Introduction to EV Chargers

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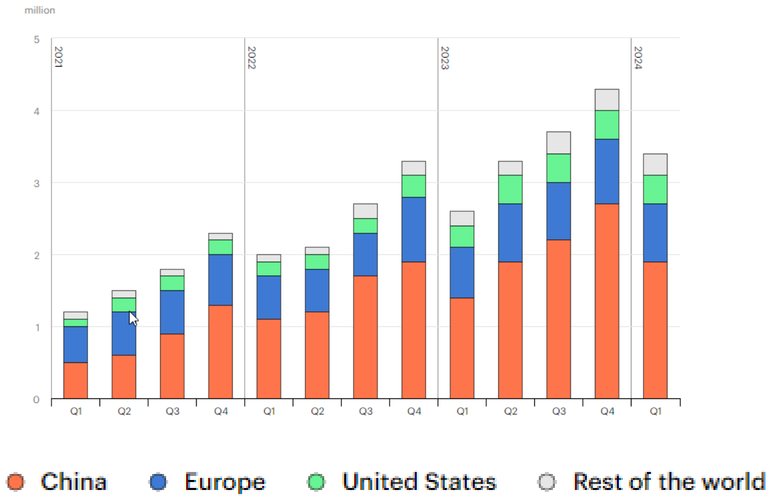
What are we discussing ?
Contents

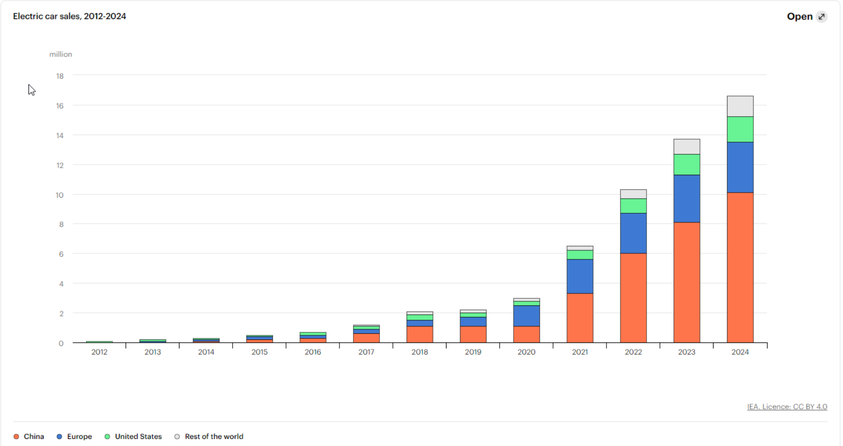
1. Introduction to Electric Vehicles and Chargers
2. Types & Levels of Chargers
3. Components of Chargers
4. Front End Power Factor Correction Circuits
5. Resonant DC-DC Converters (based on time availability)
6. QA session

Introduction

Quick Facts & Figures

- Nearly one in Five cars sold in 2023 are Evs
- Electric car sales neared 14 million in 2023, 95% of which were in China, Europe and the United States
- Second-hand markets for electric cars are on the rise
- Strong electric car sales in the first quarter of 2024 surpass the annual total from just four years ago

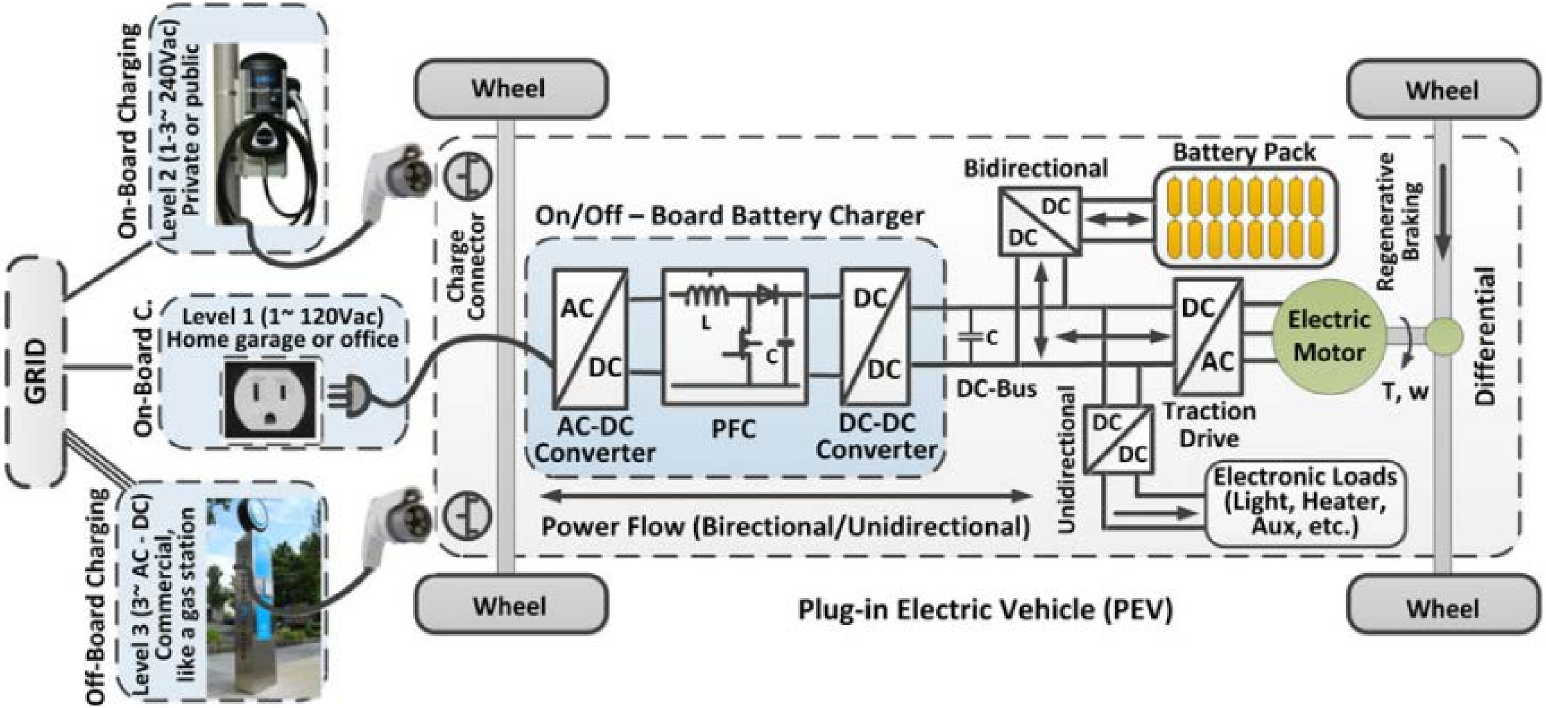




IEA (2024), Quarterly electric car sales by region, 2021-2024, IEA, Paris
https://www.iea.org/data-and-statistics, Licence: CC BY 4.0

Introduction

Block Diagram Representation



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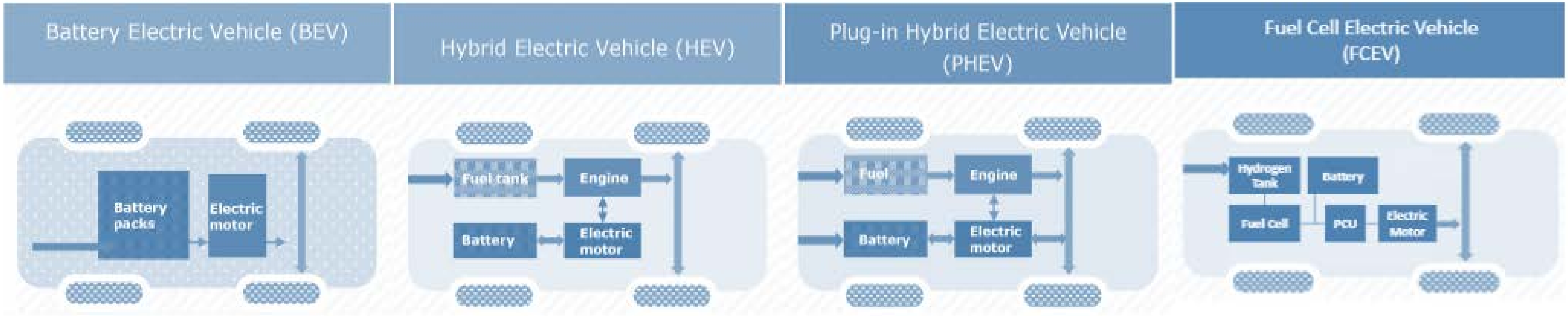
Introduction
Types of Electric Vehicles



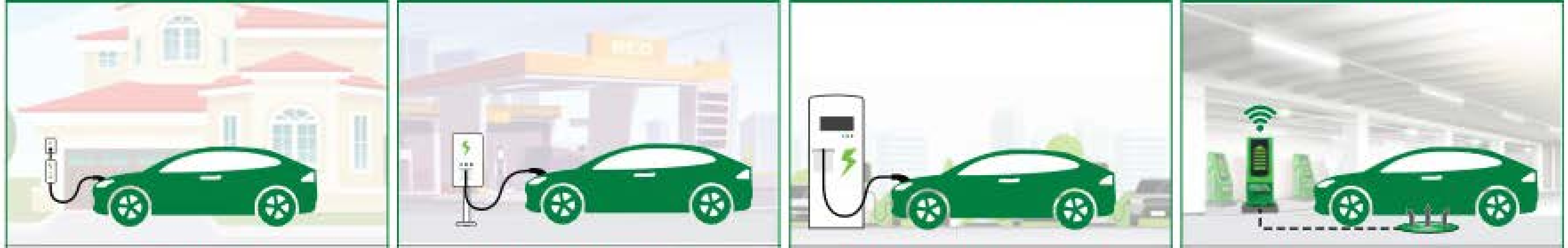
MG ZS, TATA Nexon, TATA Tigor, Mahindra E20 plus, Hyundai Kona, Mahindra Verito

Porsche Cayenne S E-Hybrid, BMW 330e, Porsche Panamera S E-hybrid, Chevy Volt, Chrysler Pacifica, Ford C-Max Energi, Mercedes C350e, Mercedes S550e, Mercedes GLE550e, Mini Cooper SE Countryman, Ford Fusion Energi, Audi A3 E-Tron, BMW i8, BMW X5 xdrive40e, Fiat 500e, Hyundai Sonata, Kia Optima, Volvo XC90 T8.

