Perbaikan Faktor Daya Menggunakan *Cuk Converter* Pada Pengaturan Kecepatan Motor *Brushless* DC

Hadyan Perdana Putra
2212 100 144

Dibawah Bimbingan:
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2. Ir. Sjamsjul Anam M.T.

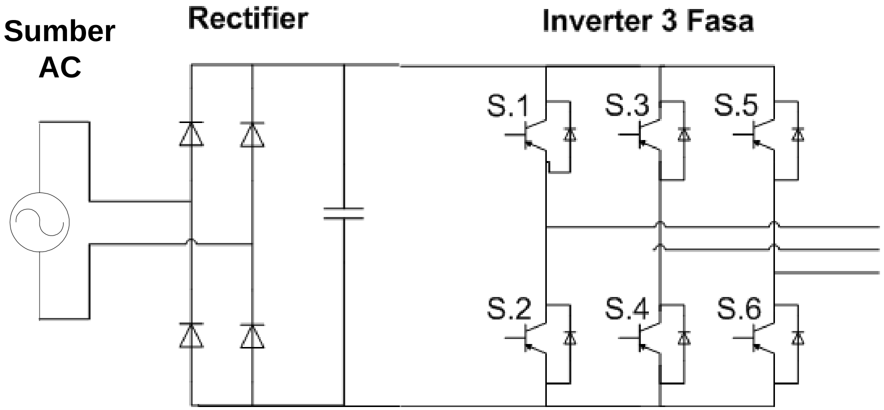
Outline

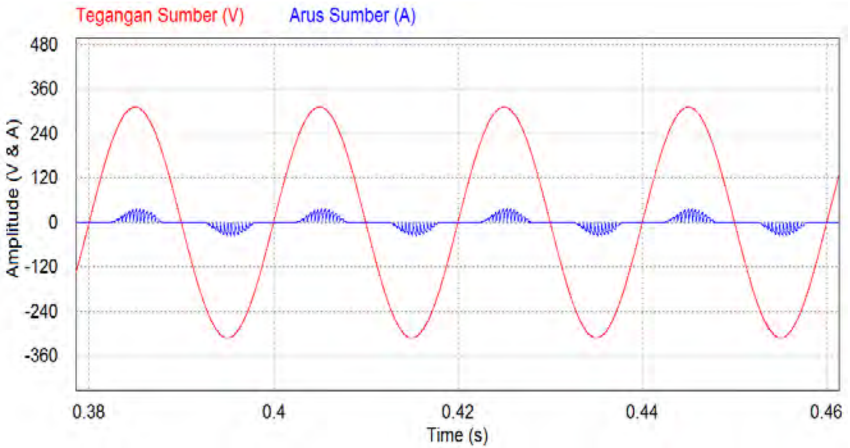
- Latar Belakang
- Tujuan
- Batasan Masalah
- Perancangan Sistem Keseluruhan
- Hasil Simulasi
- Kesimpulan

LATAR BELAKANG


FL57BL04
36V 4000RPM
FULLING MOTOR


TESLA
GIGAFACTORY 1





THD Arus (%)	74.075
TPF	0.80355

TUJUAN

Tujuan

- Mengetahui Pengaruh Penggunaan *Cuk Converter*
- Membandingkan Performa Kombinasi Mode dari Cuk Converter dan Metode Kontrol Berbasis PFC

