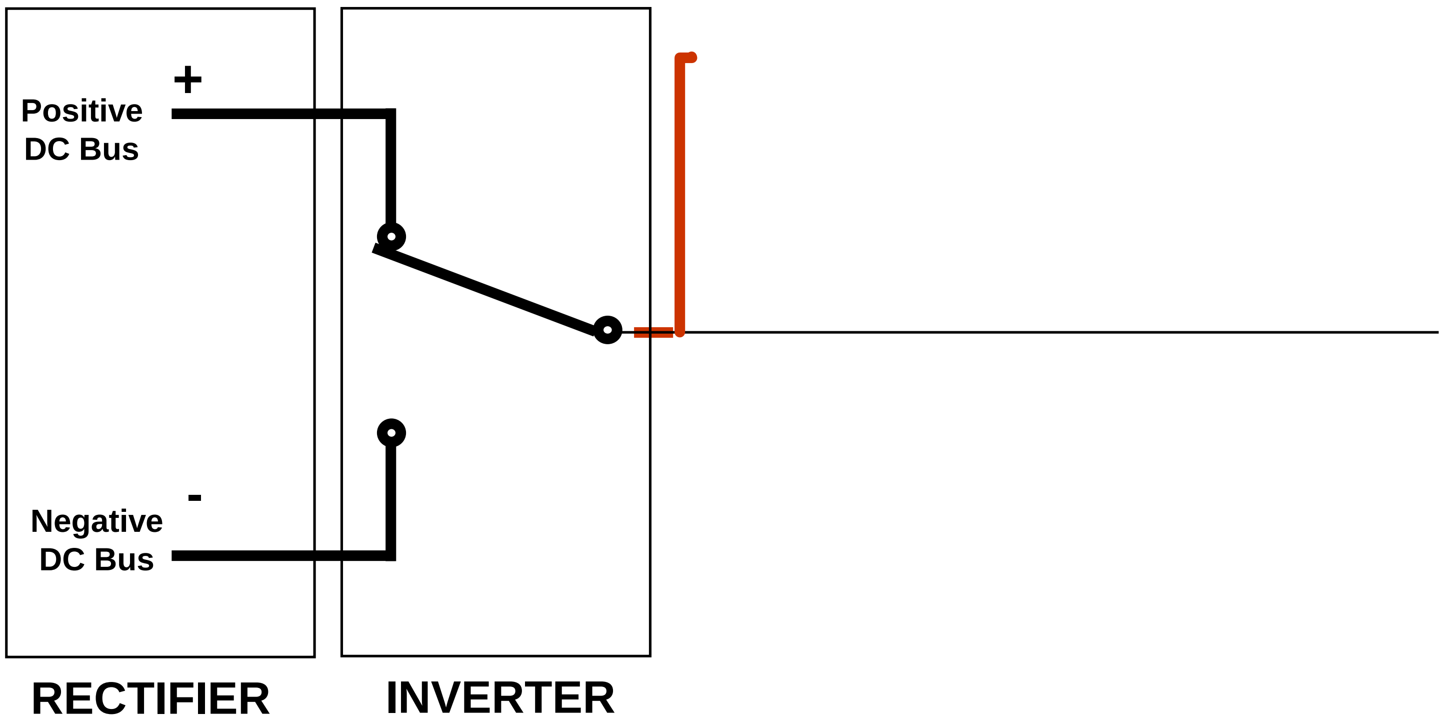

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

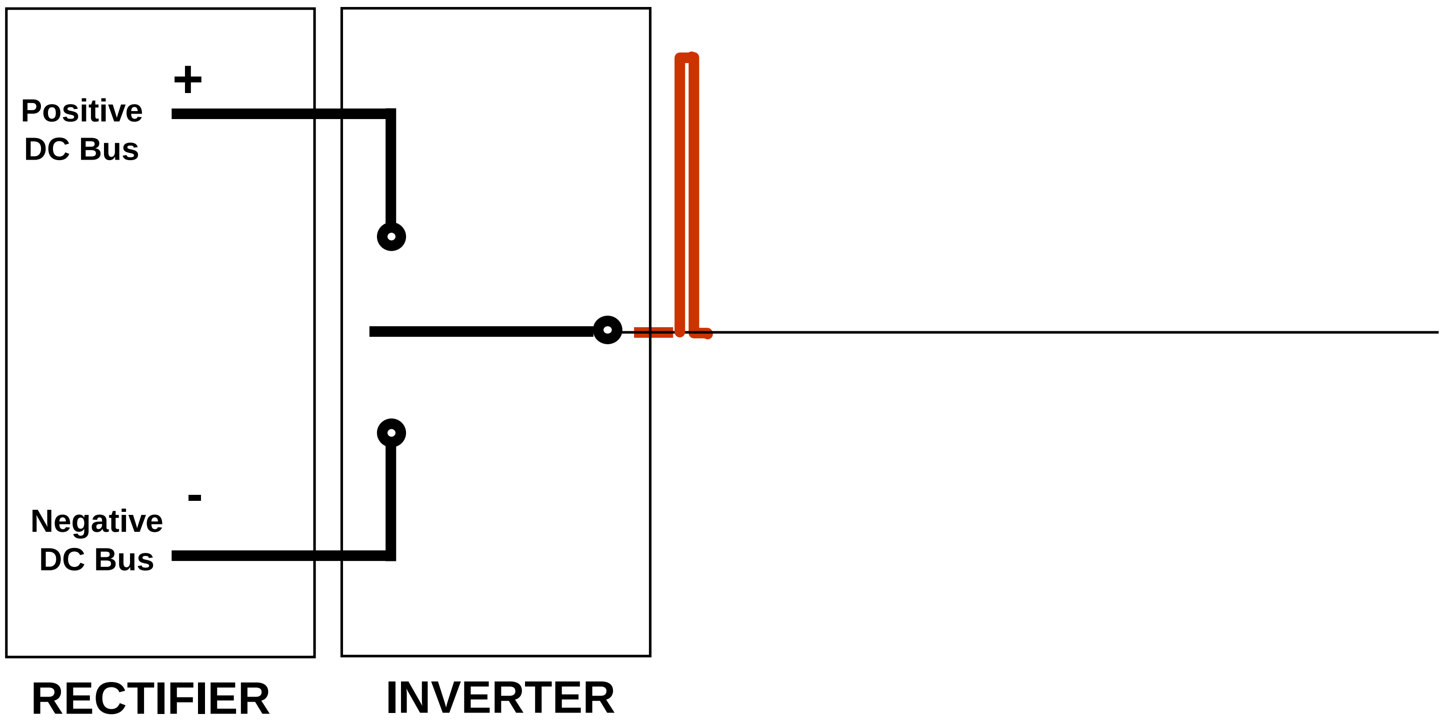

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

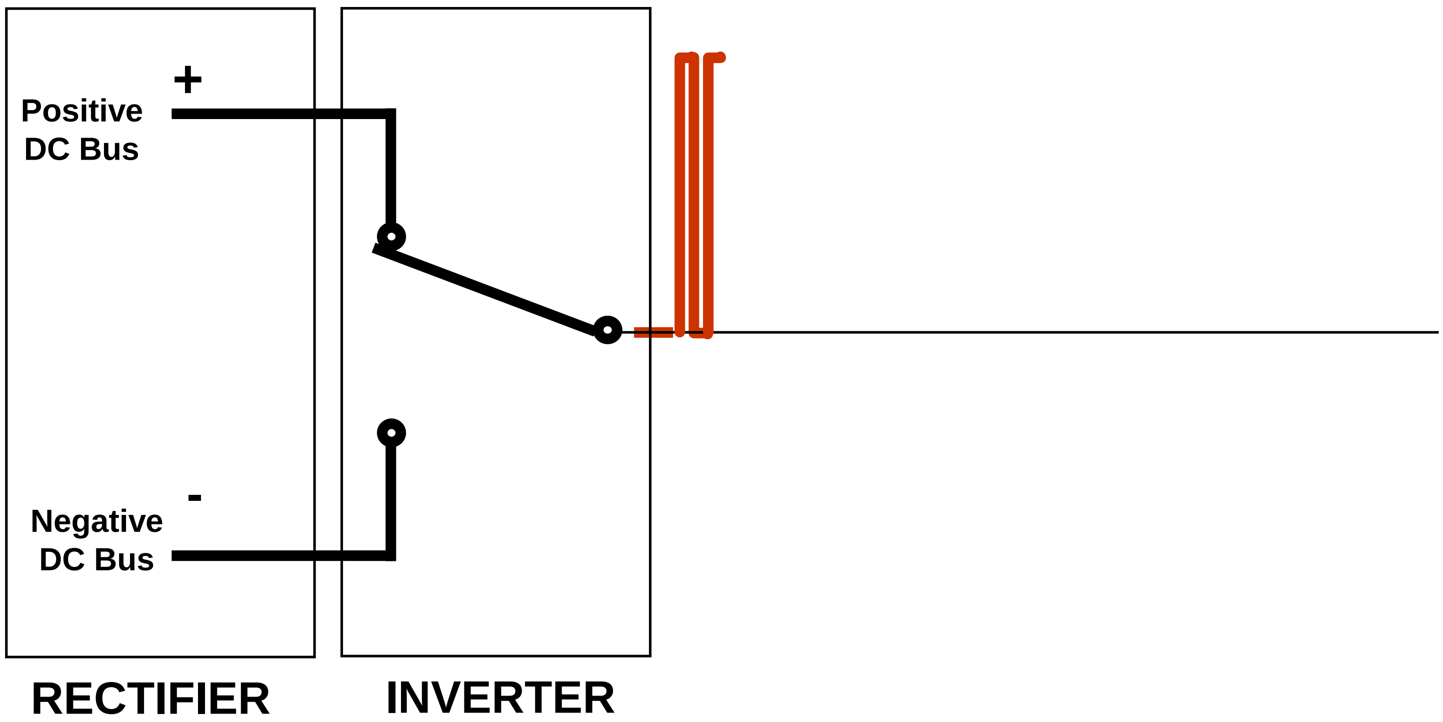

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

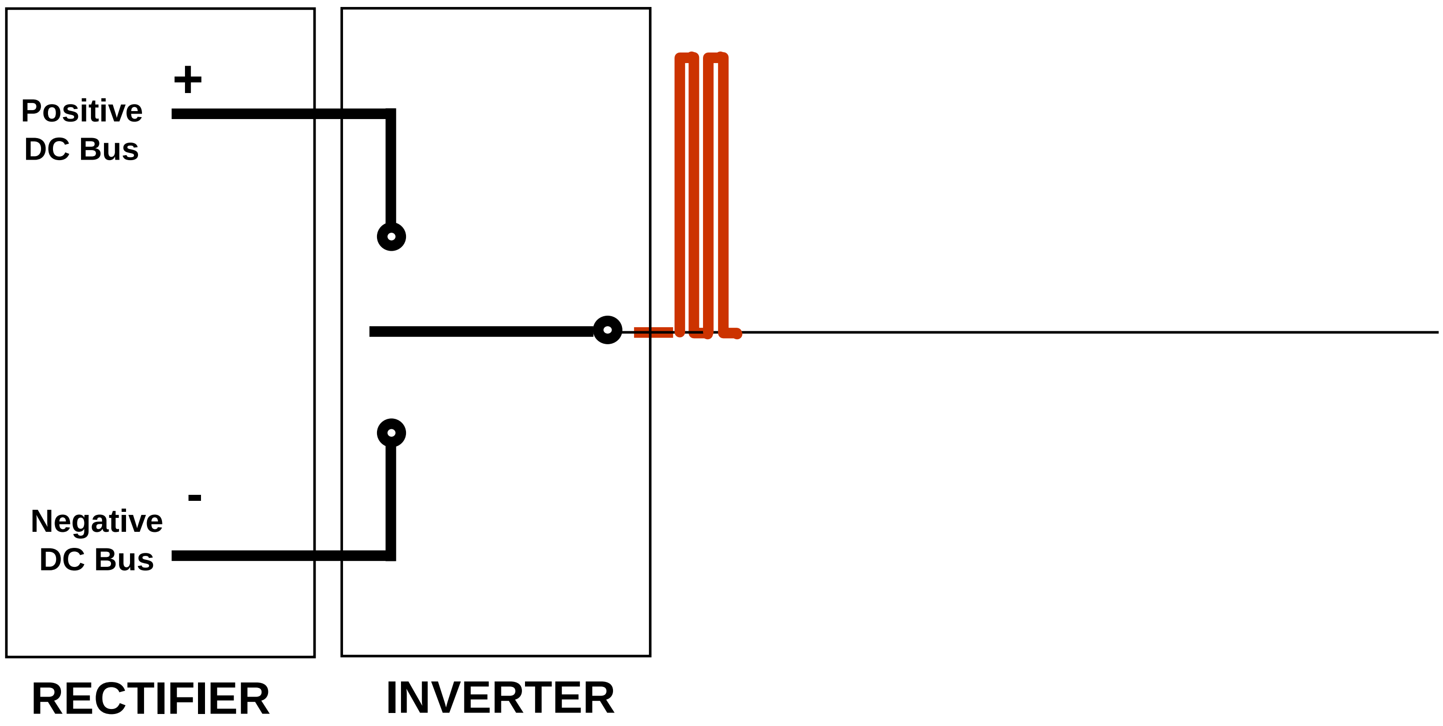

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER


+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

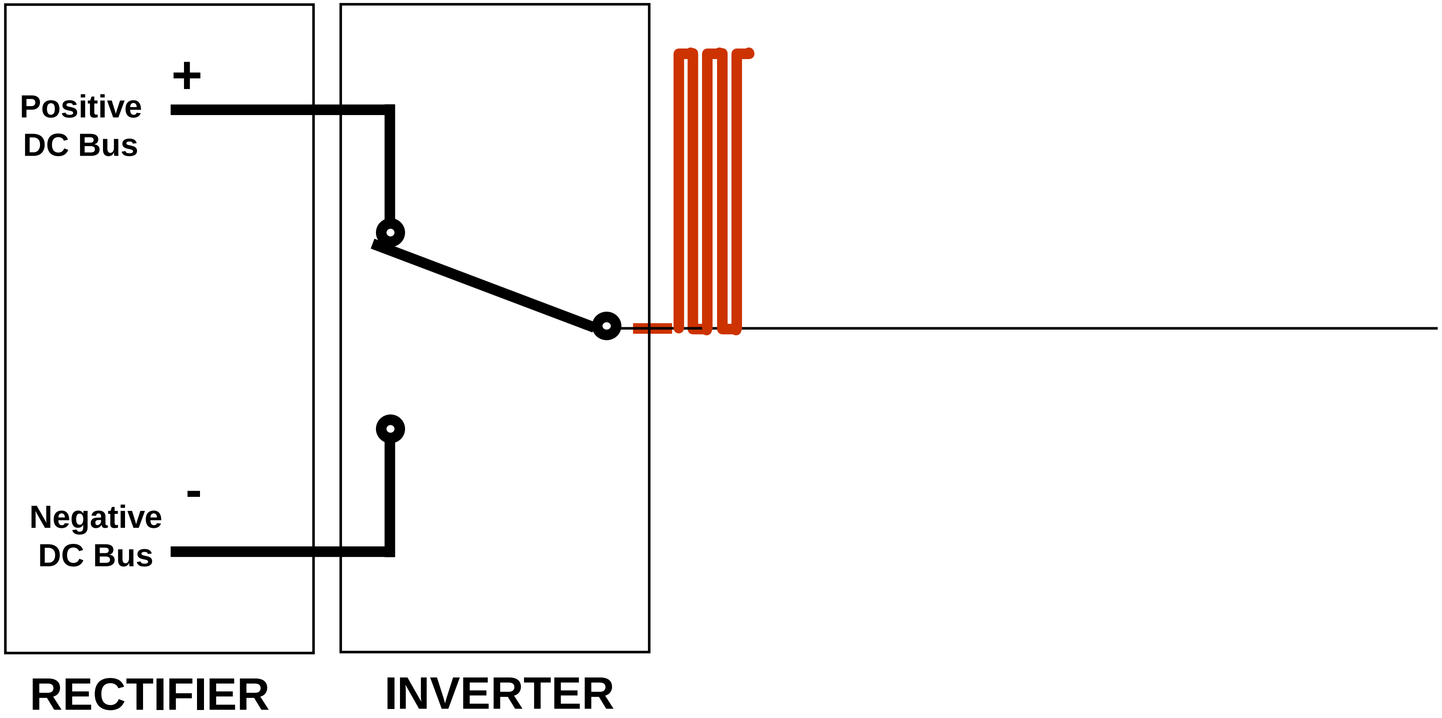