Toyota Mirai, Riversimple Rasa, Hyundai Tucson FCEV, Honda Clarity Fuel Cell, Hyundai Nexo.

https://e-amrit.niti.gov.in/types-of-electric-vehicles

Chargers
Types & Levels

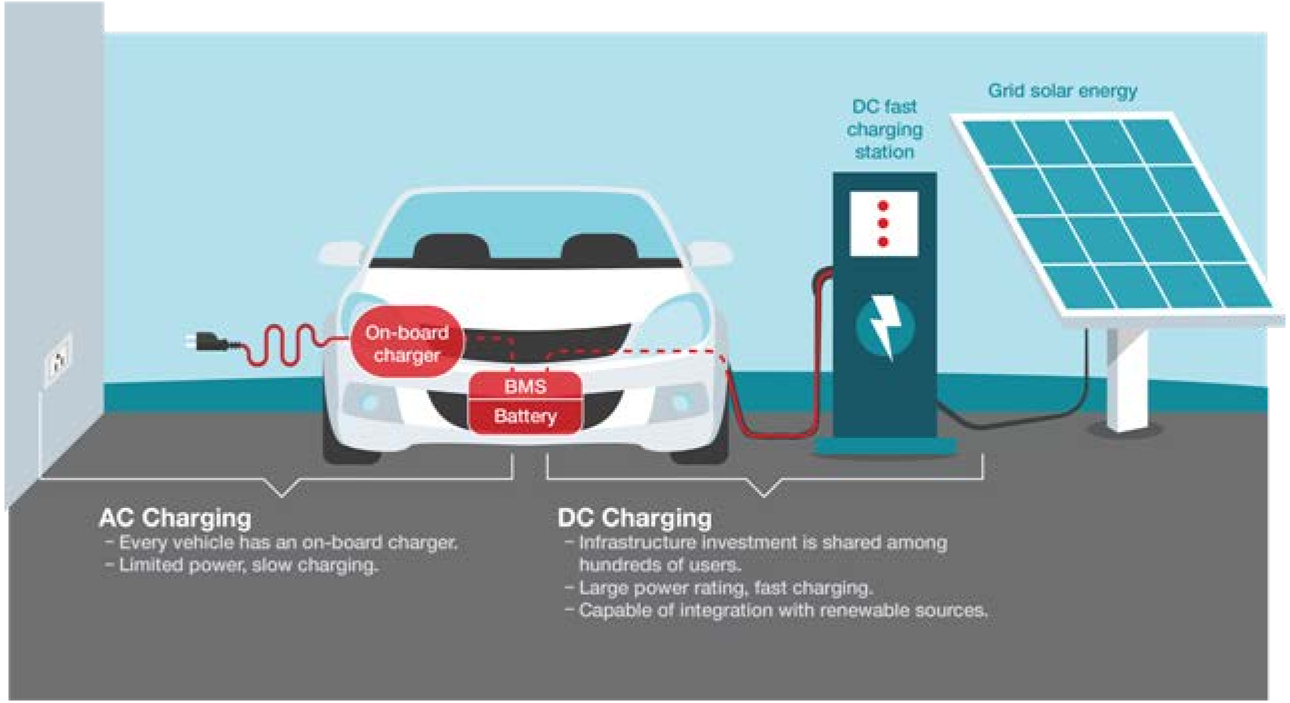


AC Level 1*	AC Level 2*	DC Fast Charger*	Wireless Charger‡
Basic home installation (Mode 1 or Mode 2)**	Home and public installation (Mode 3)**	Public and commercial installation (Mode 4)**	Home and public installation
Voltage 120 V AC, 1-phase 250 V AC, 1-phase 480 V AC, 3-phase	**Voltage** 208 V–240 V AC, 1-phase 250 V AC, 1-phase 480 V AC, 3-phase	**Voltage** 380 V–600 V AC, 3-phase	**Power levels** WPT1 – 3.7 kW WPT2 – 7.7 kW WPT3 – 11 kW
Current rating 12 A–16 A (32 A for 3-phase)	**Current rating** 12 A–80 A	**Current rating** DC output (up to 400 A)	**Grid to battery efficiency** 94% at a 10" ground clearance
Charging time 8–12 hours***	**Charging time** 4–6 hours***	**Charging time** 15–30 mins***	**Vehicle ground clearance** 100–250 mm (3.9" to 9.8")

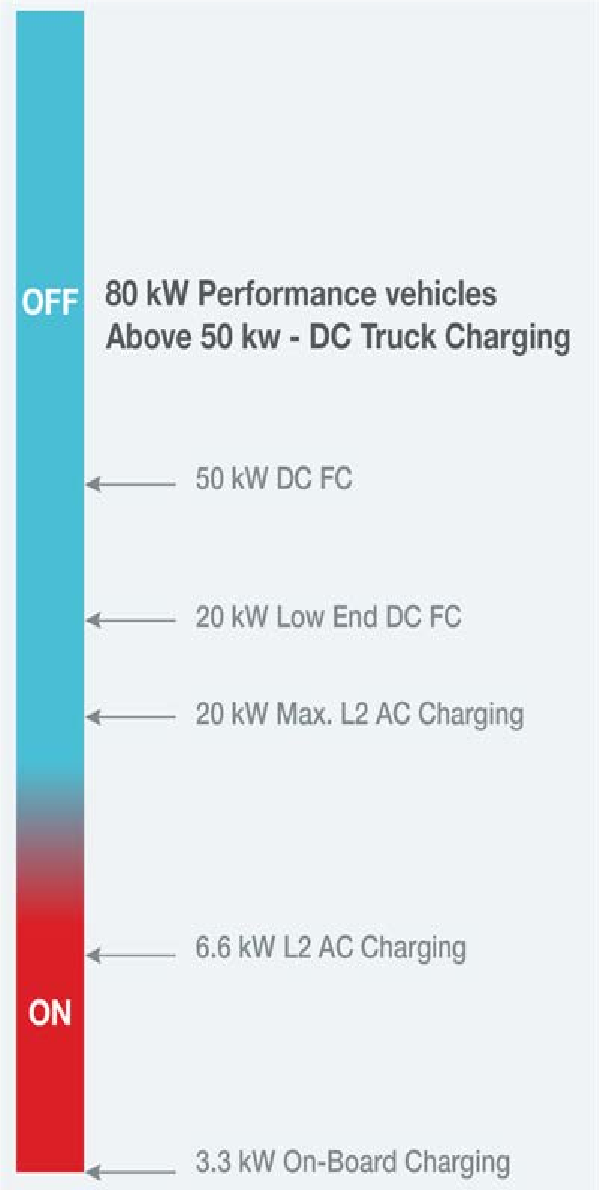
*As defined by SAE J1772 ‡ As defined by SAE J2954 ** As defined by IEC 61851-1 *** Charge time dependent on vehicle's battery capacity and charge acceptance rate

https://chargedevs.com/whitepapers/designing-dc-fast-chargers-for-next-gen-evs/

Chargers
Types & Levels



https://electronicsmaker.com/taking-charge-of-electric-vehicle-battery-charging



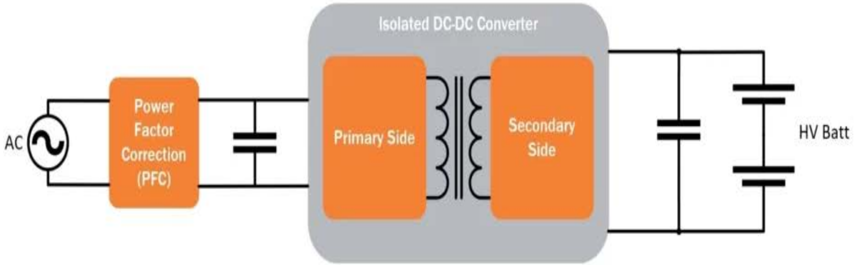
Chargers
Types & Levels

Power Level Types	Charger Location	Typical Use	Energy Supply Interface	Expected Power Level	Charging Time	Vehicle Technology
Level 1 (Opportunity) 120 Vac (US) 230 Vac (EU)	On-board 1-phase	Charging at home or office	Convenience outlet	1.4kW (12A) 1.9kW (20A)	4–11 hours 11–36 hours	PHEVs (5-15kWh) EVs (16-50kWh)
Level 2 (Primary) 240 Vac (US) 400 Vac (EU)	On-board 1- or 3-phase	Charging at private or public outlets	Dedicated EVSE	4kW (17A) 8kW (32 A) 19.2kW (80A)	1–4 hours 2–6 hours 2–3 hours	PHEVs (5-15 kWh) EVs (16-30kWh) EVs (3-50kWh)
Level 3 (Fast) (208-600 Vac or Vdc)	Off-board 3-phase	Commercial, analogous to a filling station	Dedicated EVSE	50kW 100kW	0.4–1 hour 0.2–0.5 hour	EVs (20-50kWh)

	Battery Type and Energy	All-Electric Range	Connector Type	Level 1 Charging		Level 2 Charging		DC Fast Charging	
				Demand	Charge Time	Demand	Charge Time	Demand	Charge Time
Toyota Prius PHEV(2012)	Li-Ion 4.4kWh	14 miles	SAE J1772	1.4kW (120V)	3 hours	3.8kW (240V)	2.5 hours	N/A	N/A
Chevrolet Volt PHEV	Li-Ion 16kWh	40 miles	SAE J1772	0.96–1.4 kW	5–8 hours	3.8kW	2–3 hours	N/A	N/A
Mitsubishi i-MiEV EV	Li-Ion 16kWh	96 miles	SAE J1772 JARI/TEPCO	1.5kW	7 hours	3kW	14 hours	50kW	30 minutes
Nissan Leaf EV	Li-Ion 24kWh	100 miles	SAE J1772 JARI/TEPCO	1.8kW	12–16 hours	3.3kW	6–8 hours	50 + kW	15-30 minutes
Tesla Roadster EV	Li-Ion 53kWh	245 miles	SAE J1772	1.8kW	30 + hours	9.6–16.8 kW	4–12 hours	N/A	N/A

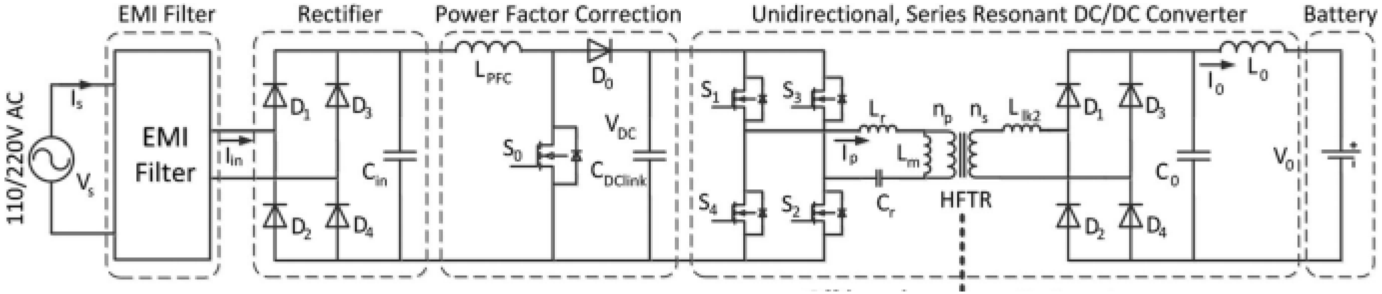
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6280677