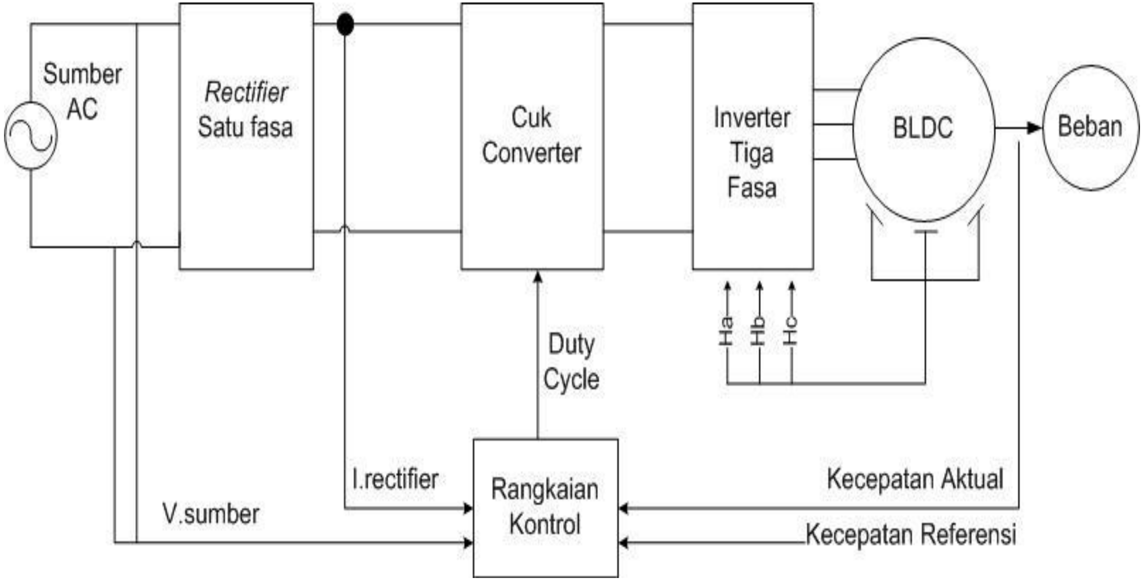
BATASAN MASALAH

Batasan Masalah

1. Hanya 2 Mode Cuk Converter yang Digunakan
2. Batas Kecepatan Min adalah 250rpm dengan Max 2500rpm
3. Batas Torsi Min adalah 1.5Nm dengan Max 2.9588Nm
4. Perbaikan Harmonisa melalui perubahan THD arus
5. Efisiensi tidak dibahas
6. Nilai PI dicari melalui *Trial & Error*