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

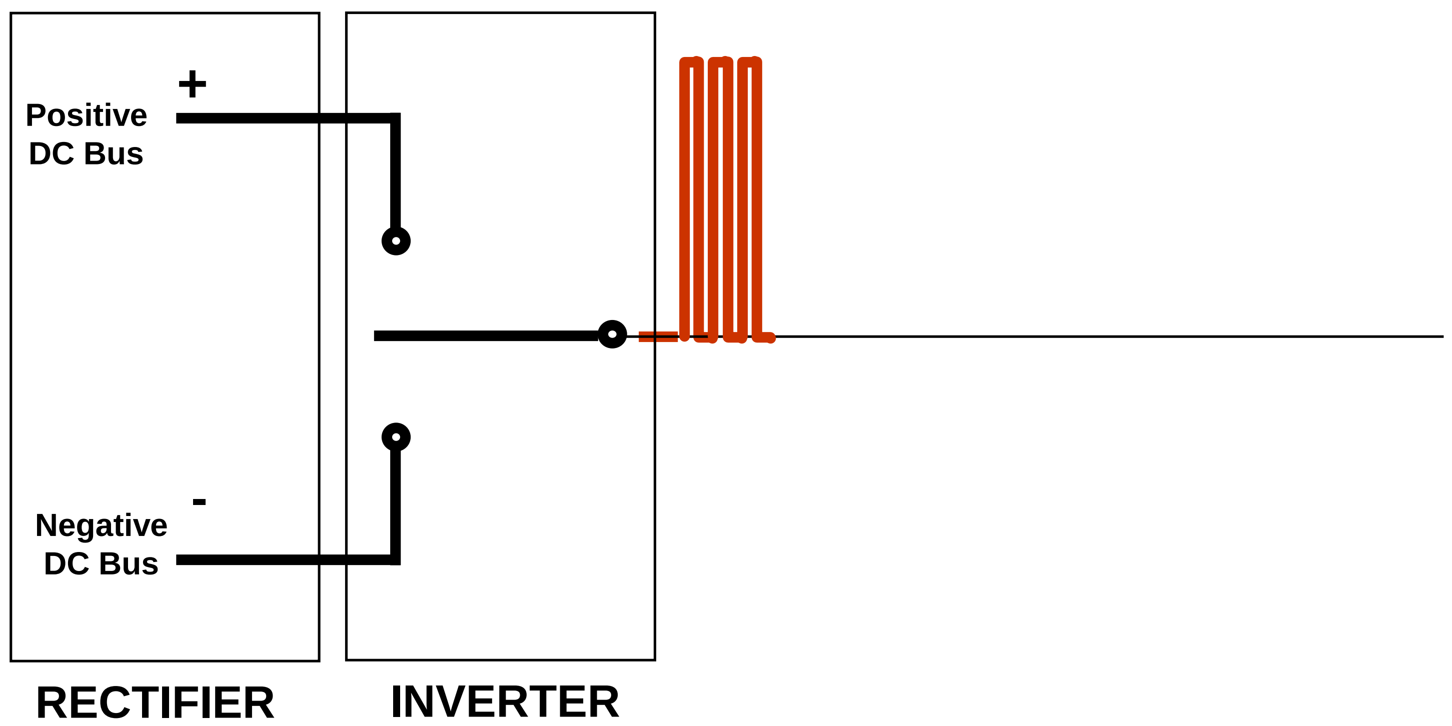

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

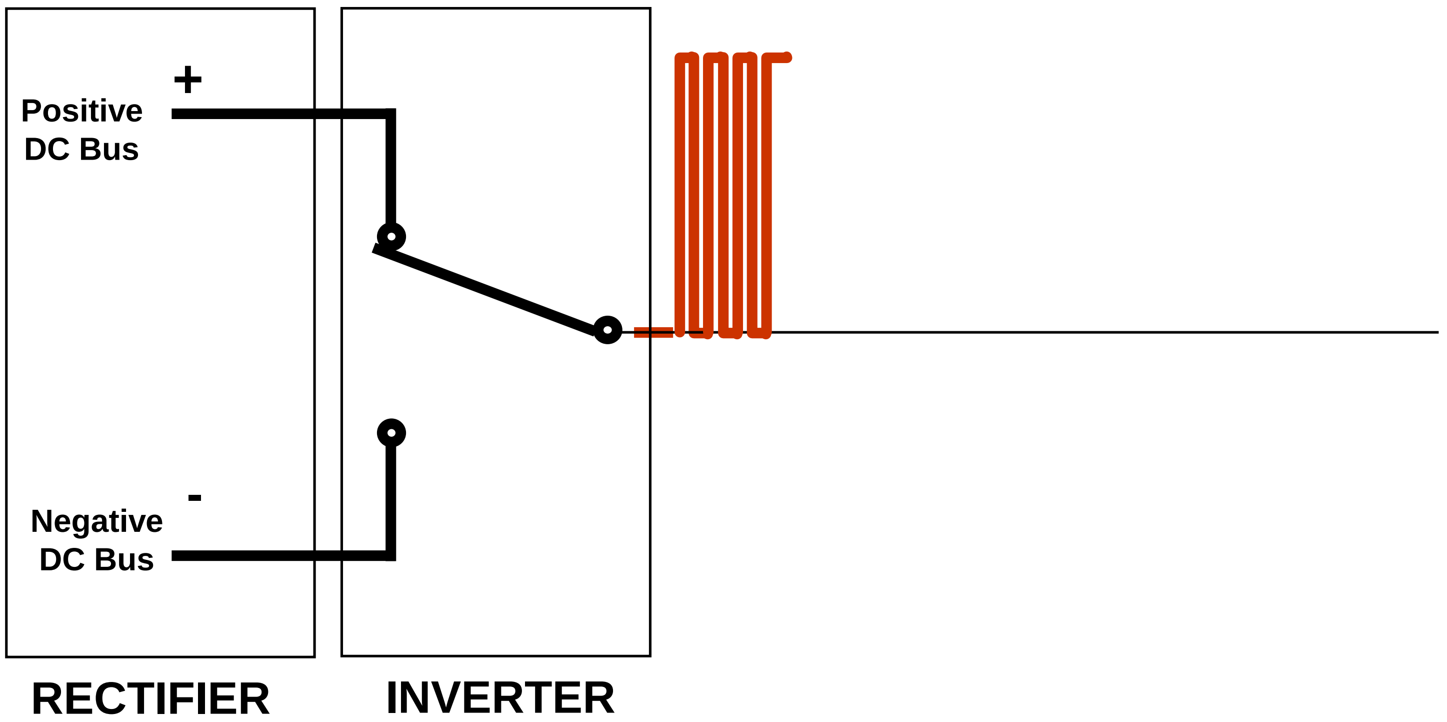

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

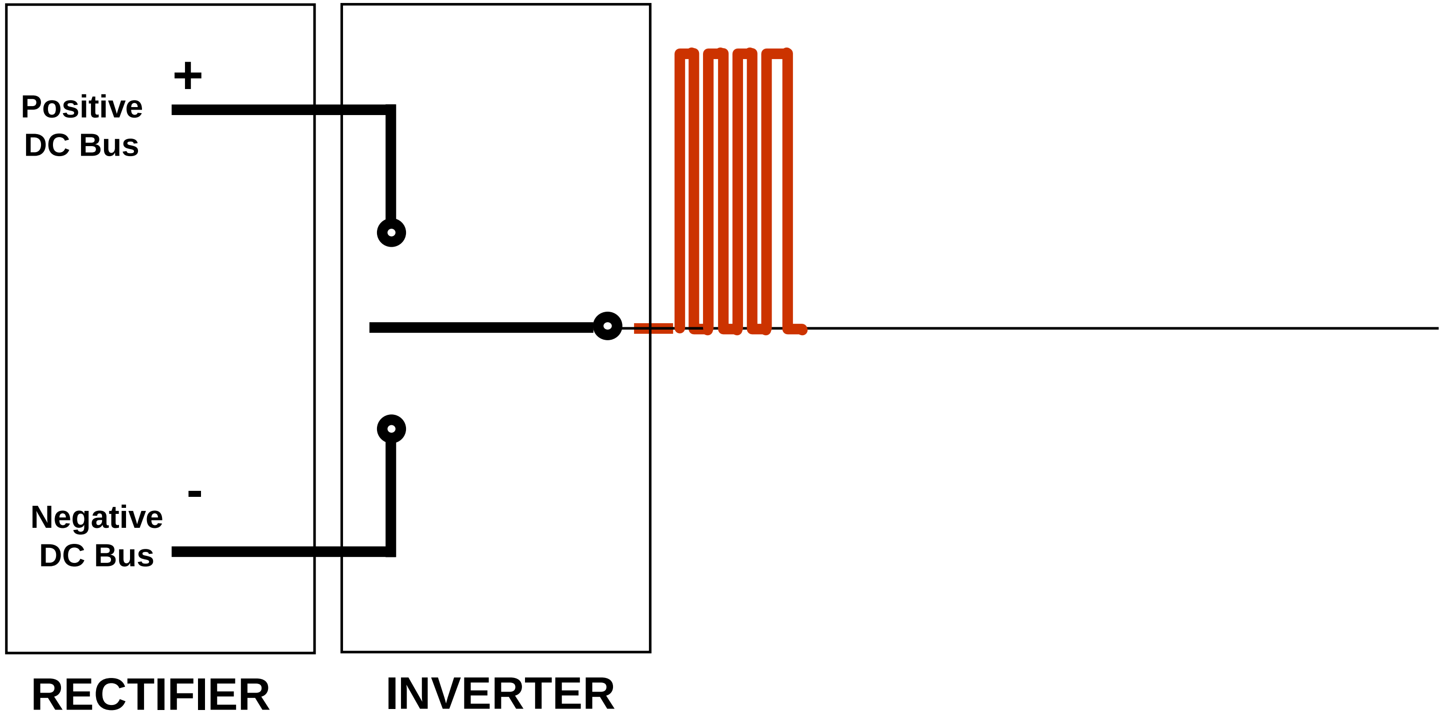


+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

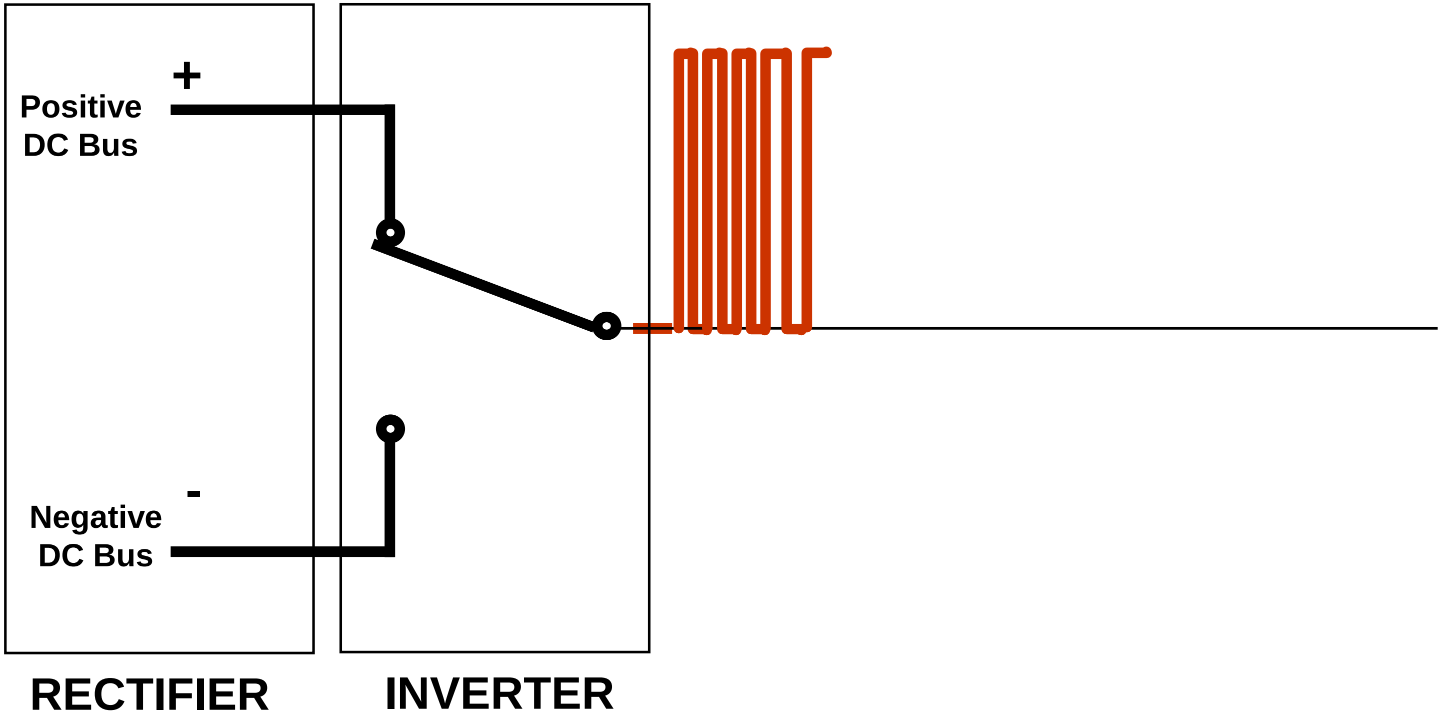

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER


+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