Chargers
On-Board Chargers

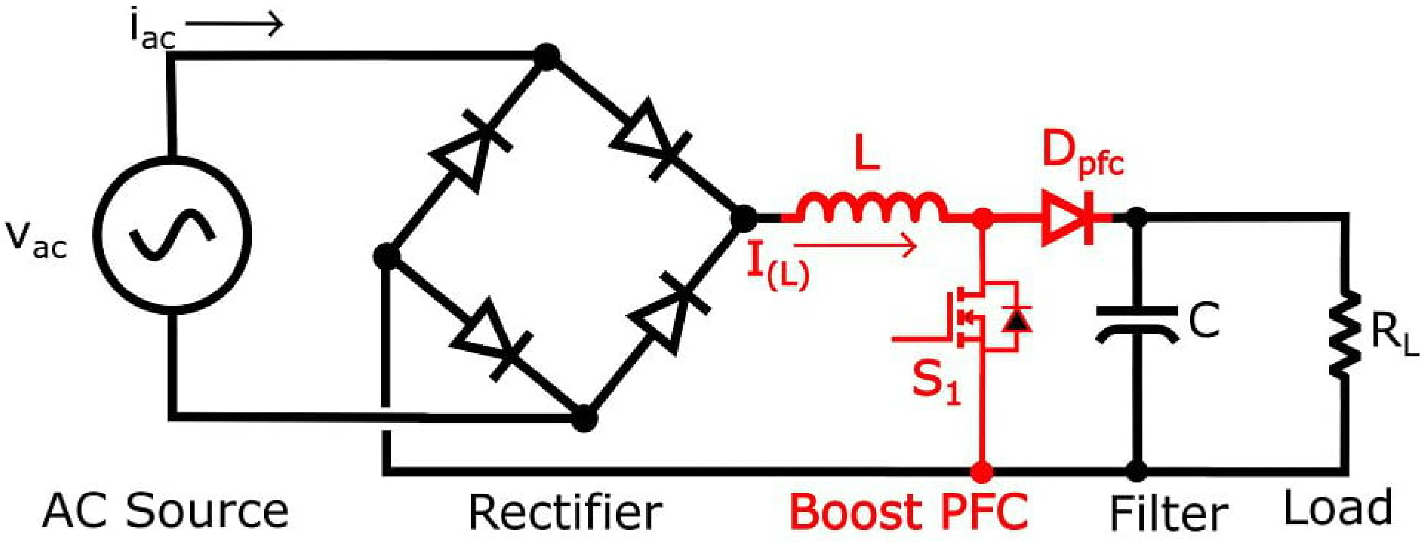


Components:

1. Rectifier + Front End PFCs
2. Isolated DC-DC



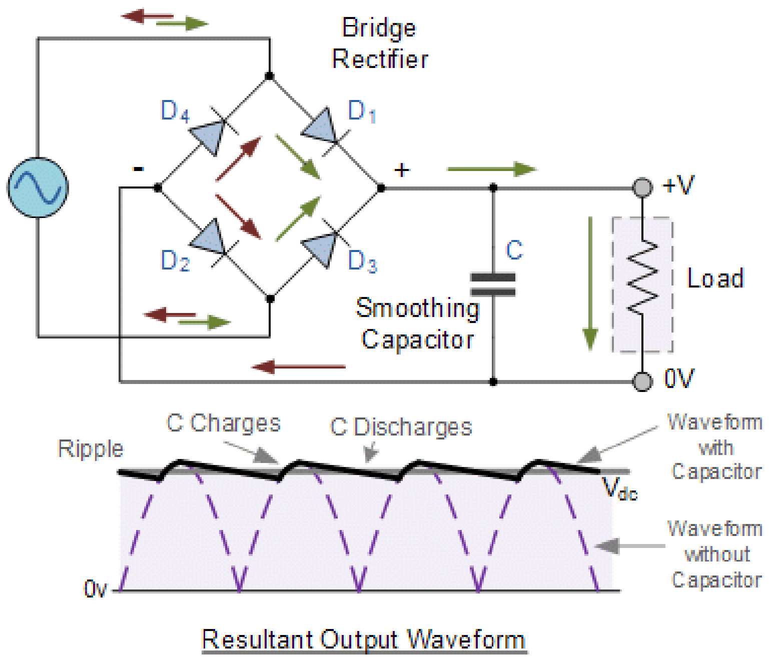
Chargers
Front End PFCs



Front End Power Factor Correction Circuits
Diode Rectifier

- Diode rectifiers play a crucial role in PFCs, converting alternating current (AC) to direct current (DC) by allowing current flow unidirectional.

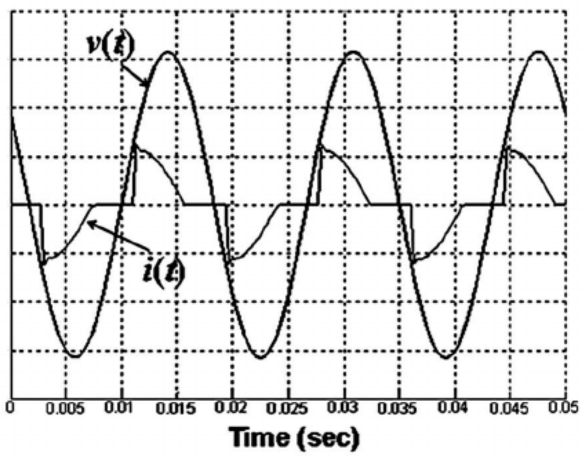
- The capacitor is connected to the terminals to smoothen the ripples.



Front End Power Factor Correction Circuits

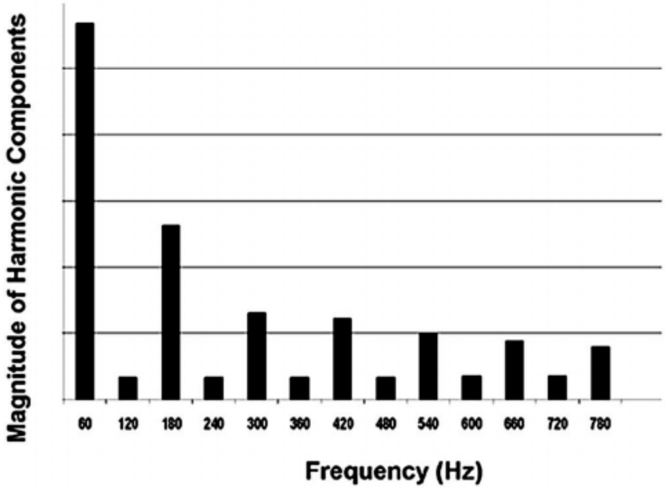
Effect of Capacitor on Power Supplies

N (Harmonic Number)	3	5	7	9	11	13	15	17
THD %	87	80	78	70	63	50	41	30



(a)

- Non Linear Current
- Harmonic Components from Capacitor
- Harmonic Resonance
- High Peak Current Magnitude
- Mismatched Components
- Switching Transients



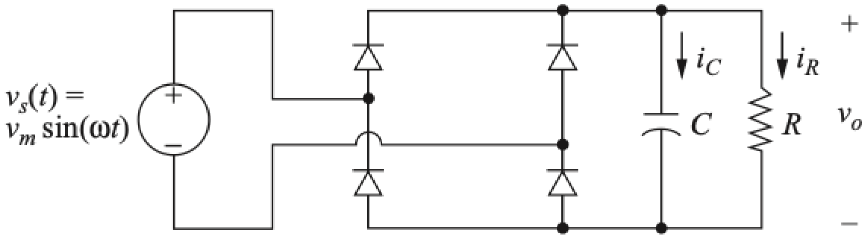
(b)

Front End Power Factor Correction Circuits

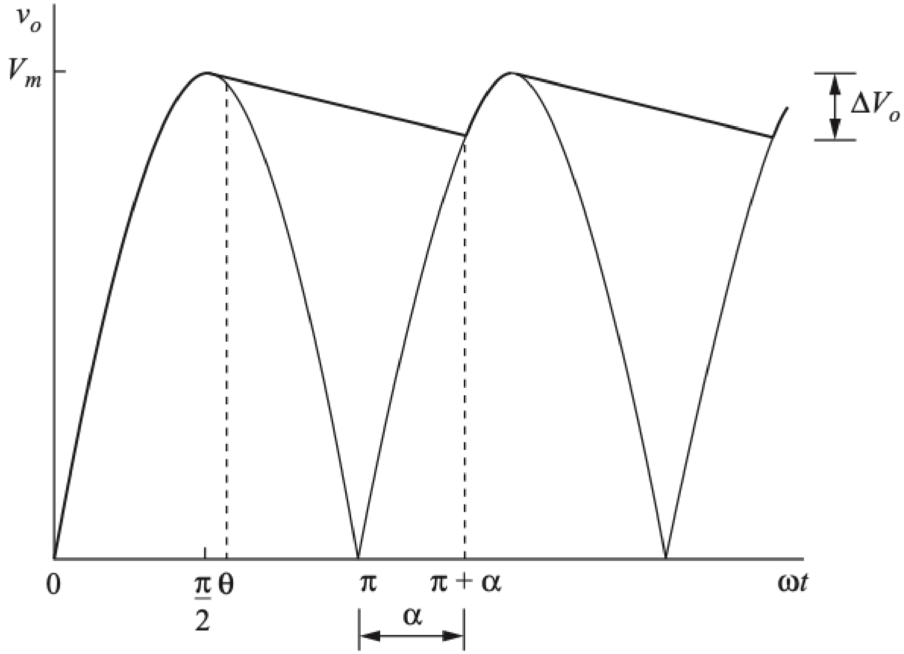
Diode Rectifiers with Capacitive Filters

$$C = \frac{1}{2fR\frac{V_o}{V_o}}$$

V_m (Peak)	Frequency (f)	Load Current (I_R)	Output Ripple (%)	Output Voltage
325 V	50 Hz	1 A	10	325 V



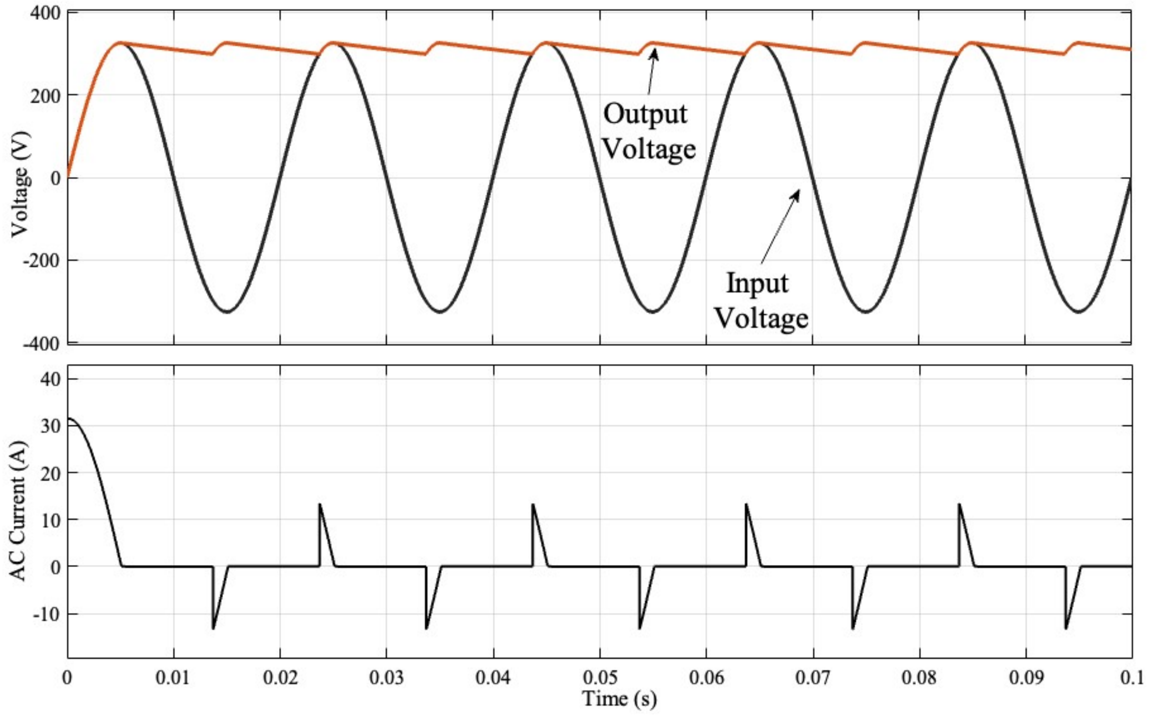
(a)



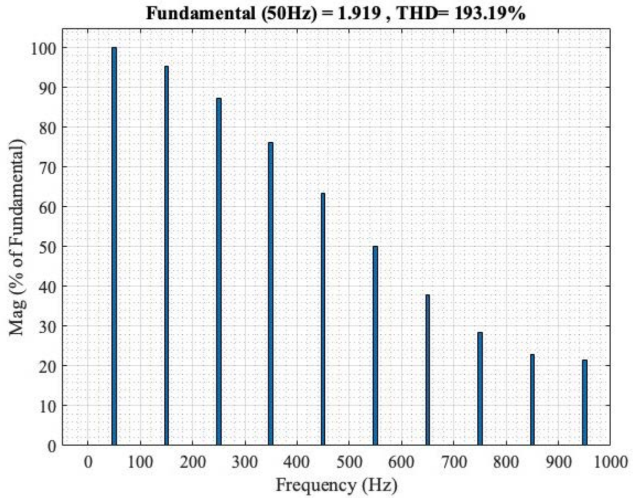
(b)

Front End Power Factor Correction Circuits

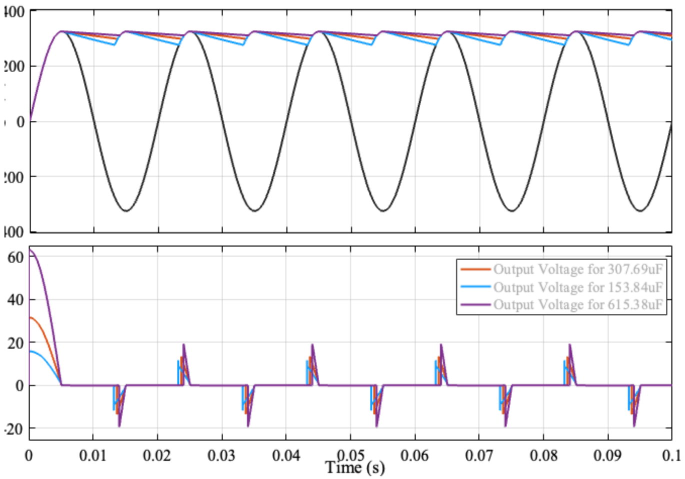
Diode Rectifiers with Capacitive Filters



Input and Output Waveforms for Diode Rectifier with capacitive filter with C=307.69uF



FFT of the AC Line Current with C = 307.69uF



Effect of capacitance on Output Ripple and Peak AC Line Currents

Front End Power Factor Correction Circuits

Diode Rectifiers with Capacitive Filters

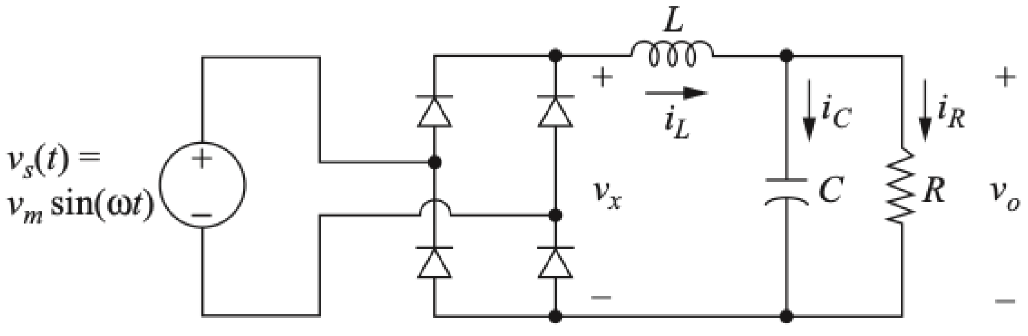
Capacitance Value	153.84uF	307.69uF	615.38uF
Output Ripple (Expected)	20%	10%	5%
Output Ripple (Simulated)	19.54%	9.5%	4.85%
THD %	154.67	193.2	237.47

Table showing effect of capacitance value on Output ripple and THD values

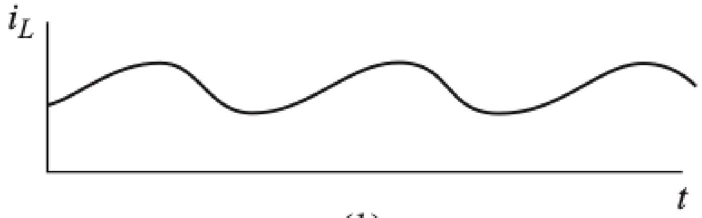
Front End Power Factor Correction Circuits

Diode Rectifiers with LC Filters

- $\frac{Vo(s)}{Vx(s)} = \frac{\frac{1}{LC}}{s^2+\frac{L}{R}s+\frac{1}{LC}}$
- Re-writing in standard form, the resonant frequency (ω) is and quality factor (Q) is .
- It is desired to keep f = <<100 Hz. Hence, choosing f=50 Hz and C=1000uF, L is found to be 10mH.

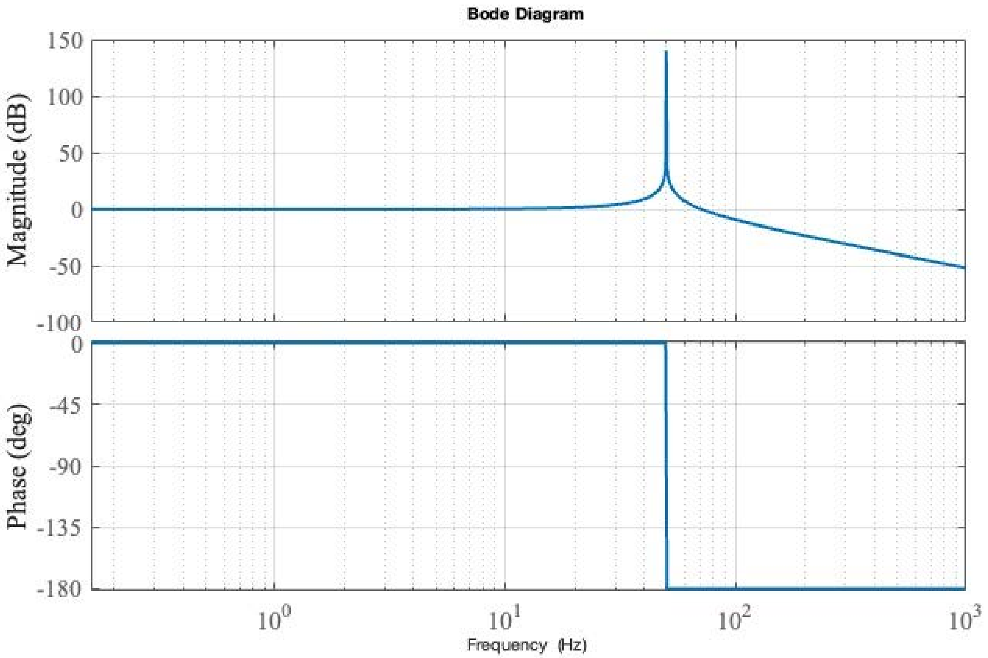


(a)

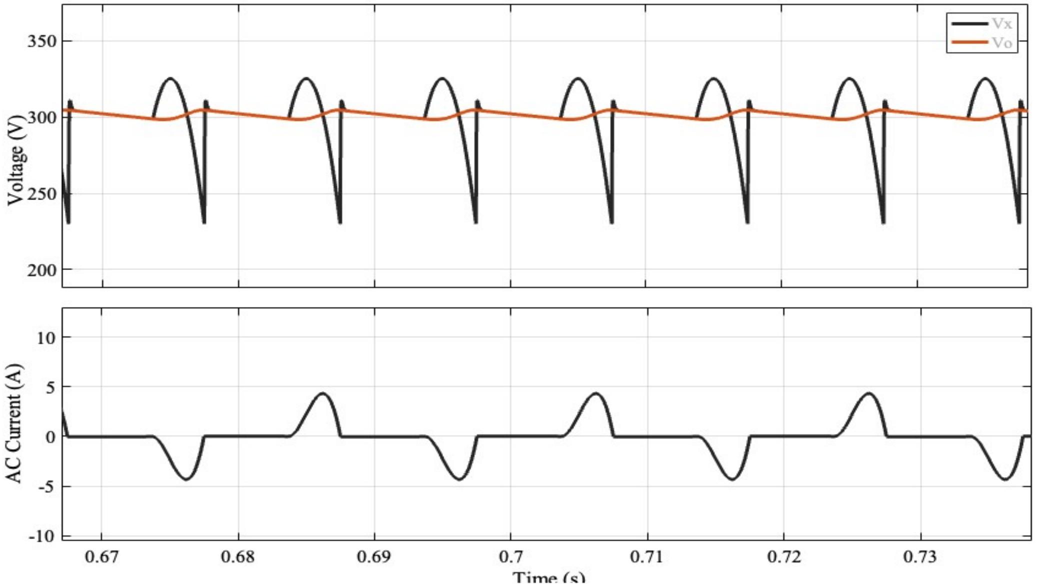


(b)