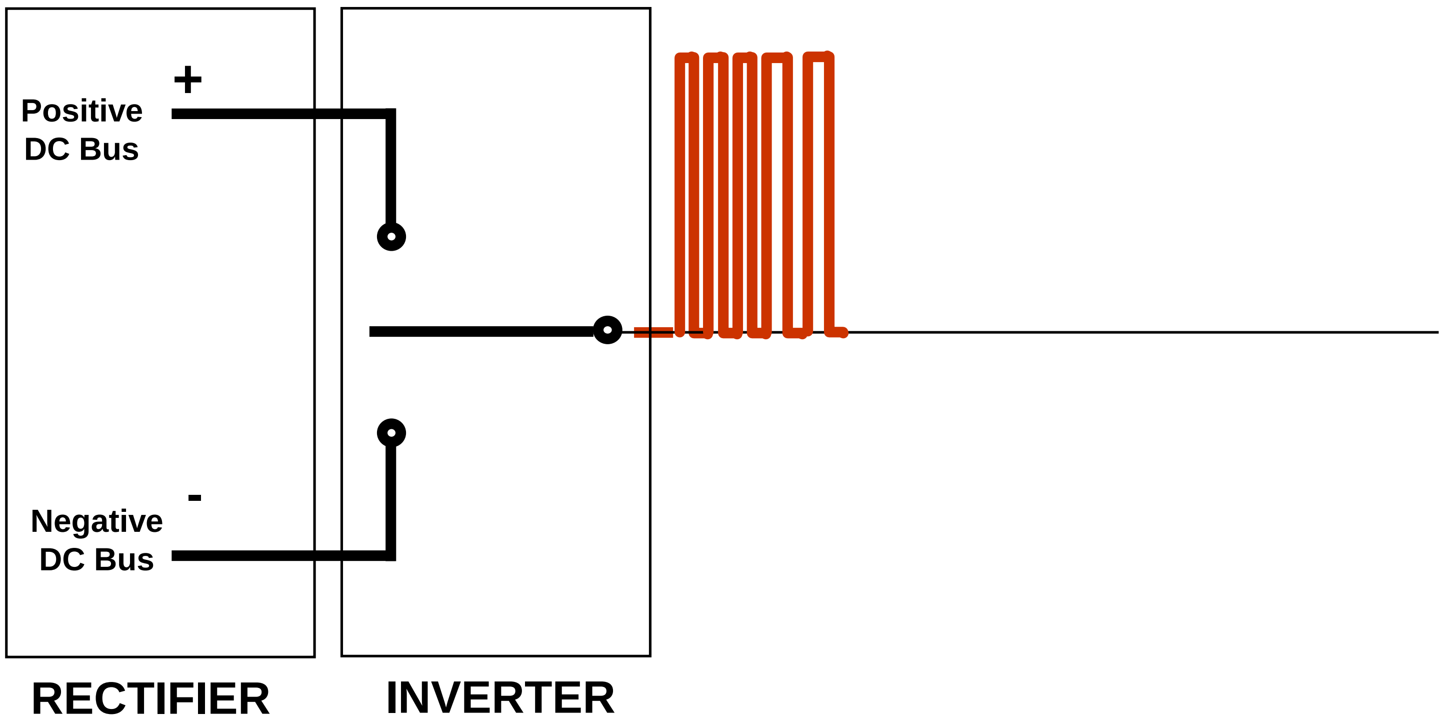

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER



+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER



+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER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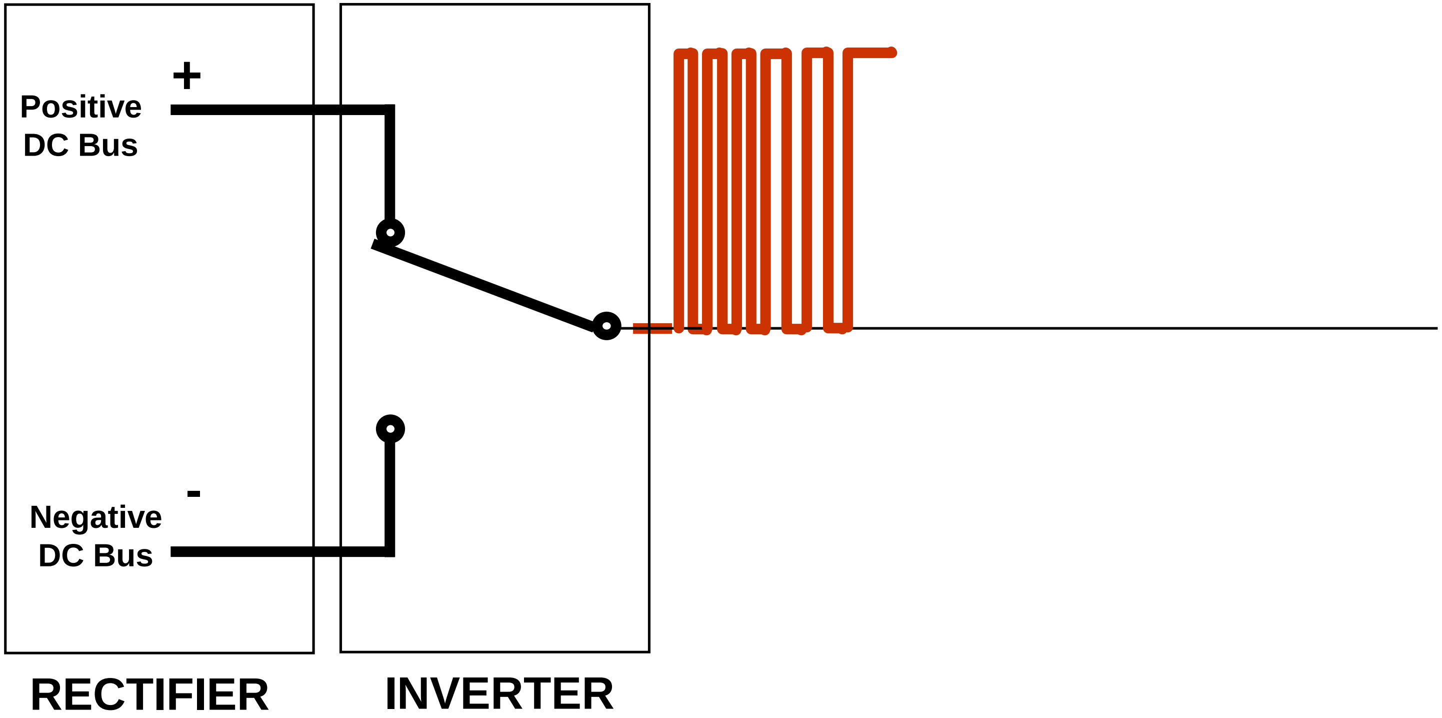
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER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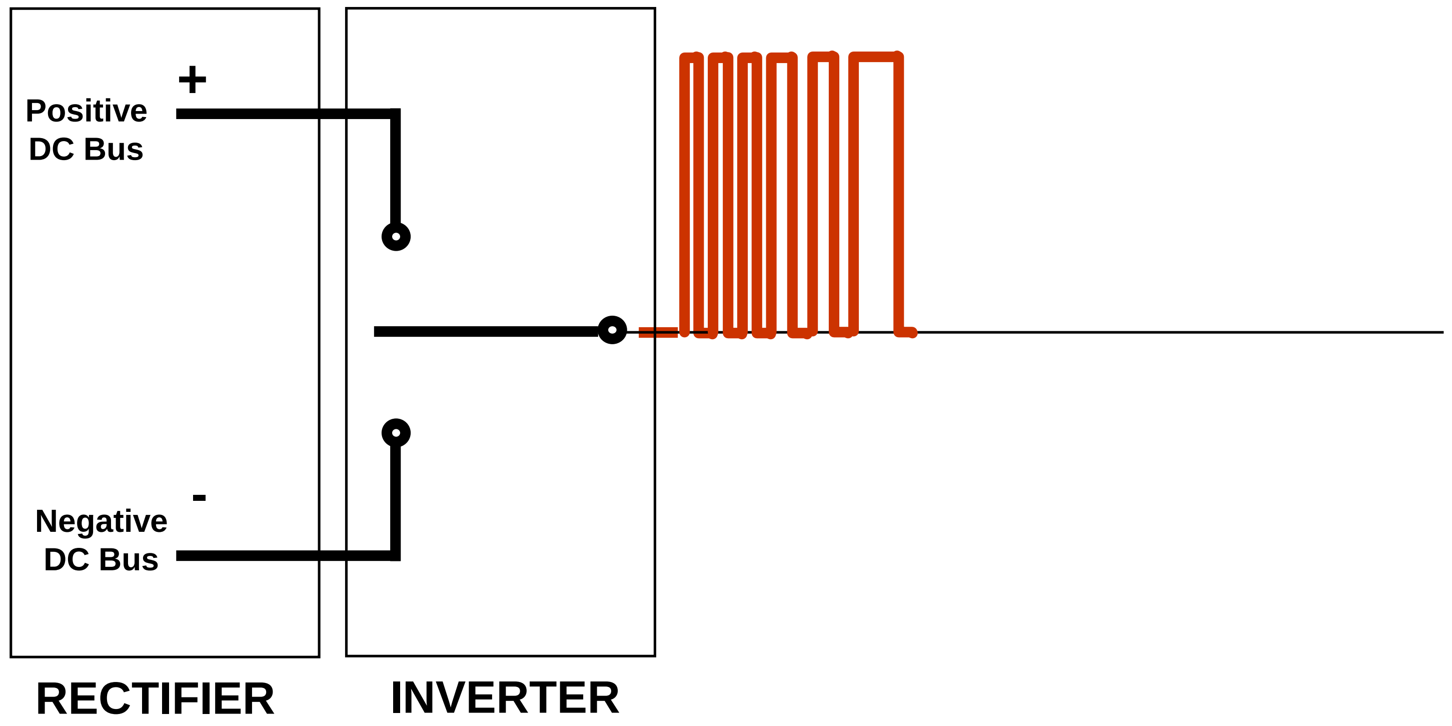