Diode Rectifiers with LC Filters

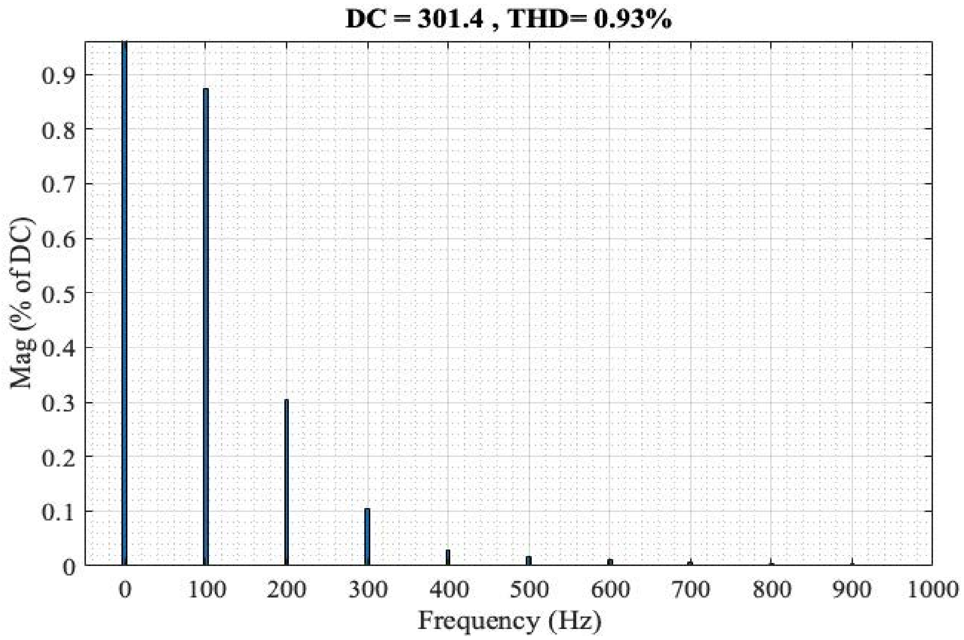


Bode Plot for L=2.5mH and C=1000uF

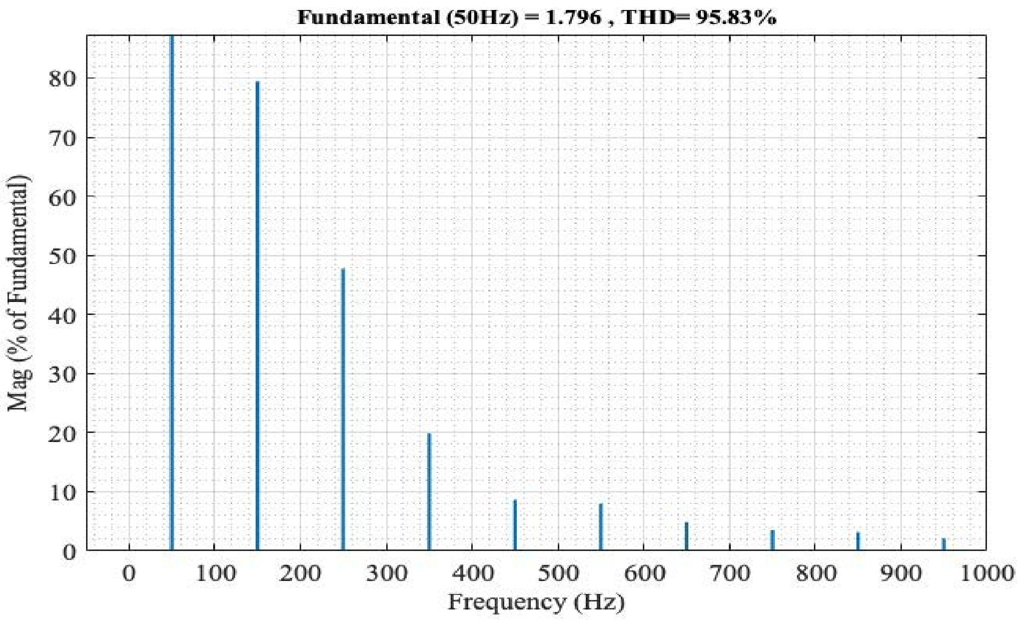


Output Voltage and Input Current for L=2.5mH and C=1000uF

Diode Rectifiers with LC Filters



FFT Spectrum of Output Voltage for L=2.5mH and C=1000uF

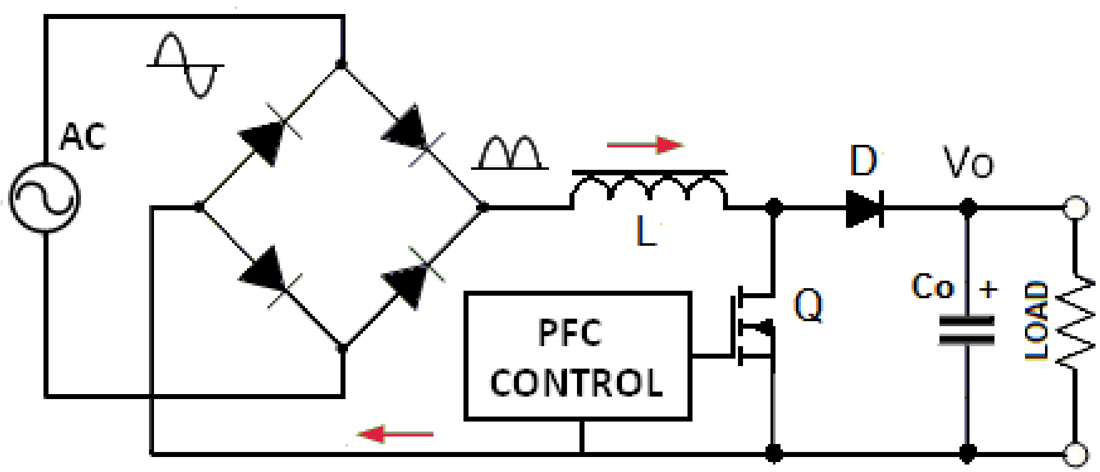


FFT Spectrum of AC Line Current for L=2.5mH and C=1000uF

Front End Power Factor Correction Circuits

Active Power Factor Correction

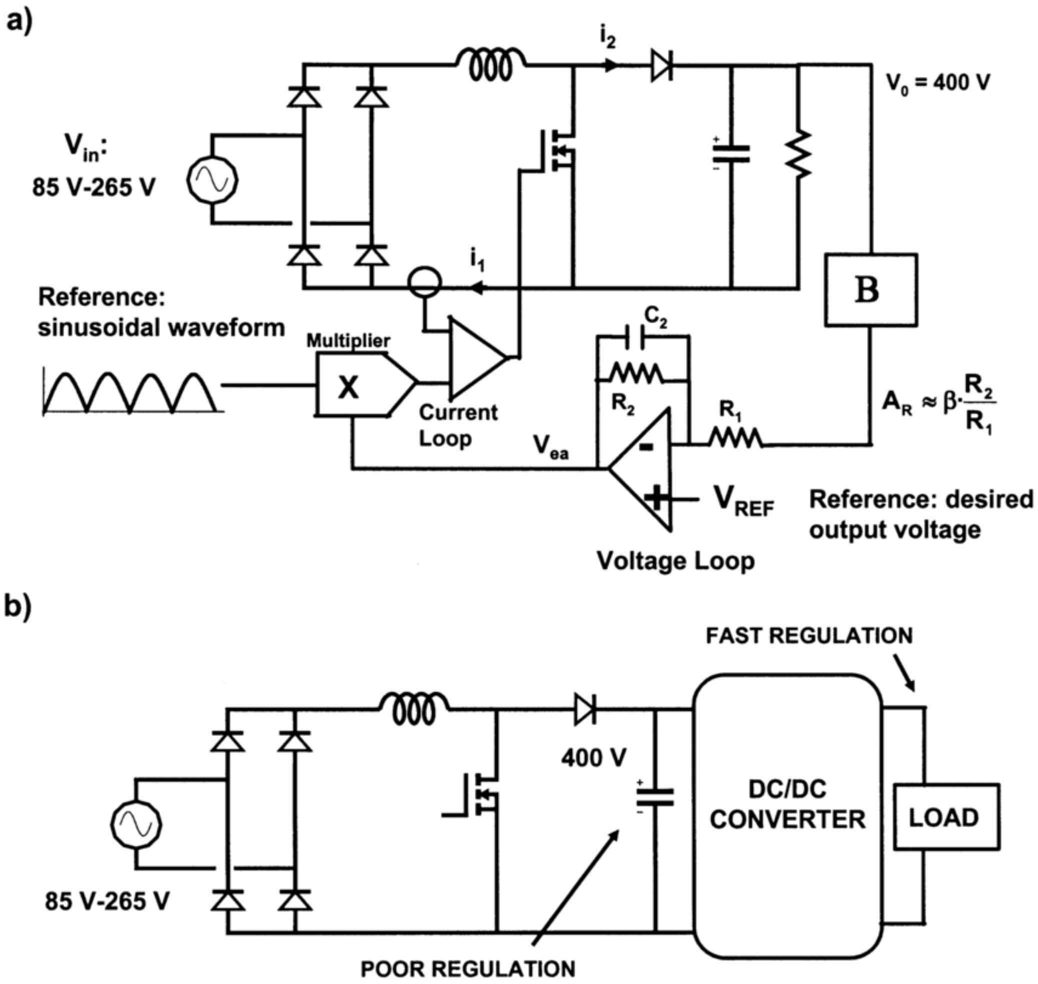
- Active Power Factor Correction (PFC) is a crucial approach employed in power supplies to enhance the power factor and efficiency of electrical systems. Active PFC circuits actively correct and adjust the power factor, typically aiming to achieve a near-unity power factor of 1.



Feedback Loop in APFC

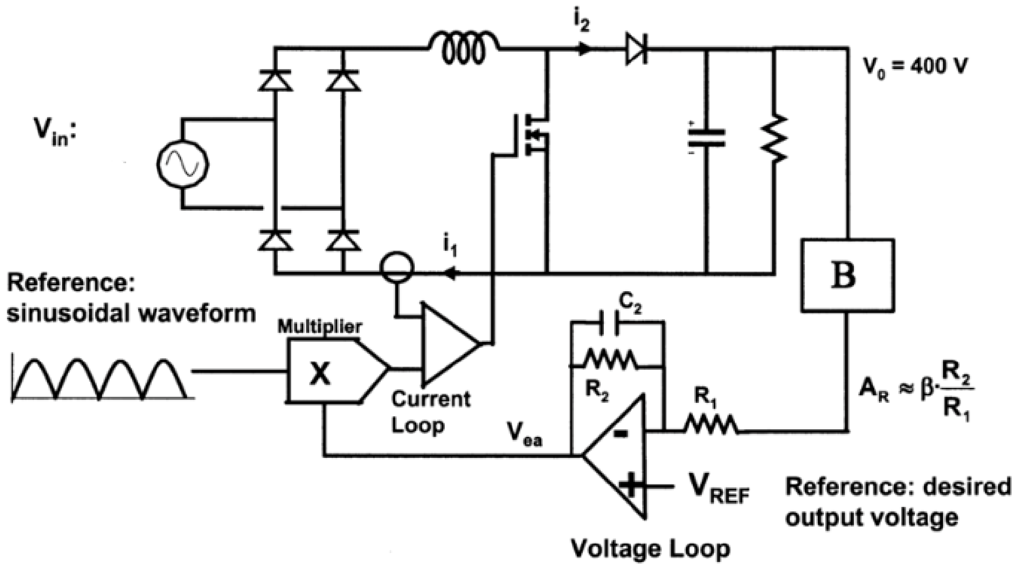
- The feedback loop acts as a critical element, enabling the system to actively correct the power factor by continuously monitoring and adjusting the input current waveform.