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER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DC Bus
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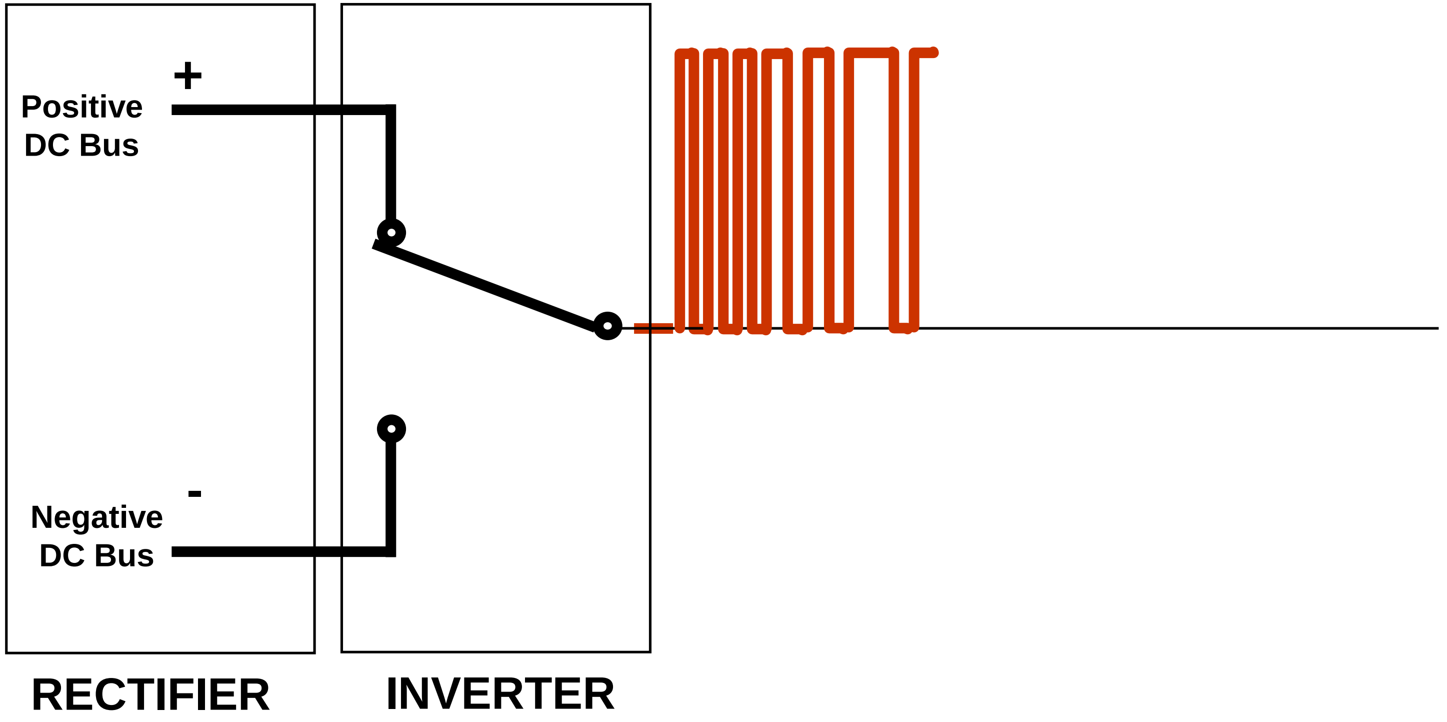
Negative
DC Bus
RECTIFIER
INVERTER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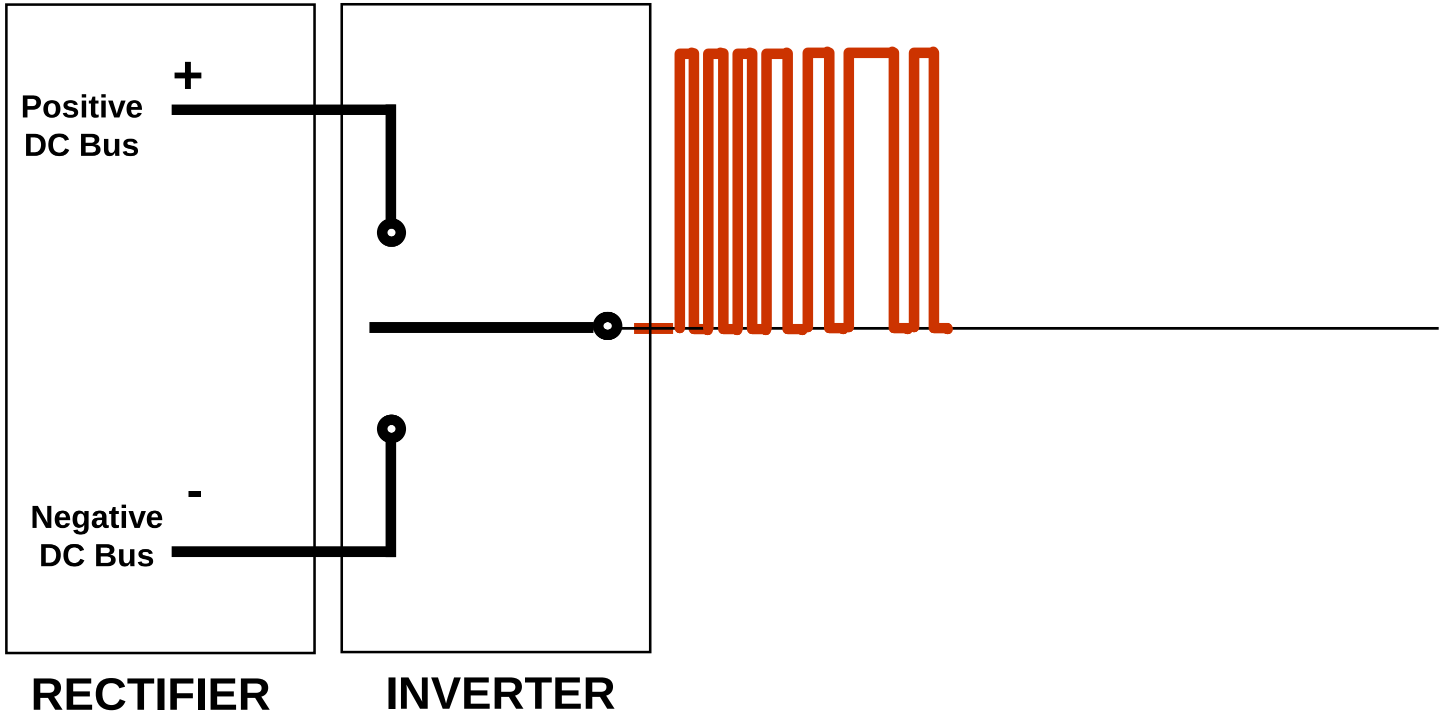
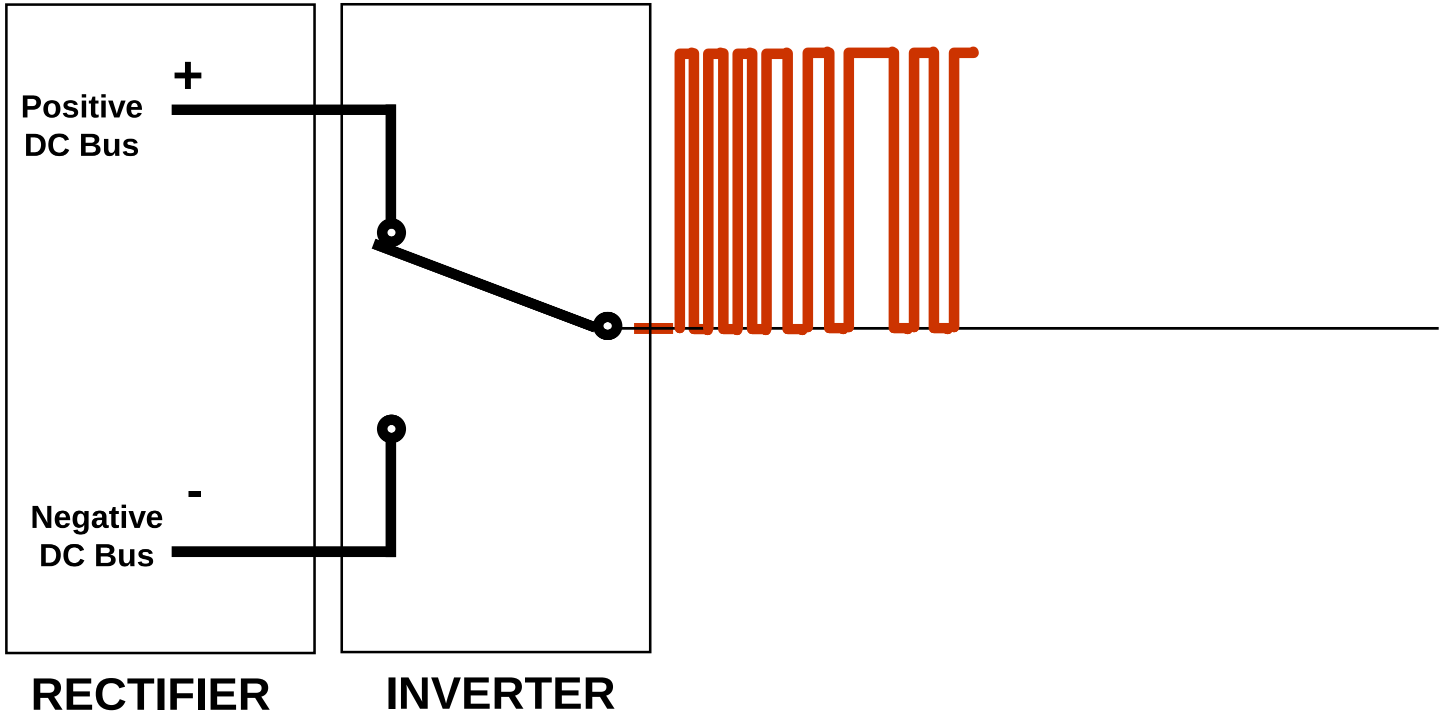
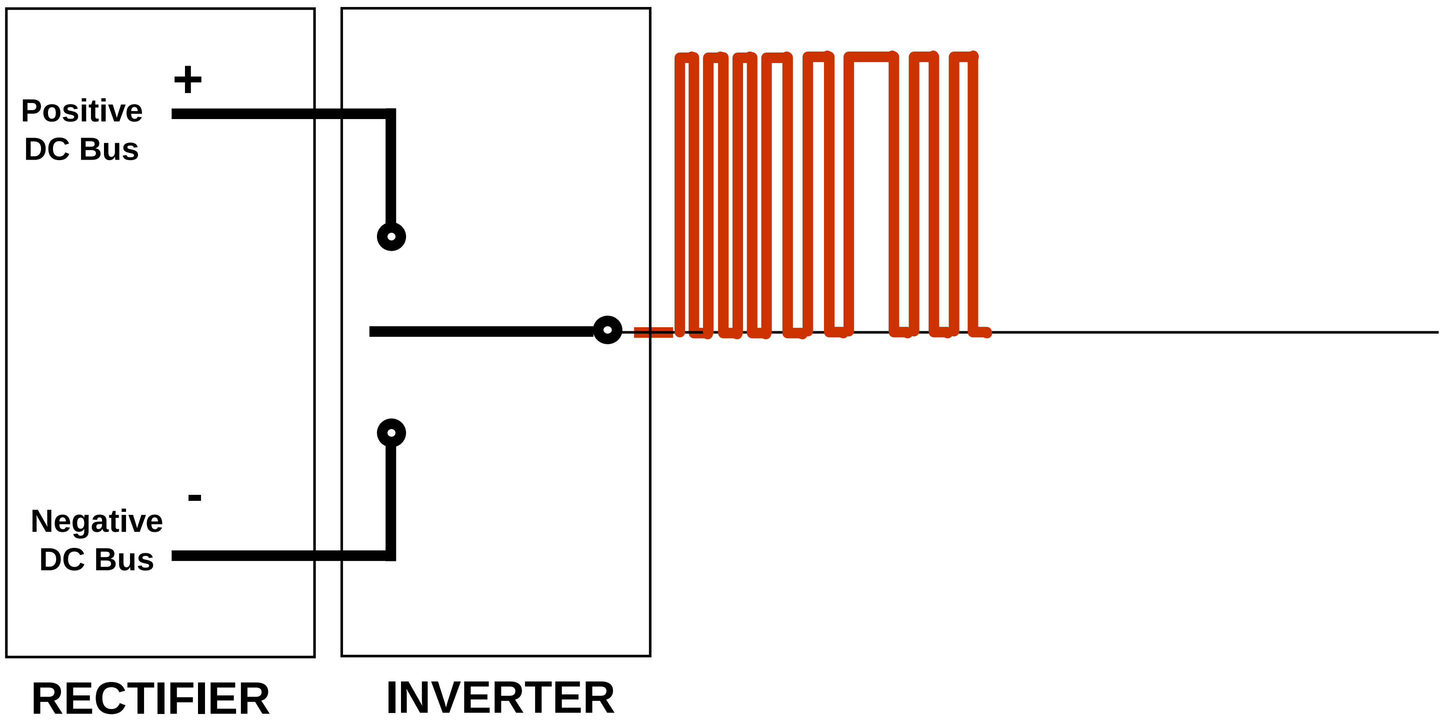
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER



+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER



+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER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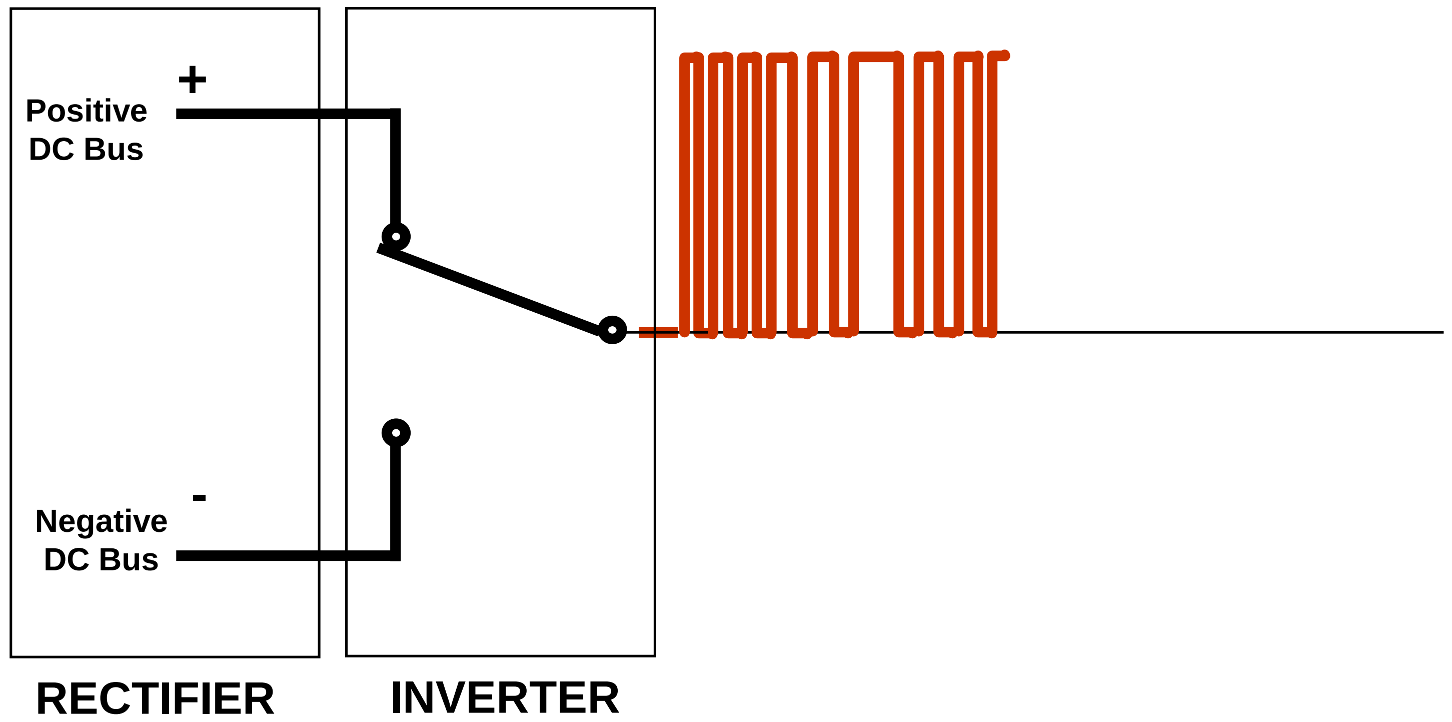
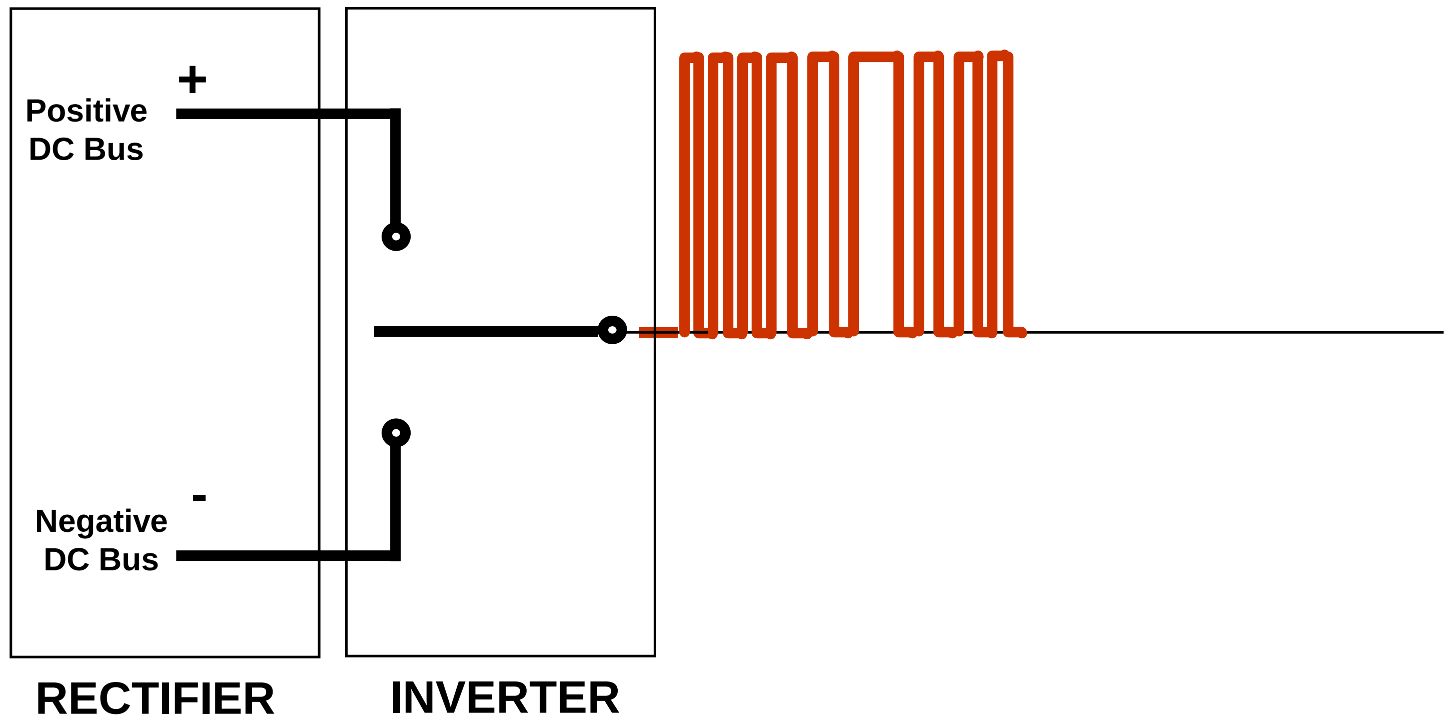
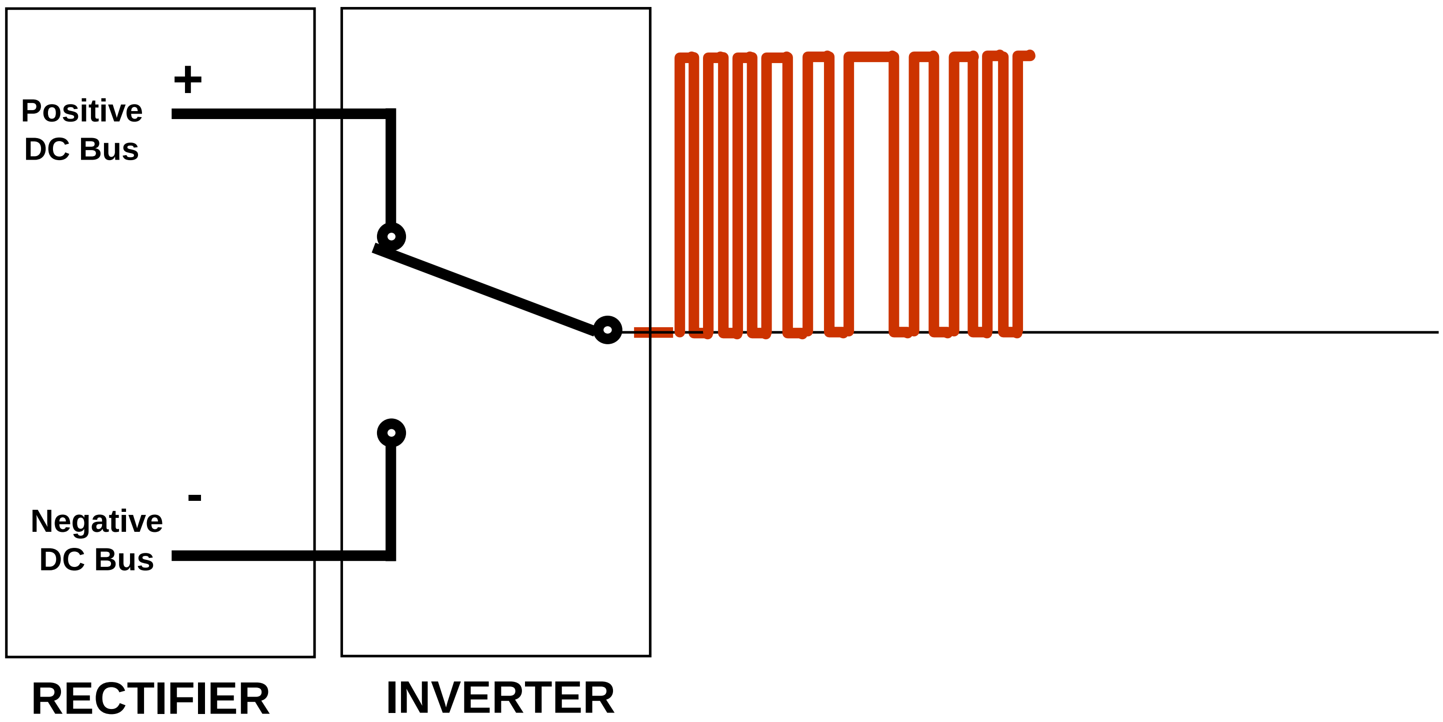
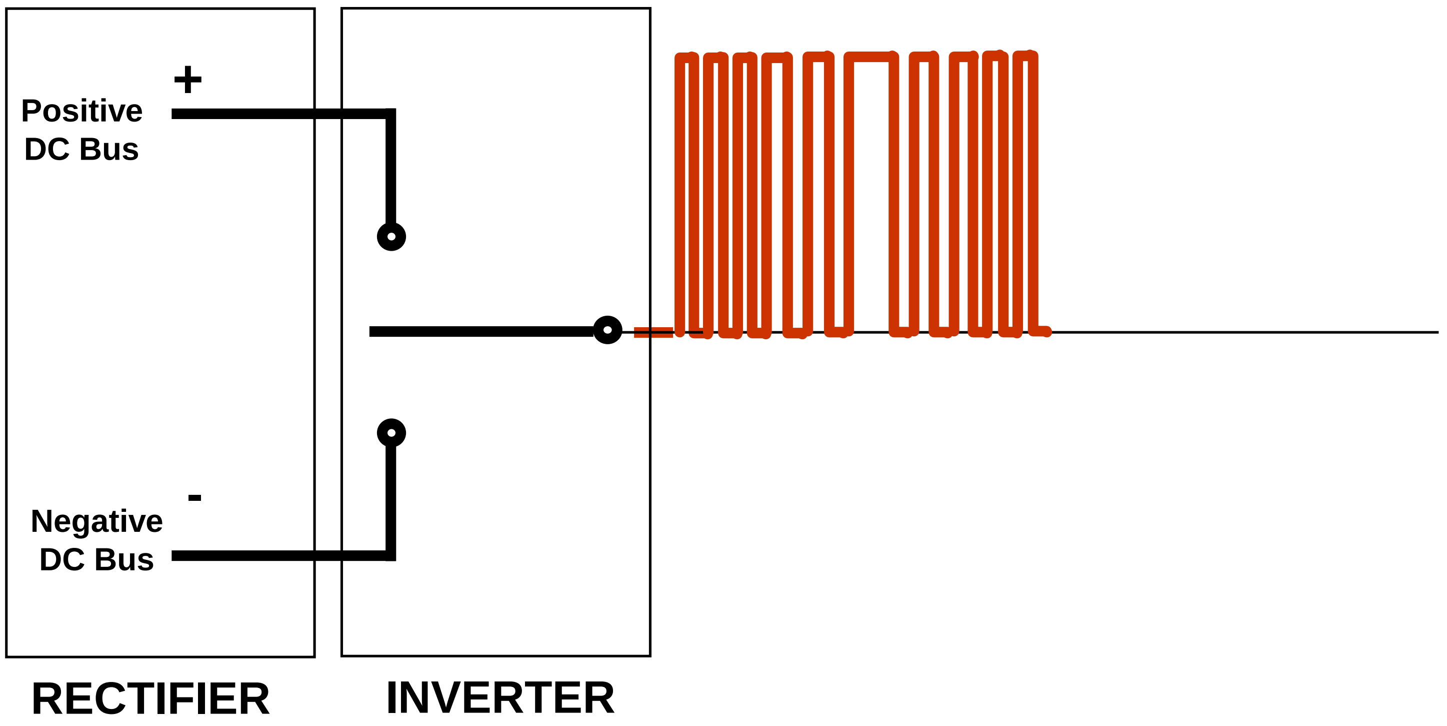
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

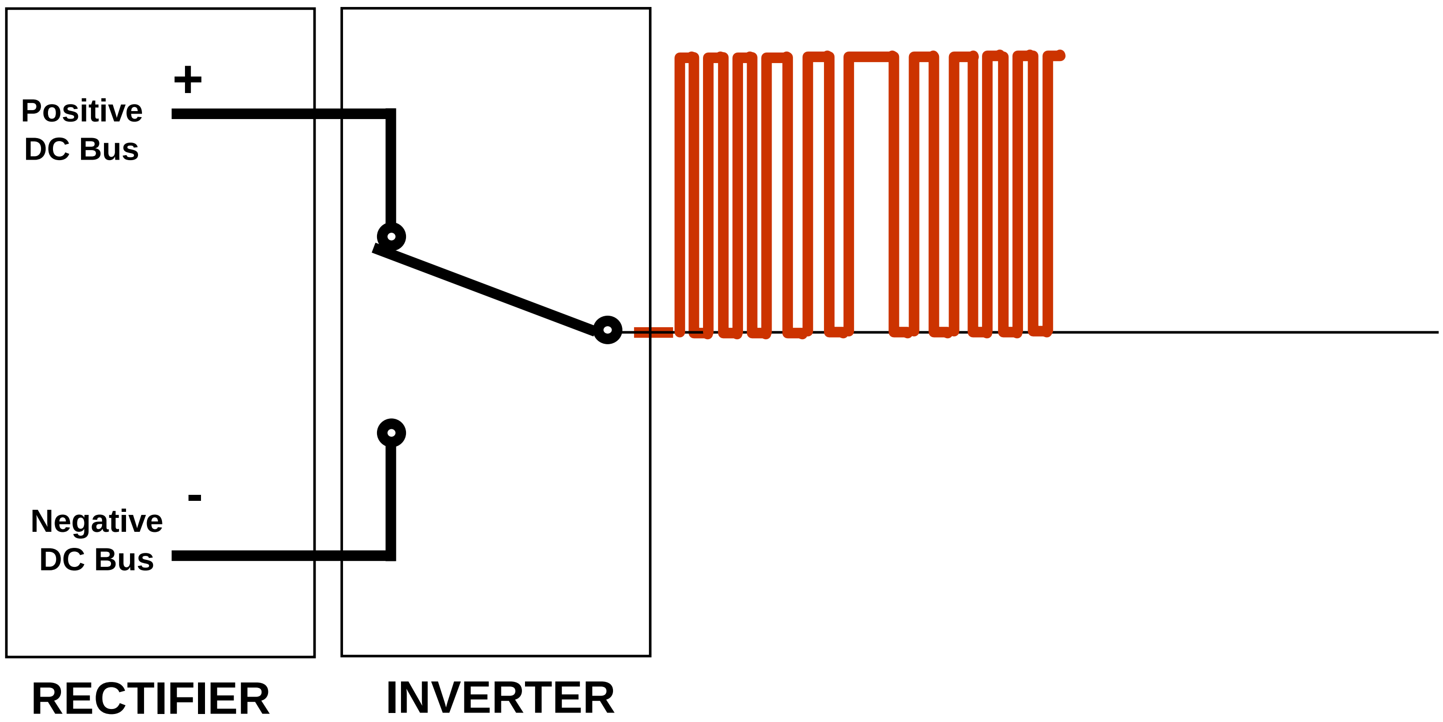


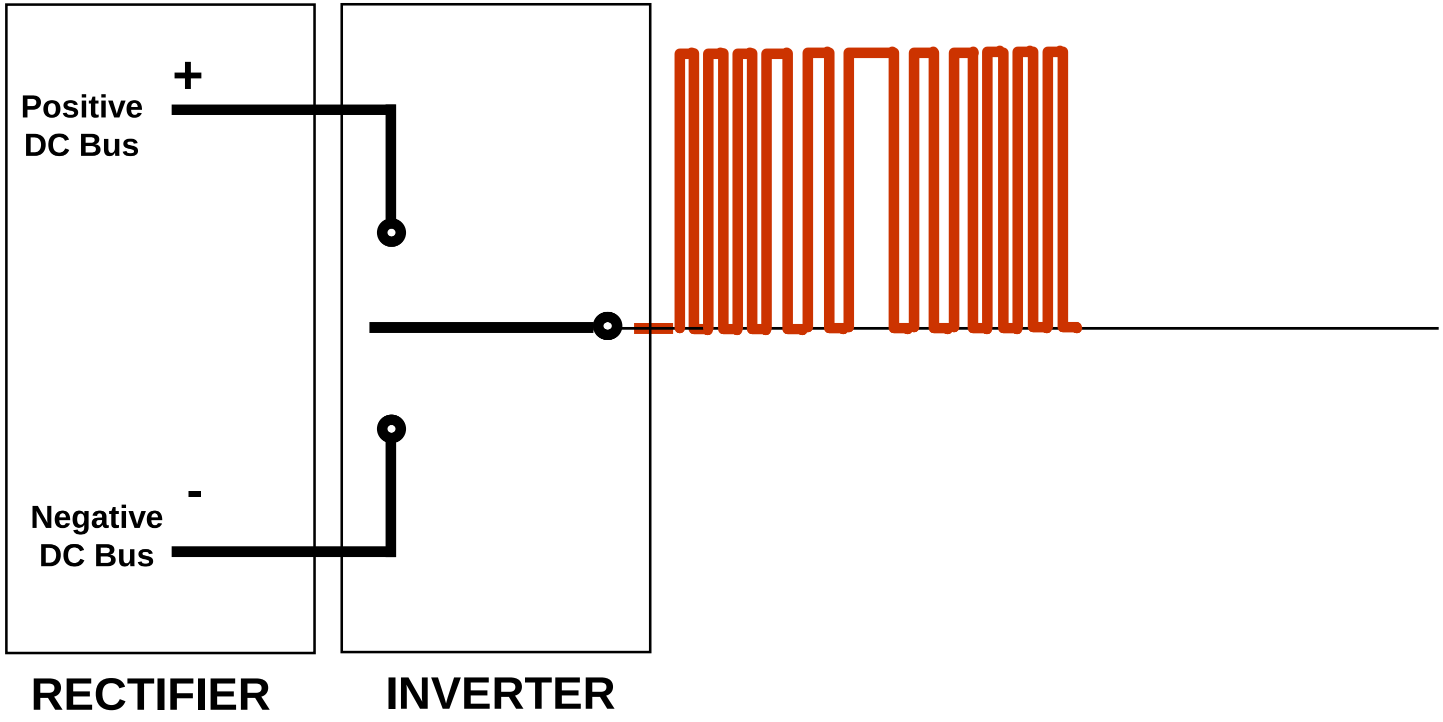
+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

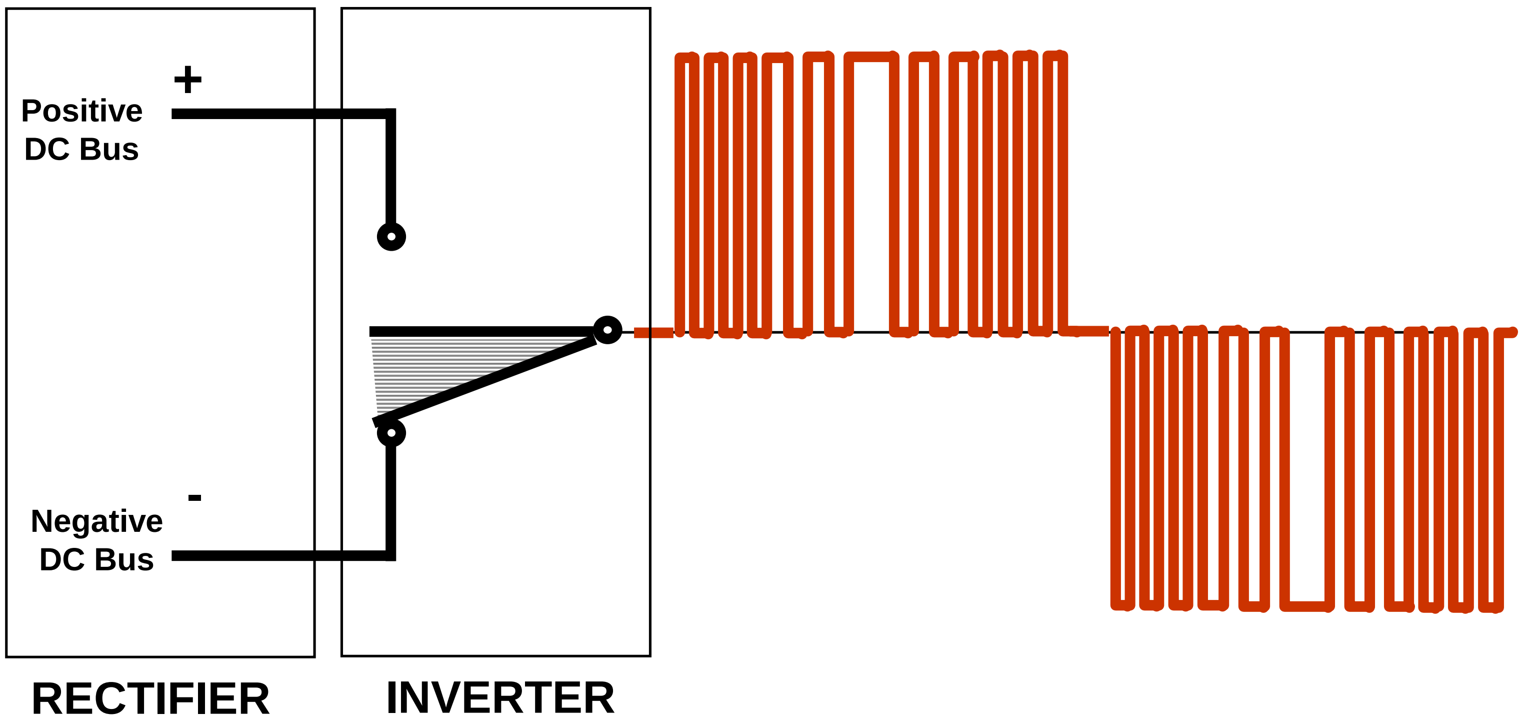

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER


+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

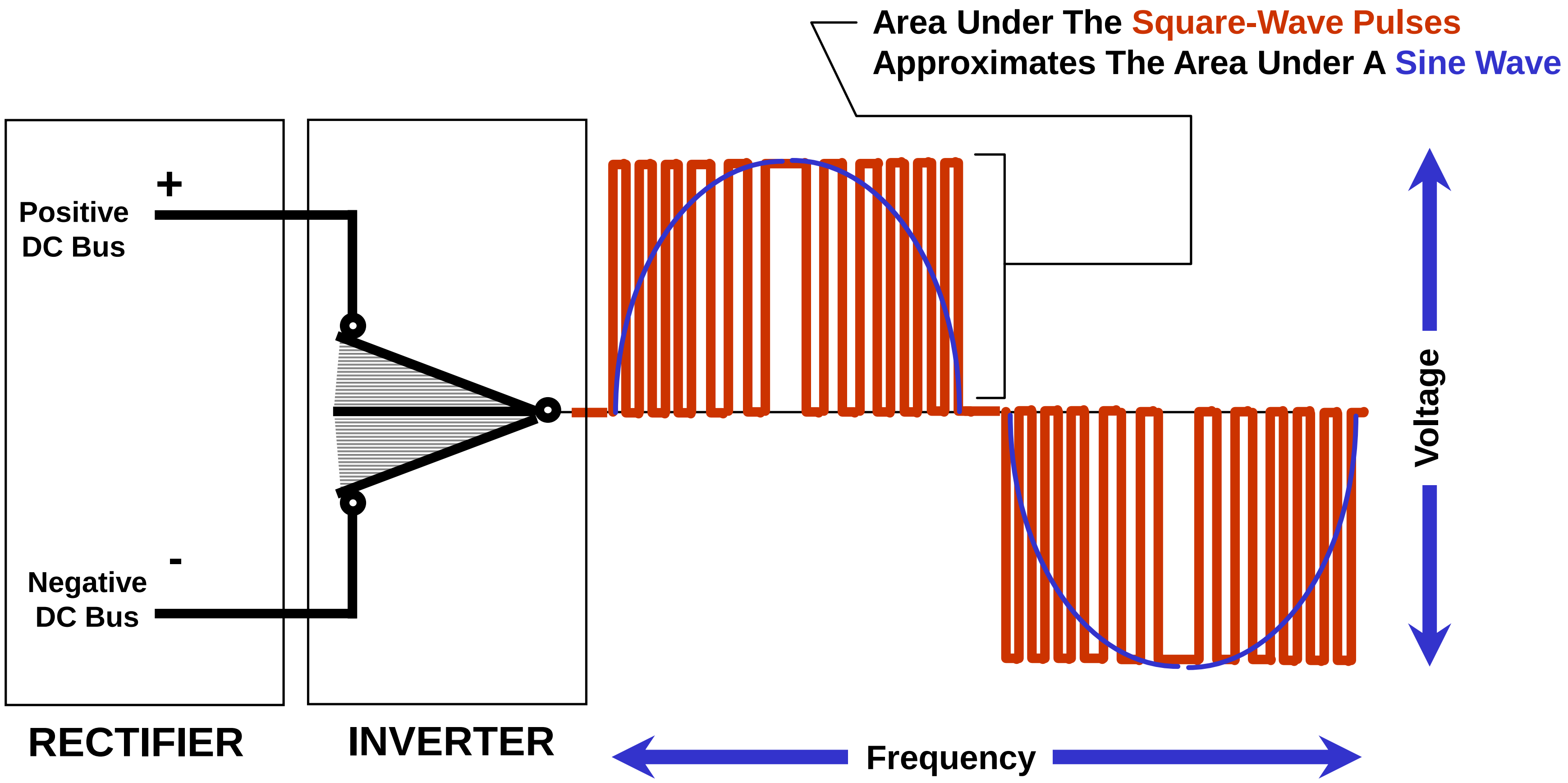

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

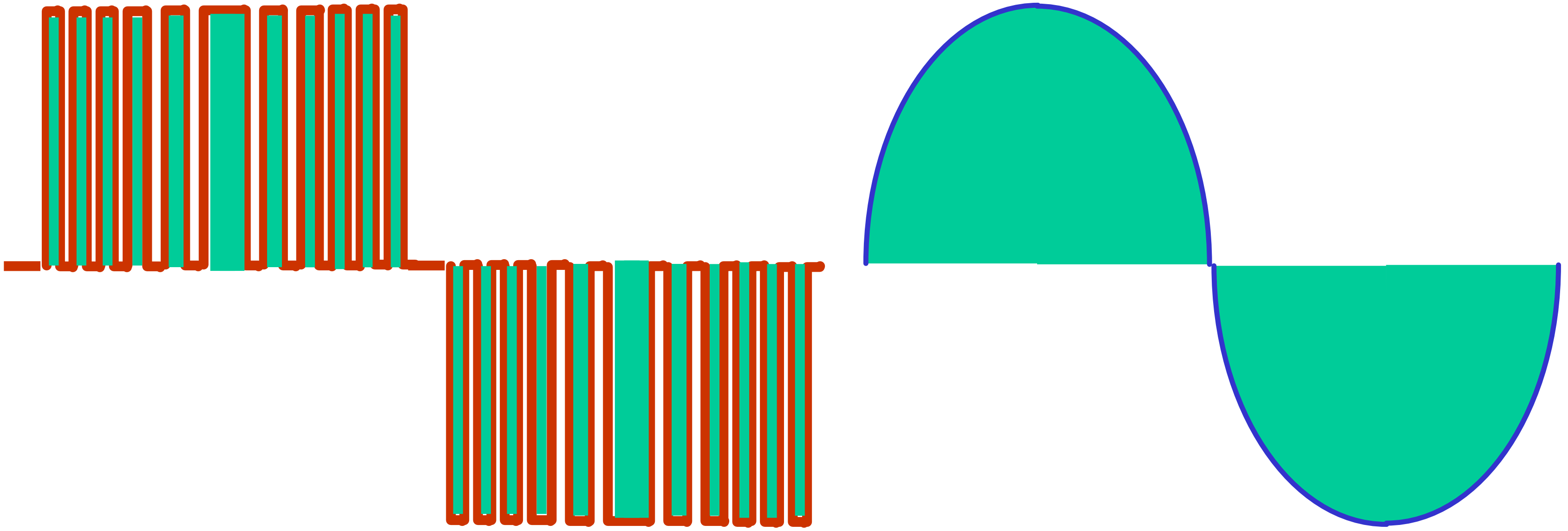

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

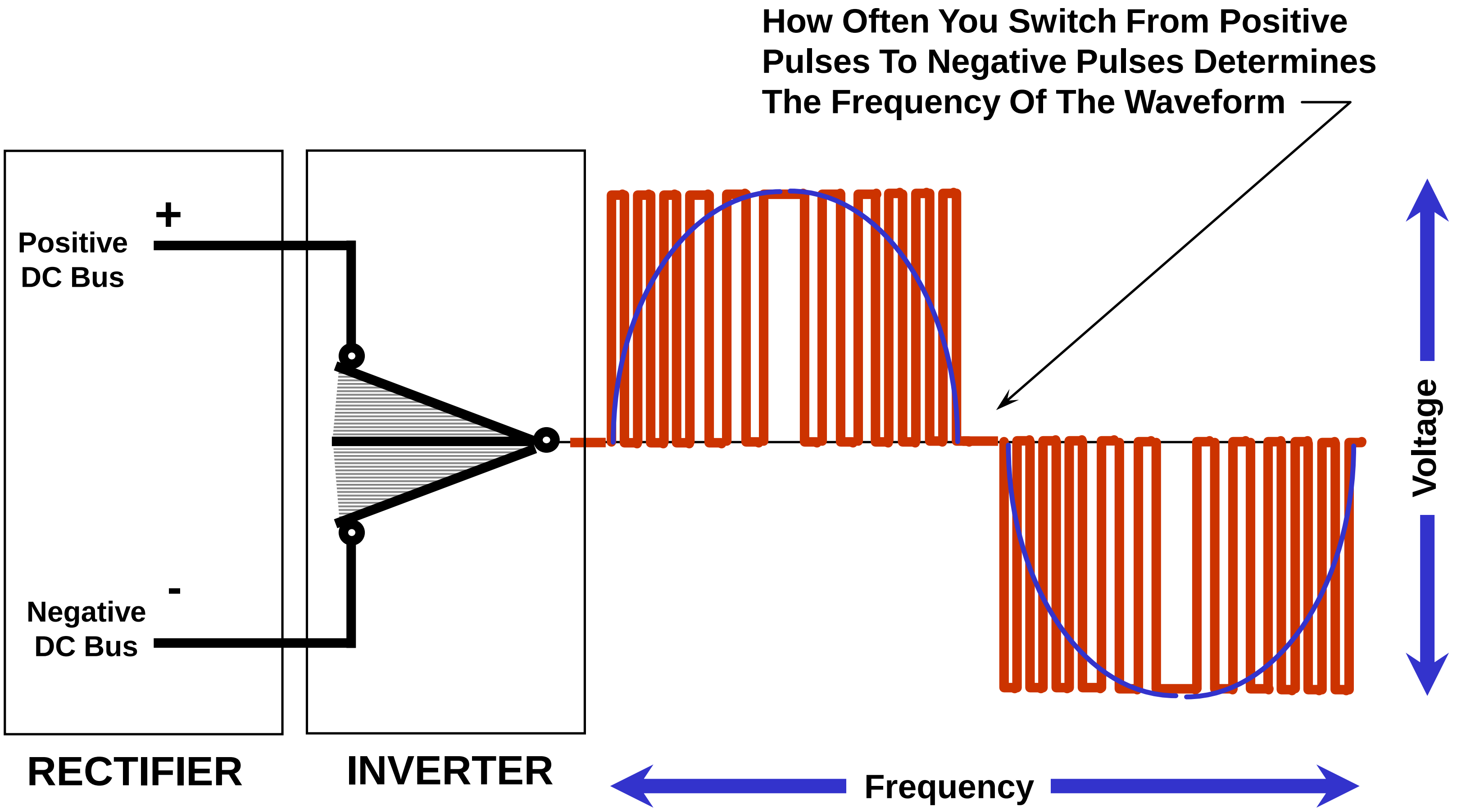

+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER



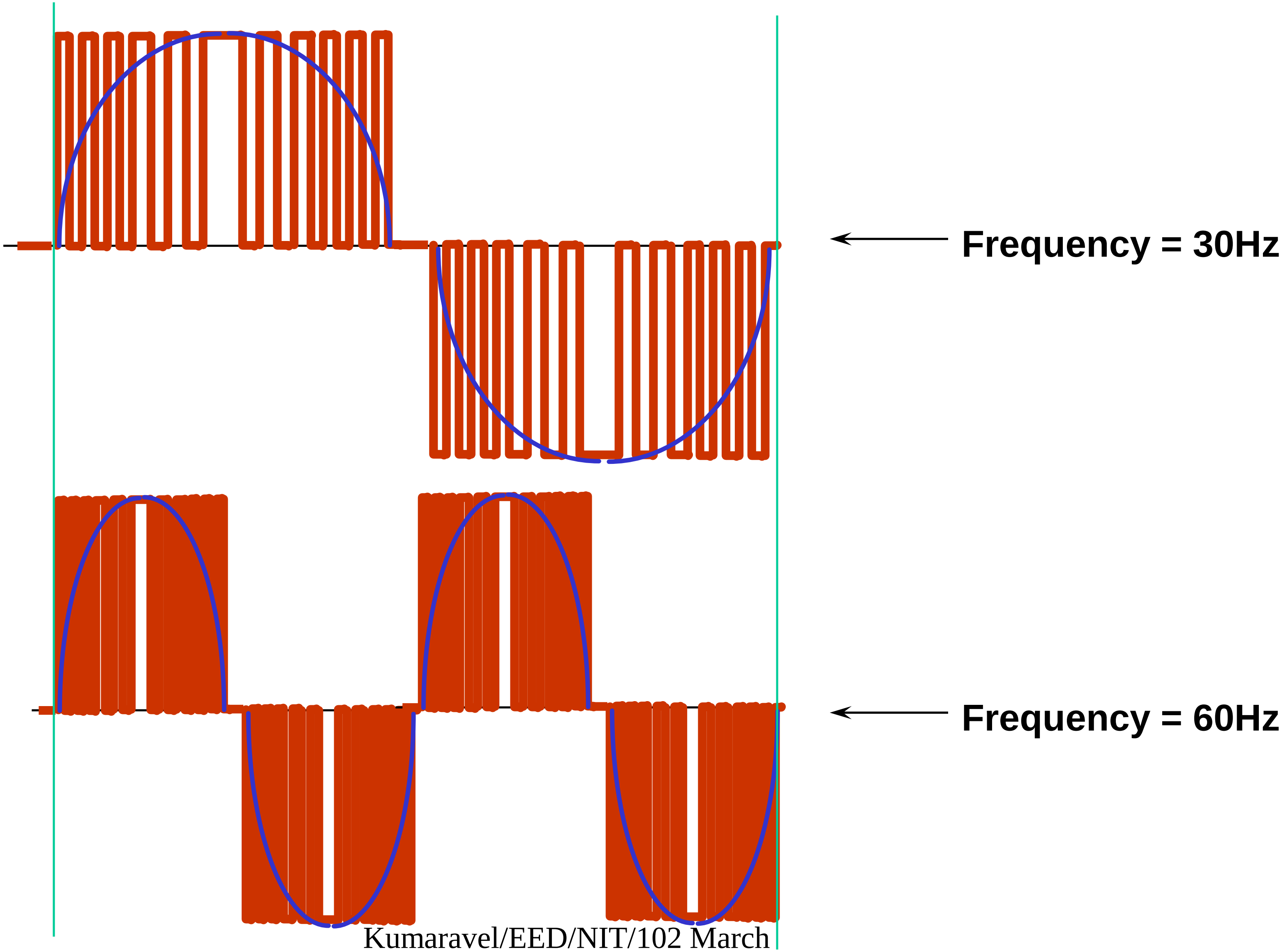
+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER

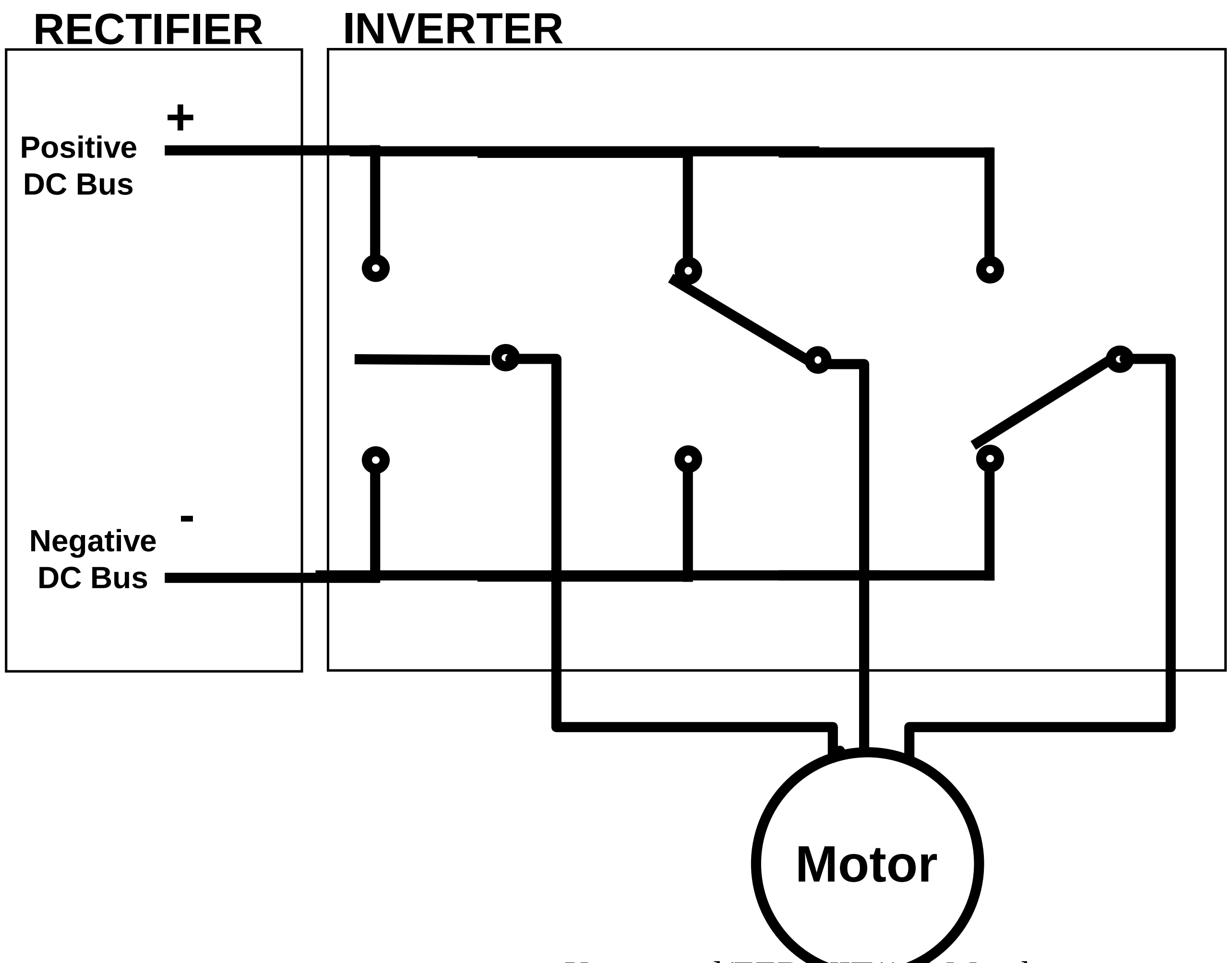

Area Under The Square-Wave Pulses
Approximates The Area Under A Sine Wave
+
Positive
DC Bus
-
Negative
DC Bus
RECTIFIER
INVERTER
Frequency
Voltage

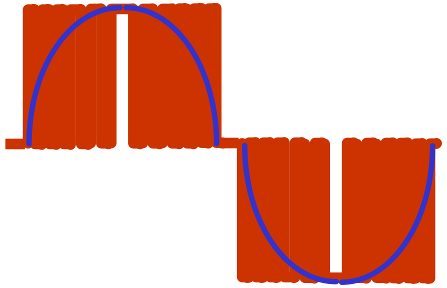


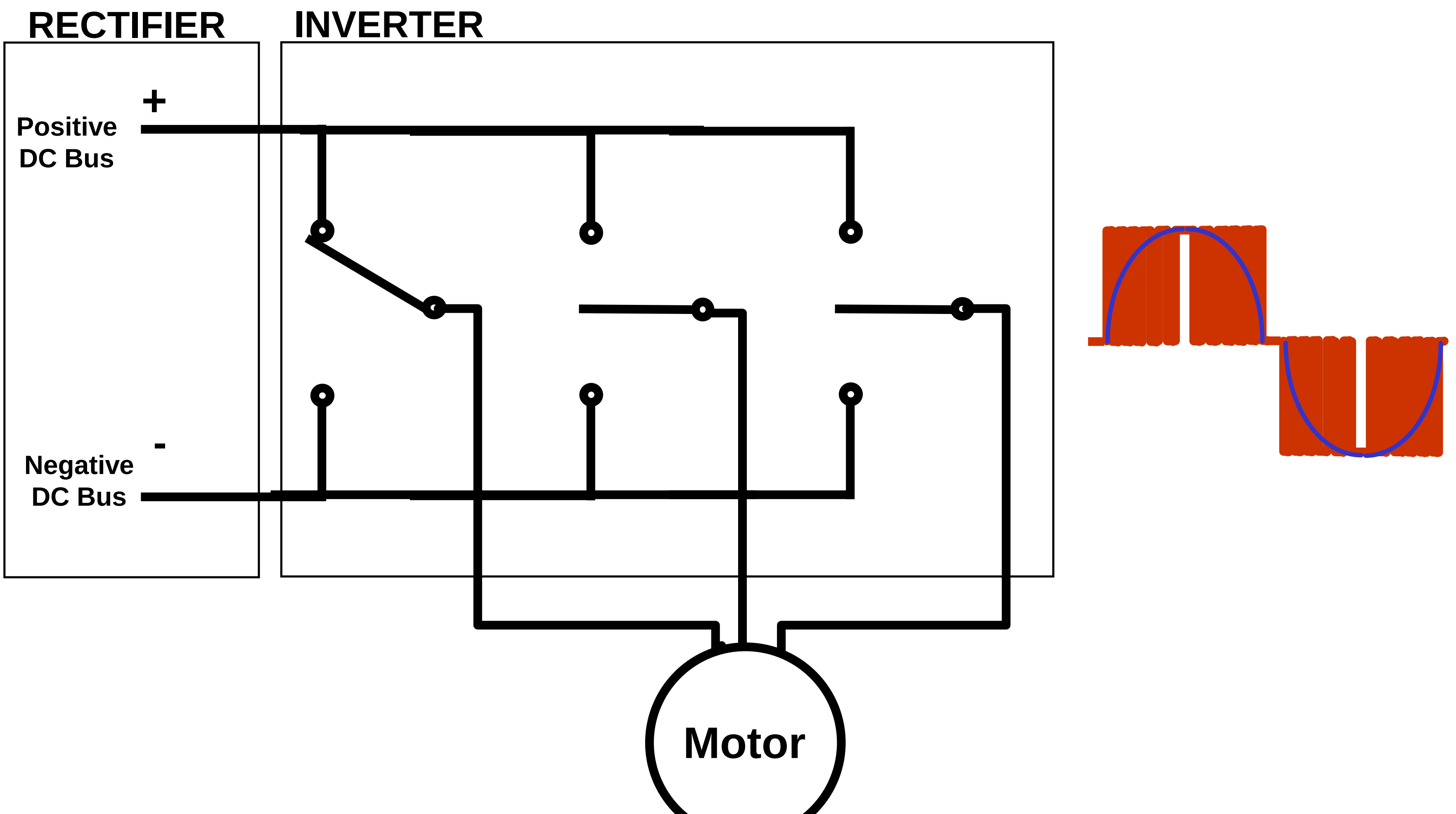


How Often You Switch From Positive Pulses To Negative Pulses Determines The Frequency Of The Waveform
+
Positive DC Bus
-
Negative DC Bus
RECTIFIER
INVERTER
Frequency
Voltage