- This closed-loop control system ensures that the PFC circuit responds dynamically to changes in load and input conditions, providing efficient power factor correction and contributing to the overall effectiveness and reliability of the power supply.



Design

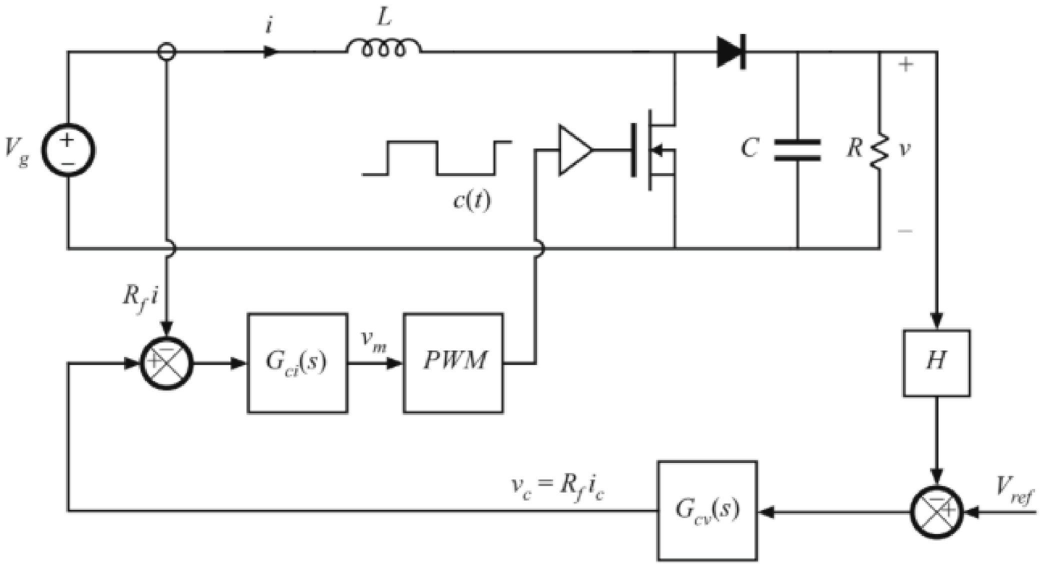
- $D = 1 - \frac{V_m}{V_o} = 0.1875.$
- $L = \frac{V_m D}{f_{sw} \Delta i_L} = 990.2\mu H$
- $C = \frac{D}{R f_{sw} \frac{\Delta V_o}{V_o}} = 2.343\mu F$

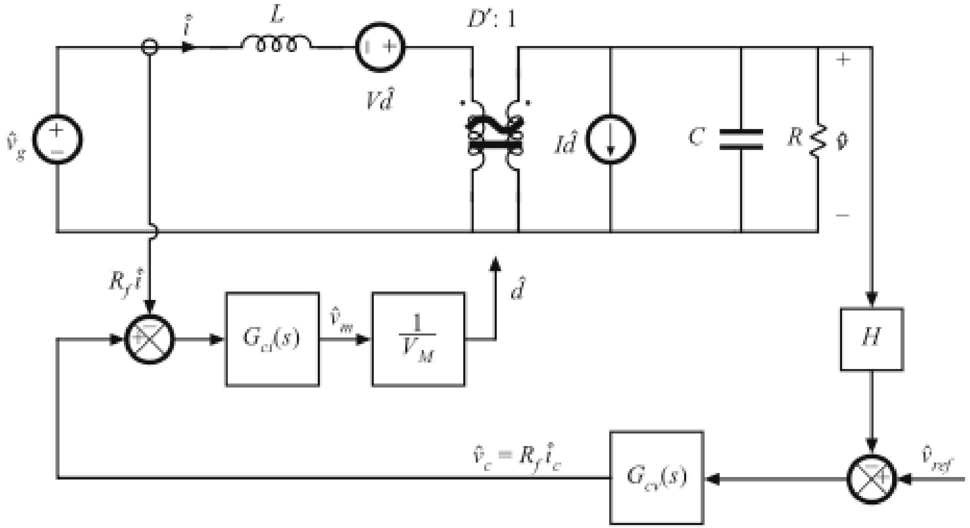


Parameter	Vm (Peak)	Line-frequency	Switching frequency (fsw)	Output Voltage (Vo)	Current Ripple %	Voltage Ripple %	Load Current (Io)
Value	325 V	50 Hz	100 kHz	400 V	10	1	5 A

Controller Design

- The control technique of a PFC is very similar to that of the average current control except that the fact that the current reference generated by the outer loop is not constant, but its shape is that of |sin(ωt)|, and that the voltage loop has very low bandwidth, much lesser than 100 Hz.





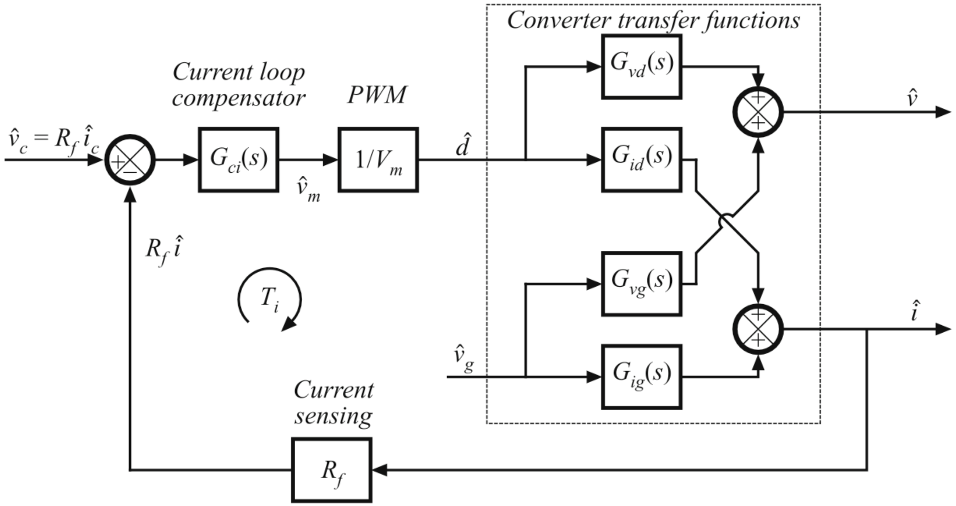
Controller Design

- $T_i = R_f G_{ci} \frac{1}{V_M} G_{id}$

- $G_{id}(s) = \frac{2V_o}{R(1-D)^2} \frac{1+\frac{s}{w_{zi}}}{1+\frac{s}{Q\omega_0}+\left(\frac{s}{\omega_0}\right)^2}$

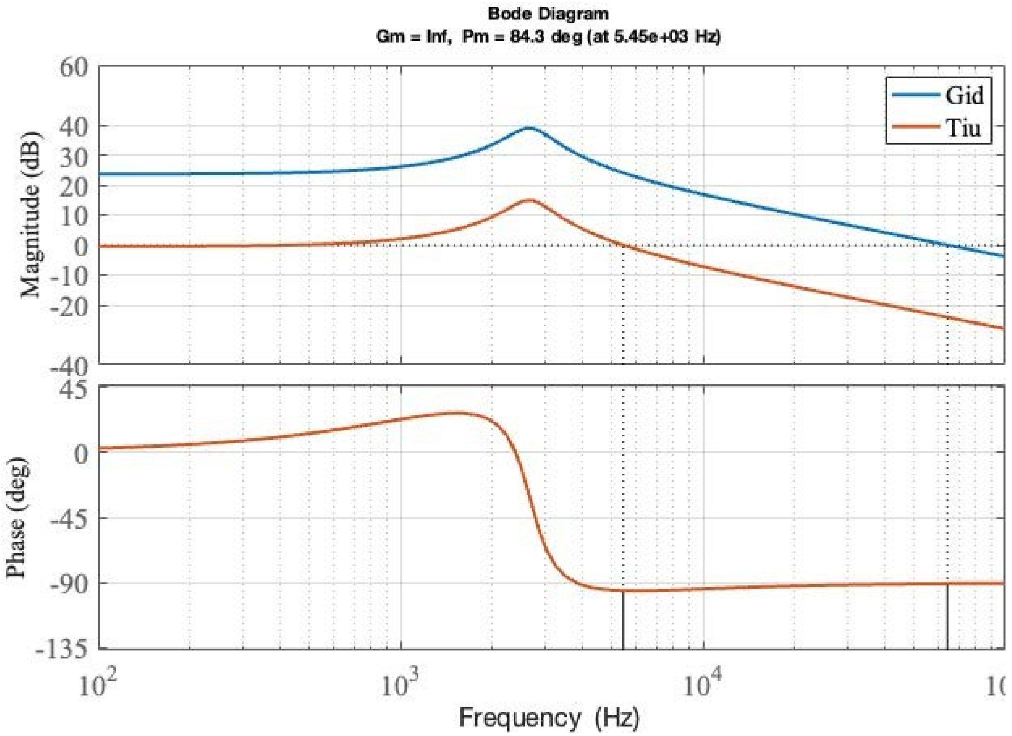
- $G_{vc}(s) = \frac{1}{R_f} \frac{G_{vd}}{G_{id}} \frac{T_i}{1+T_i}$