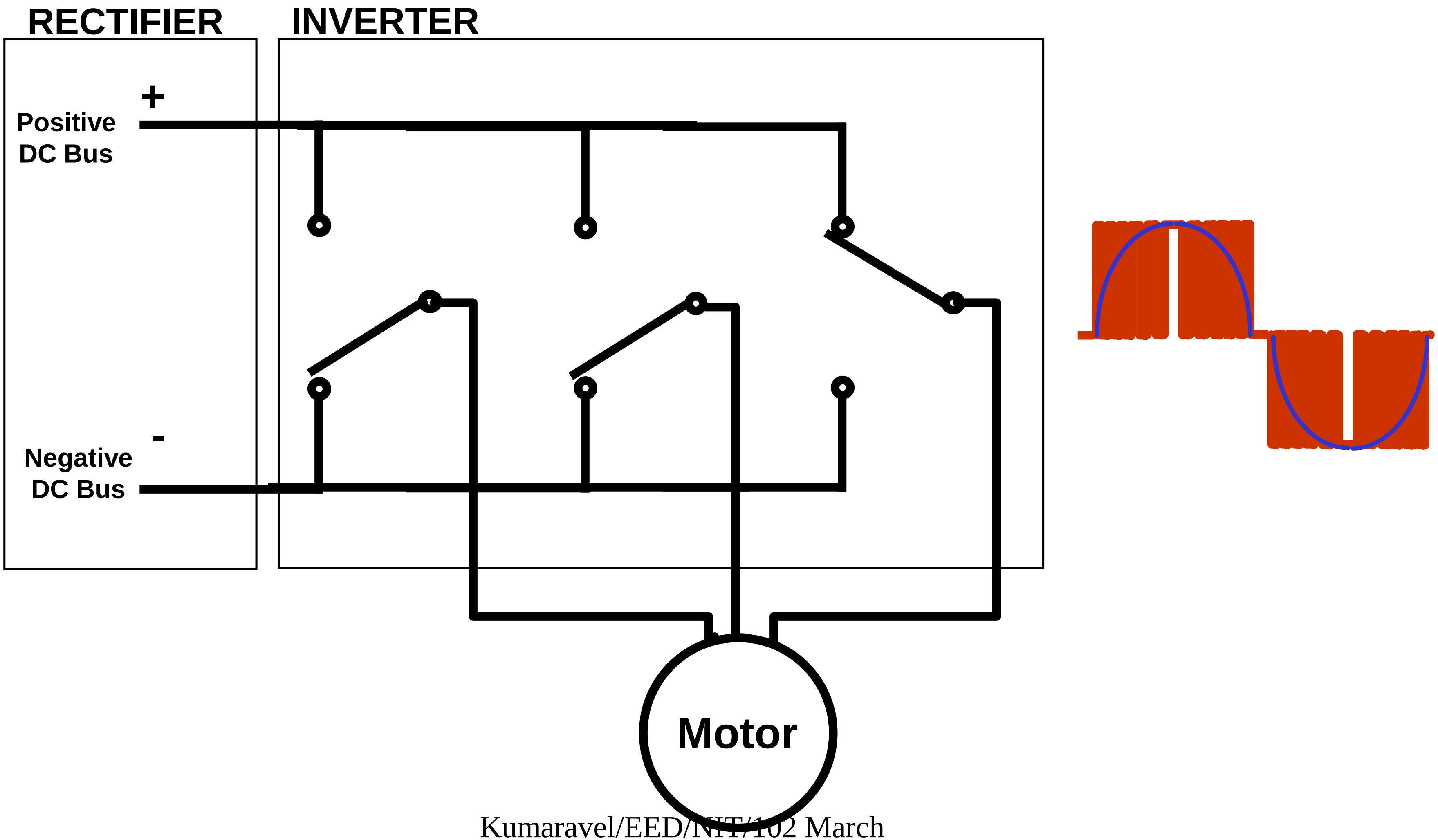

Frequency = 30Hz
Frequency = 60Hz


RECTIFIER
INVERTER
+
Positive
DC Bus
-
Negative
DC Bus
Motor

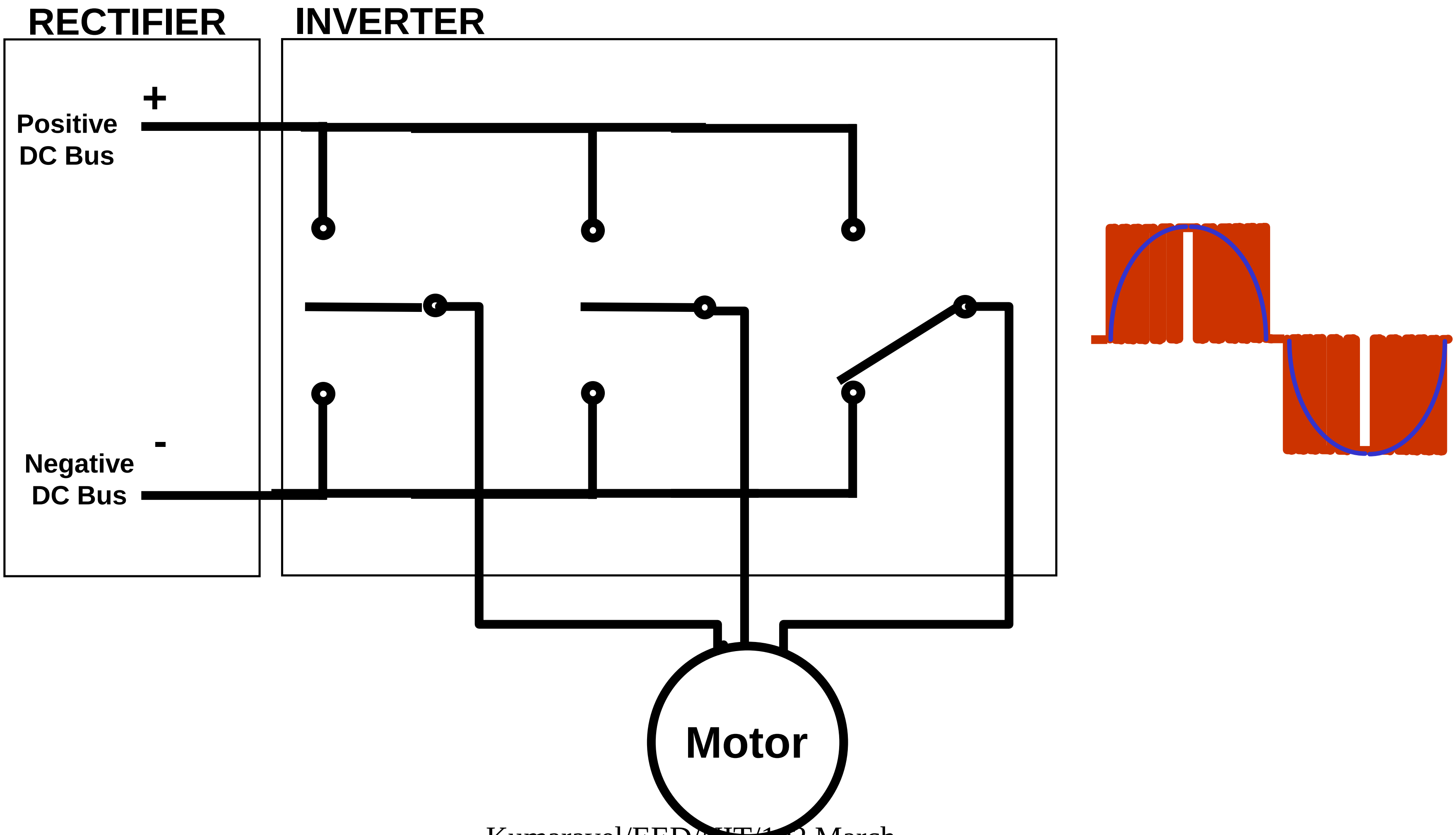


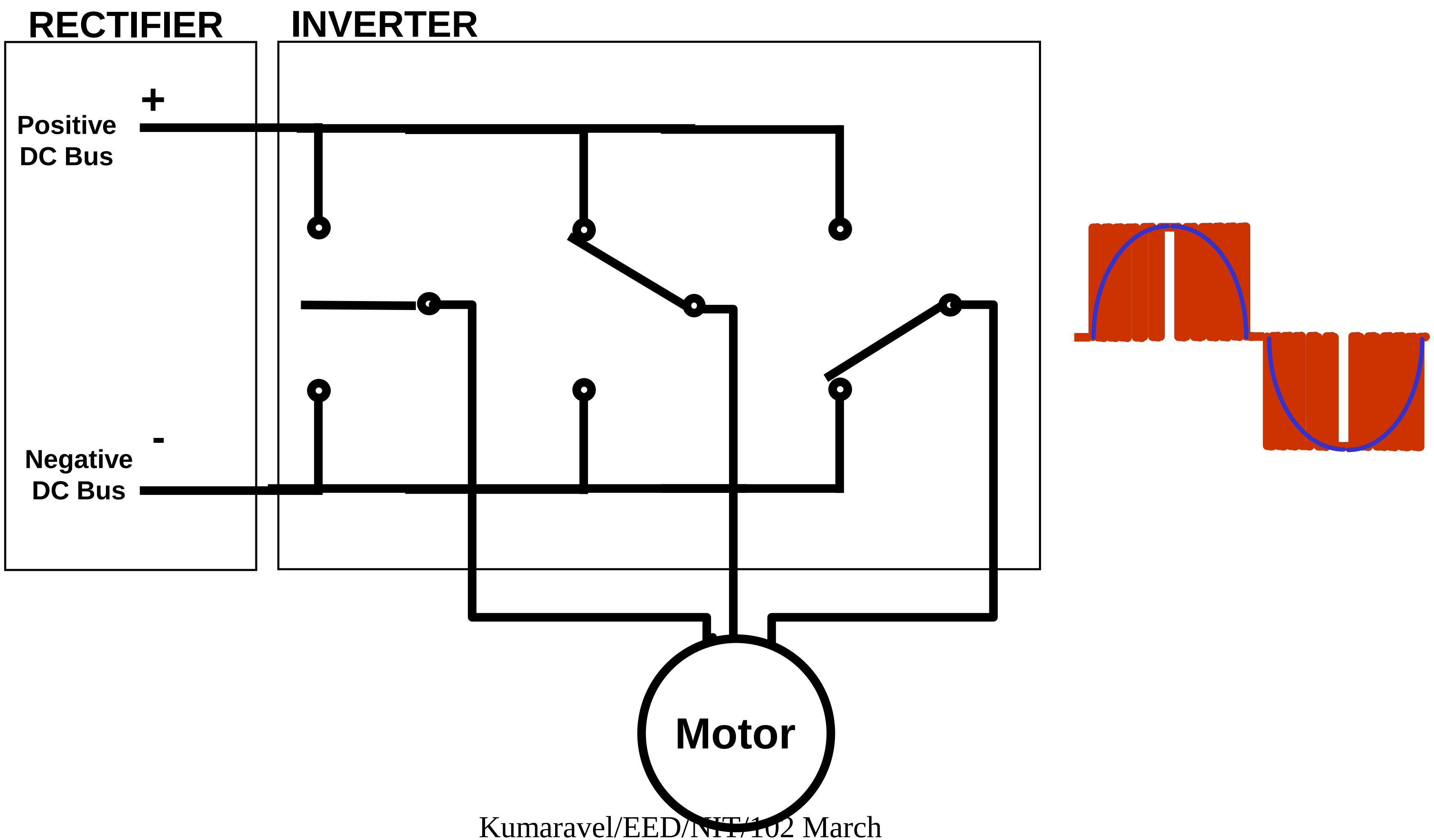


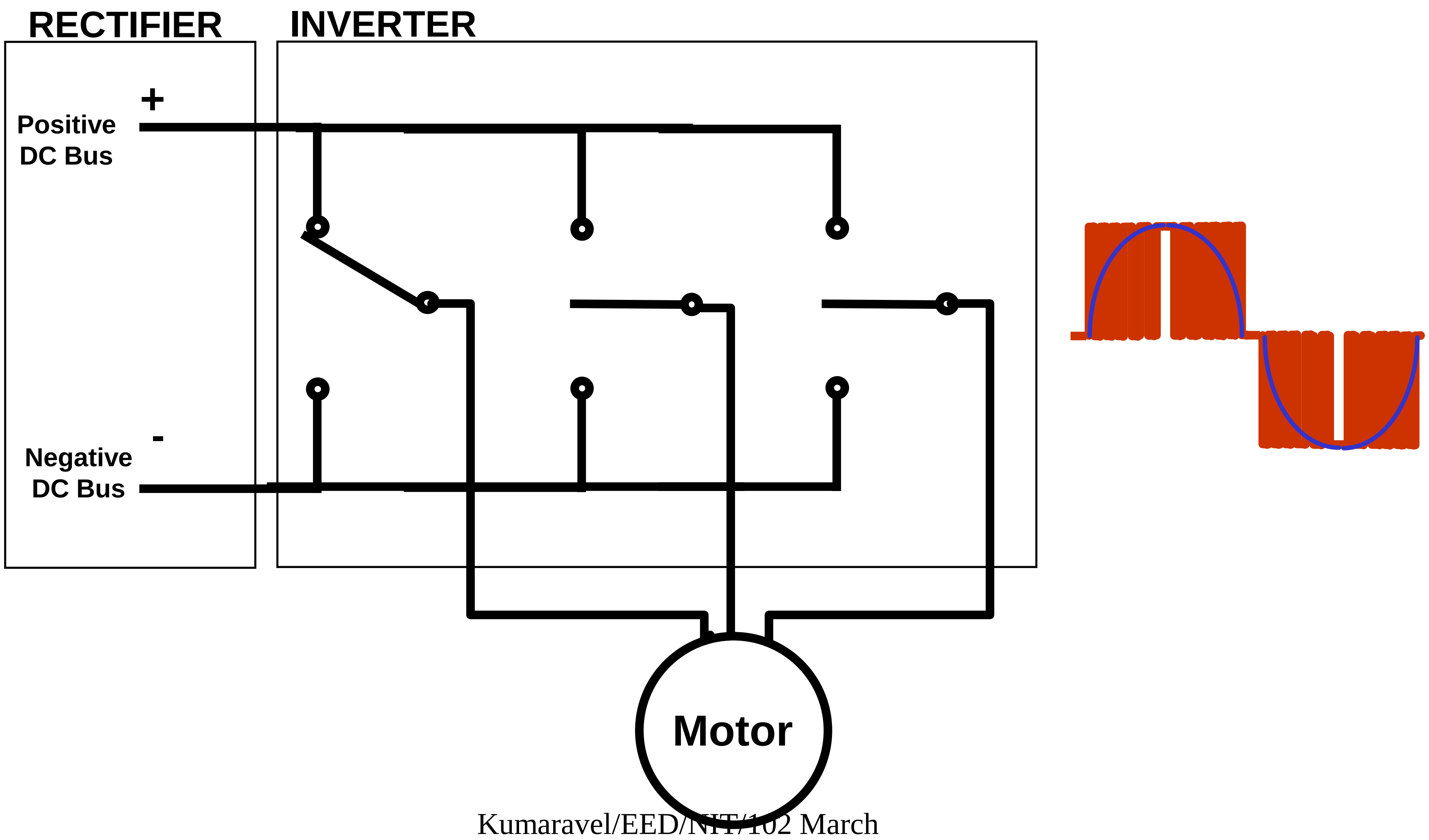
RECTIFIER
INVERTER
+
Positive
DC Bus
-
Negative
DC Bus
Motor

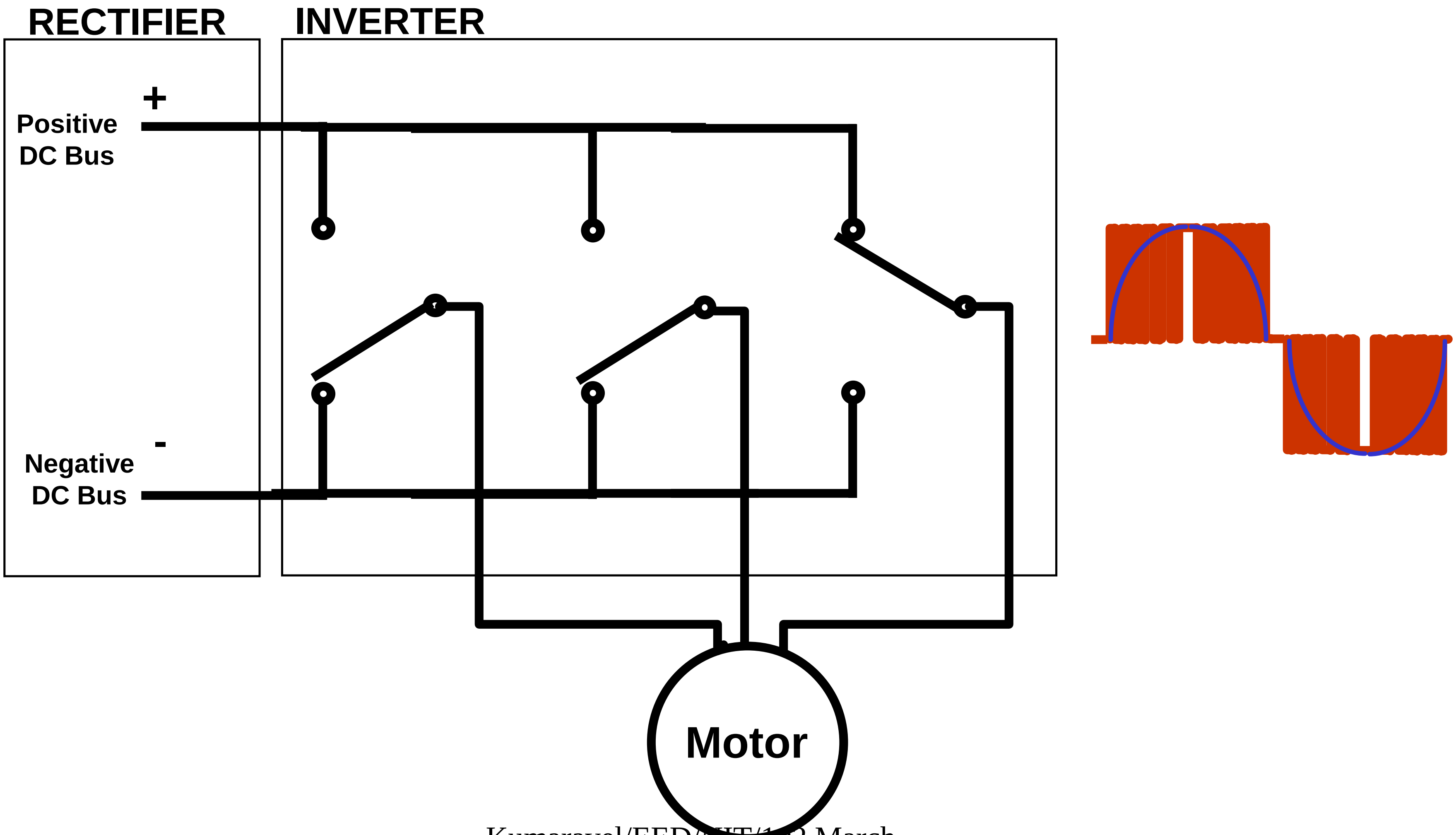


RECTIFIER
INVERTER
+
Positive
DC Bus
-
Negative
DC Bus
Motor


RECTIFIER
INVERTER
+
Positive
DC Bus
-
Negative
DC Bus
Motor


RECTIFIER
INVERTER
+
Positive DC Bus
-
Negative DC Bus
Motor


RECTIFIER
INVERTER
+
Positive
DC Bus
-
Negative
DC Bus
Motor


RECTIFIER
INVERTER
+
Positive
DC Bus
-
Negative
DC Bus
Motor

Thank You

By

Dr. Kumaravel S.

kumaravel_s@nitc.ac.in

You gain strength, courage and confidence by every experience in which you really stop to look fear in the face. You must do the thing you think you can not - Eleanor Roosevelt