- $T_v = H G_{cv} G_{vc}$

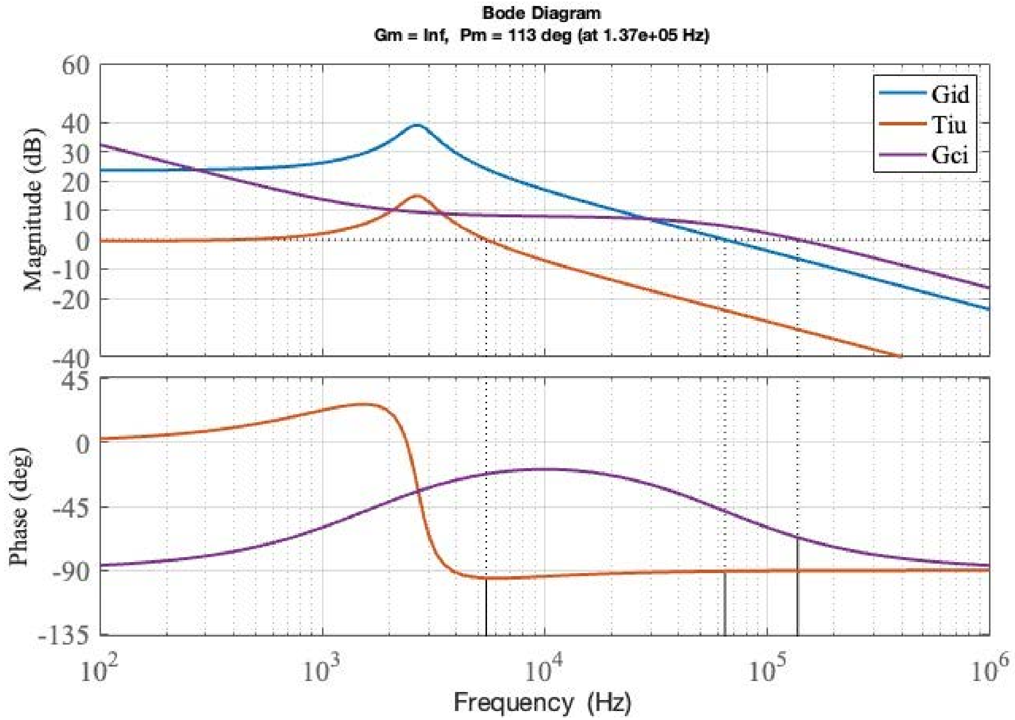


Parameter	VM	H	Rf	Bandwidth of inner loop	Bandwidth of inner loop
Value	4	3/400	0.25	10kHz	10 Hz

Results - Controller Design



Bode Plot for Transfer function of Control to Current Gid(s) and Tiu(s)



Bode Plot for Transfer function of Control to Current Gid(s), Tiu(s) and Gci(s)

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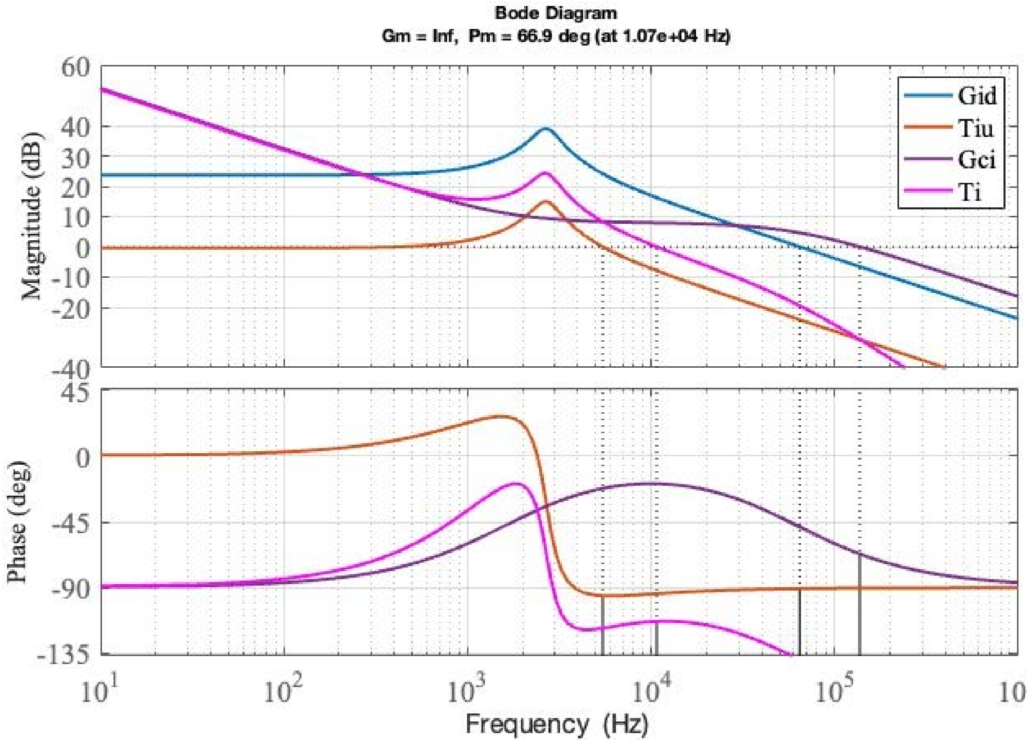
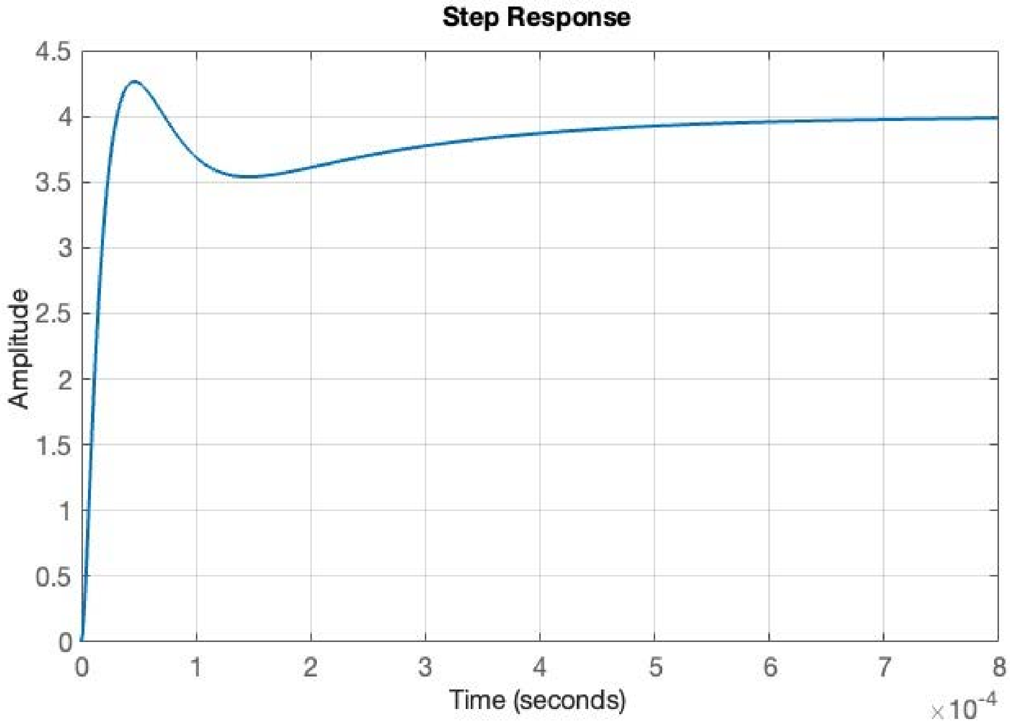
Results - Controller Design



Bode Plot for Transfer function of compensated current loop gain.



Step Response of the inner current Loop

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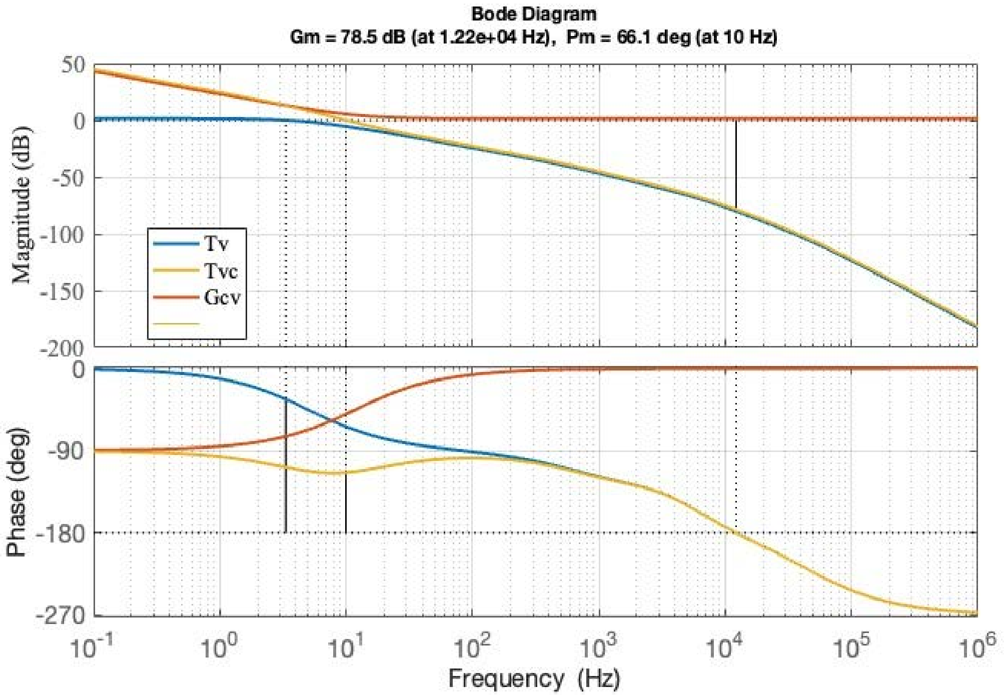
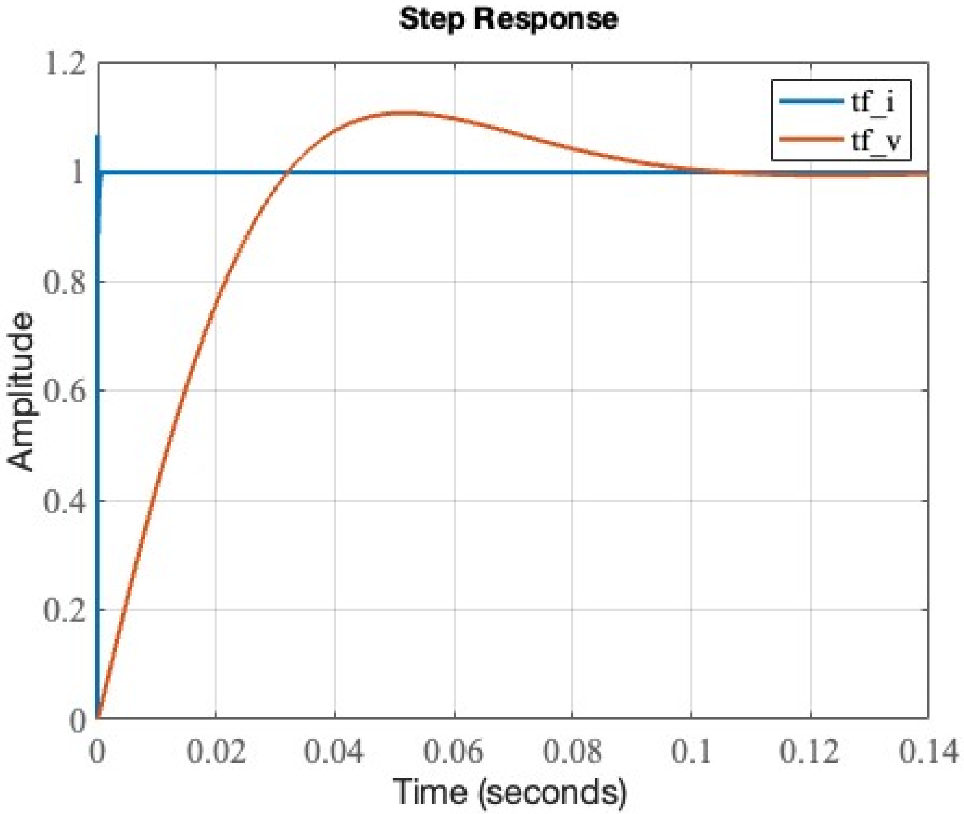
Results - Controller Design

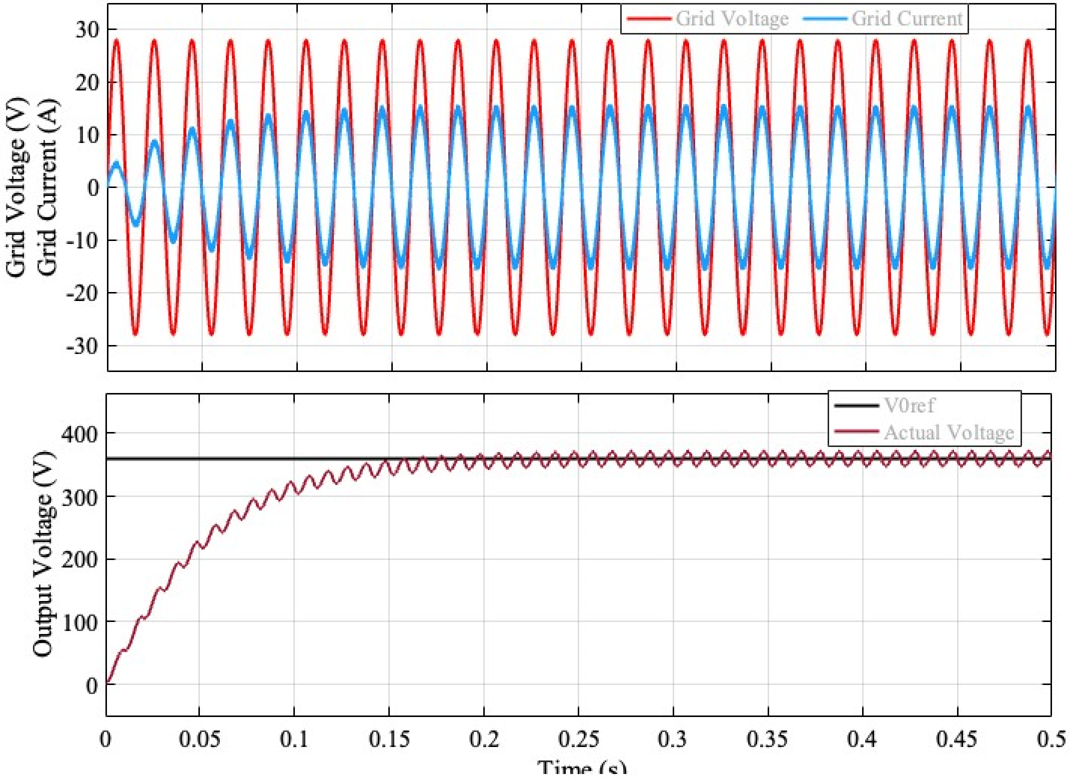


Bode Plot for Transfer function of compensated voltage loop gain

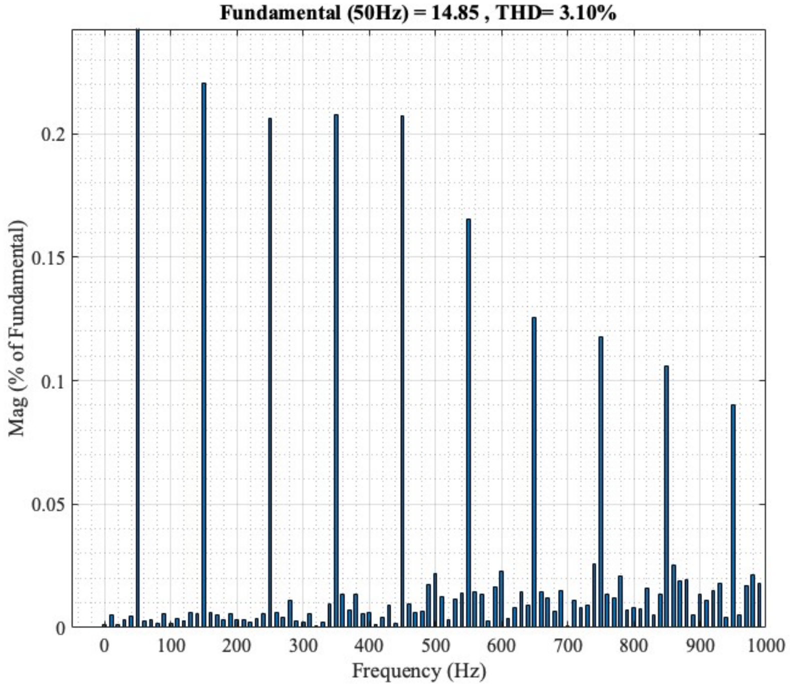


Step Response of the inner current and Outer Voltage Loop

Results - Controller Design

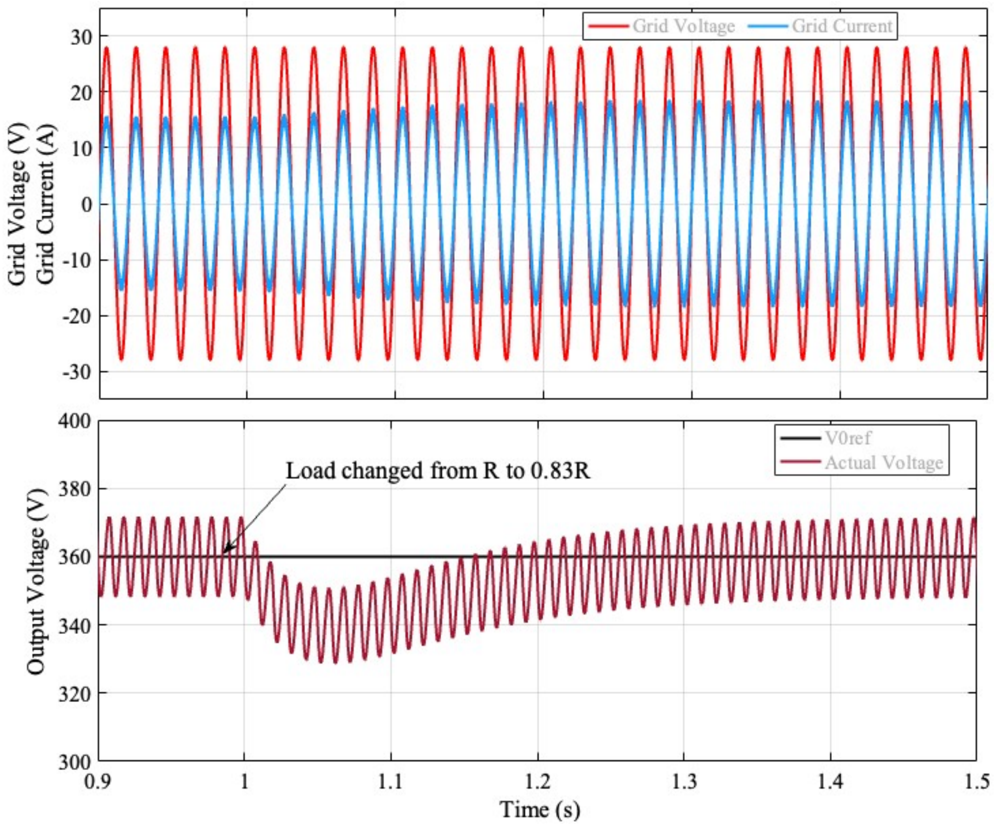


Grid Voltage and Current along with output voltage waveforms for CBC

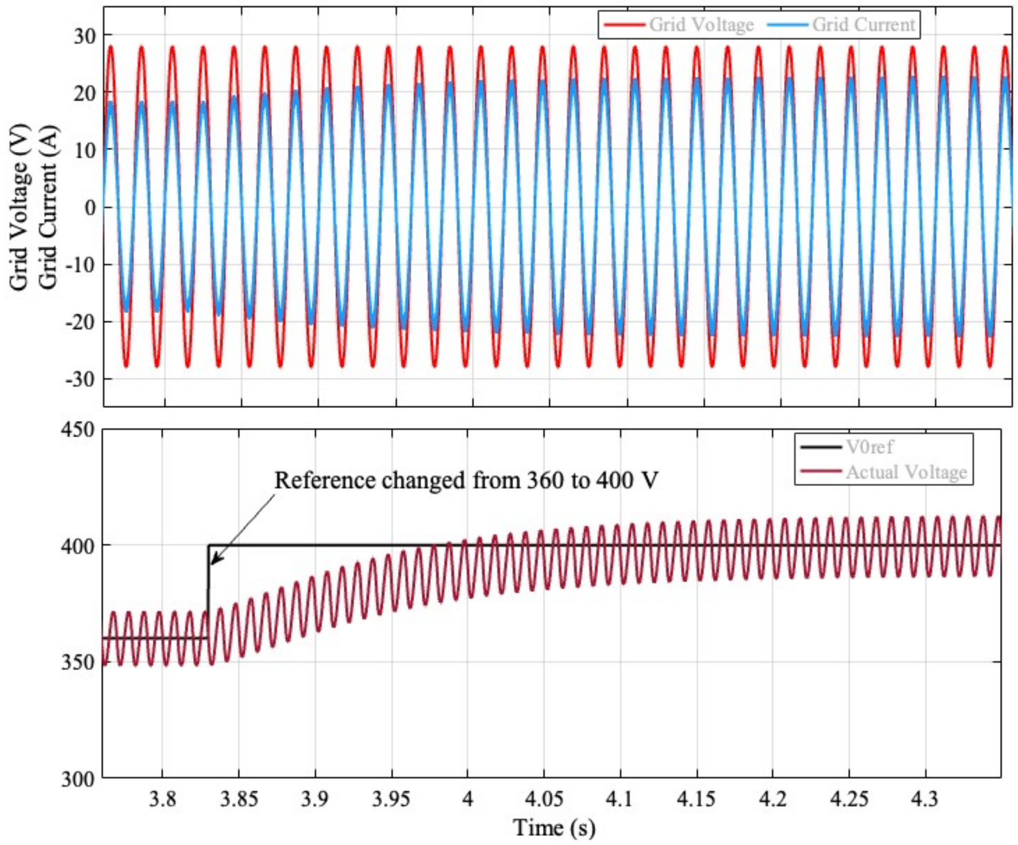


FFT spectrum of AC Line Current for Resistance R=80 Ohms and Vref = 360 V

Results - Controller Design



Response of PFC for step change in Load from R to 83% of R



Response of PFC for step change in reference from 360 V to 400 V