PERANCANGAN SISTEM KESELURUHAN

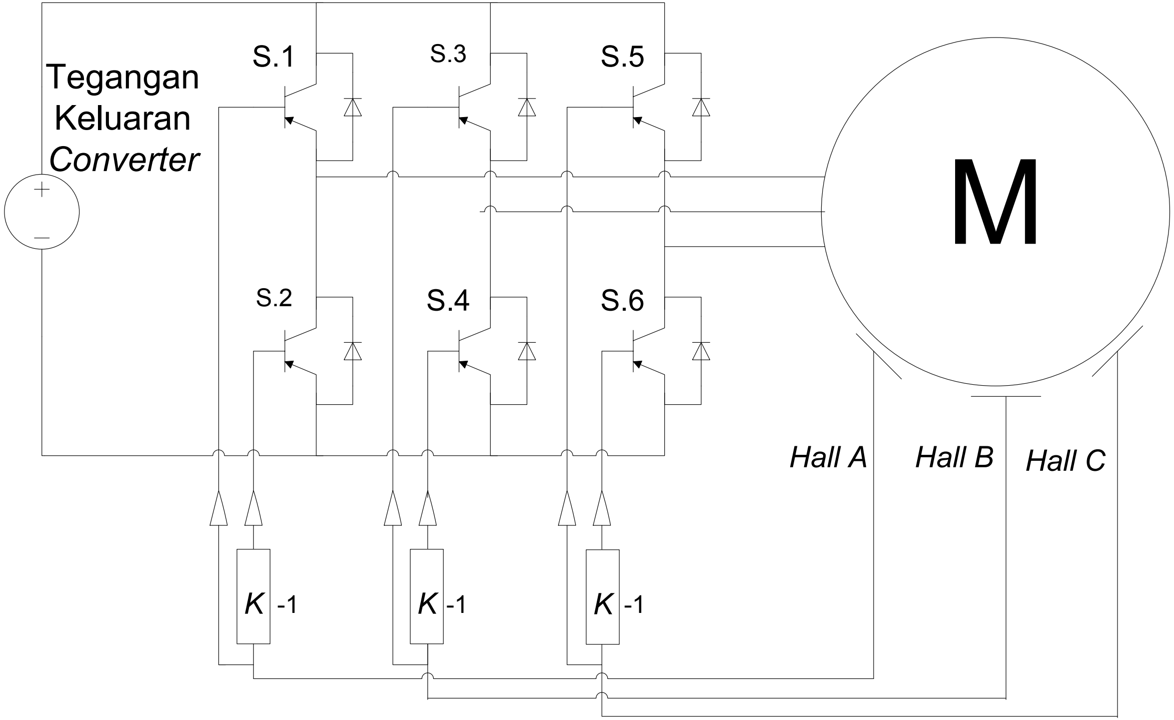
Sistem Keseluruhan



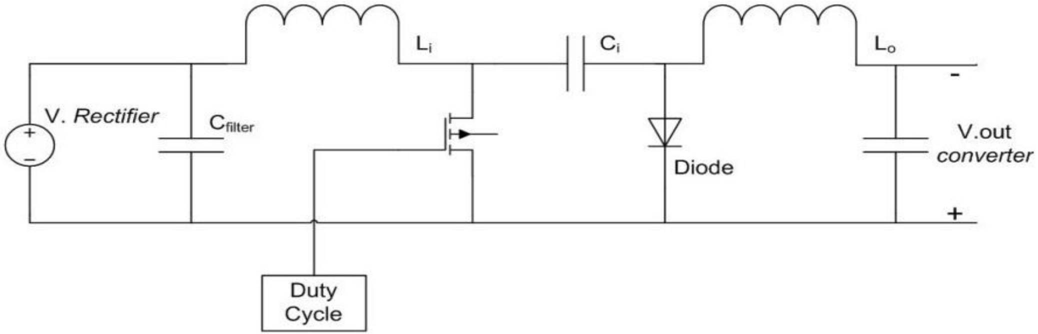
Motor BLDC Moog BN42-53IP-03

Parameter	Nilai
Rated Power	874 Watt
Rated Speed	2820 rpm
Rated Torque	2.9588 Nm
Resistance (phase-phase)	0,408 Ω
Inductance (phase-phase)	1.71 mH
Speed Constant (krpm/V)	29.239
Torque Constant (Nm/A)	0.3269
No. of Poles	8
Moment of Inertia	$0,4939 \times 10^{-3}$ kg.m^2
No Load Speed	2920 rpm
Rated Voltage	100 V

Sistem Komutasi Inverter Berbasis Sensor *Hall-Effect*

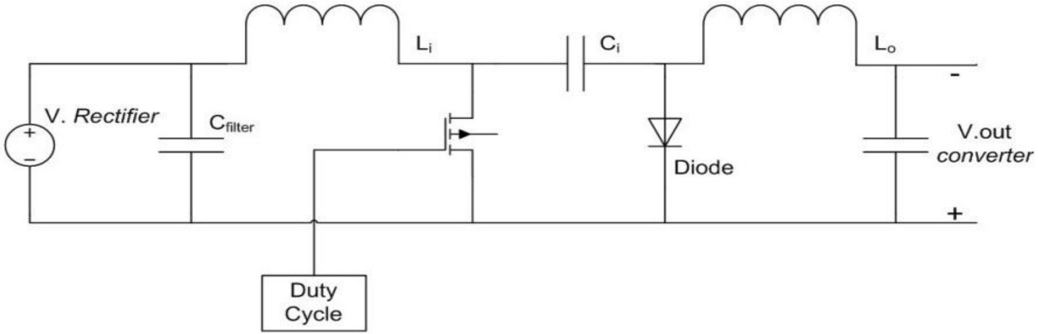


Perancangan *Cuk Converter*



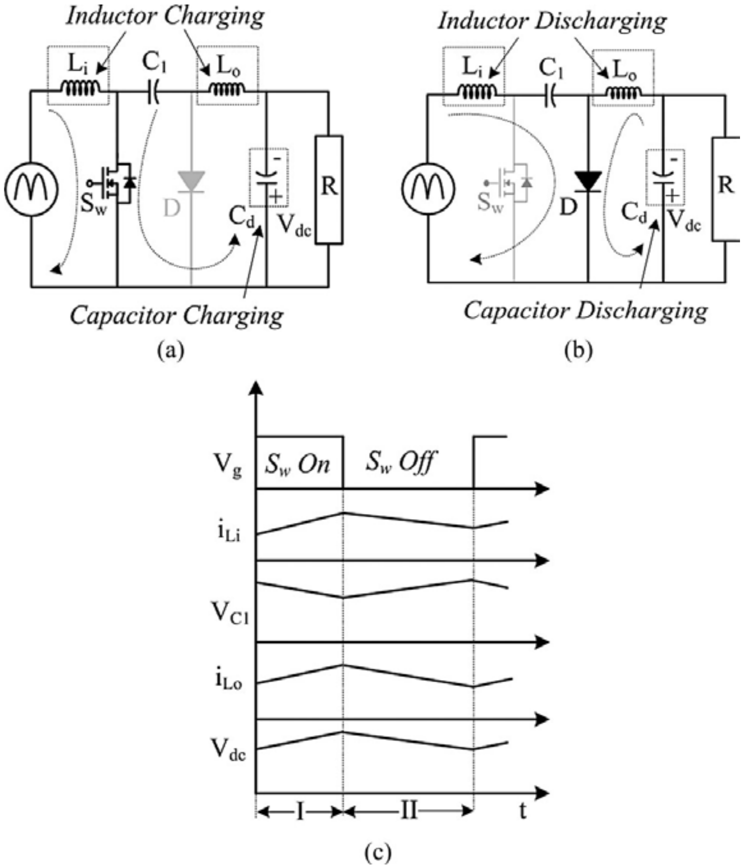
Vi Max (rms) = 240 V	Vo Max = 110 V	Pmax = 900 Watt
Vin Min (rms) = 200 V	Vo Min = 10 V	Pmin = 10 Watt

Penentuan Nilai Komponen

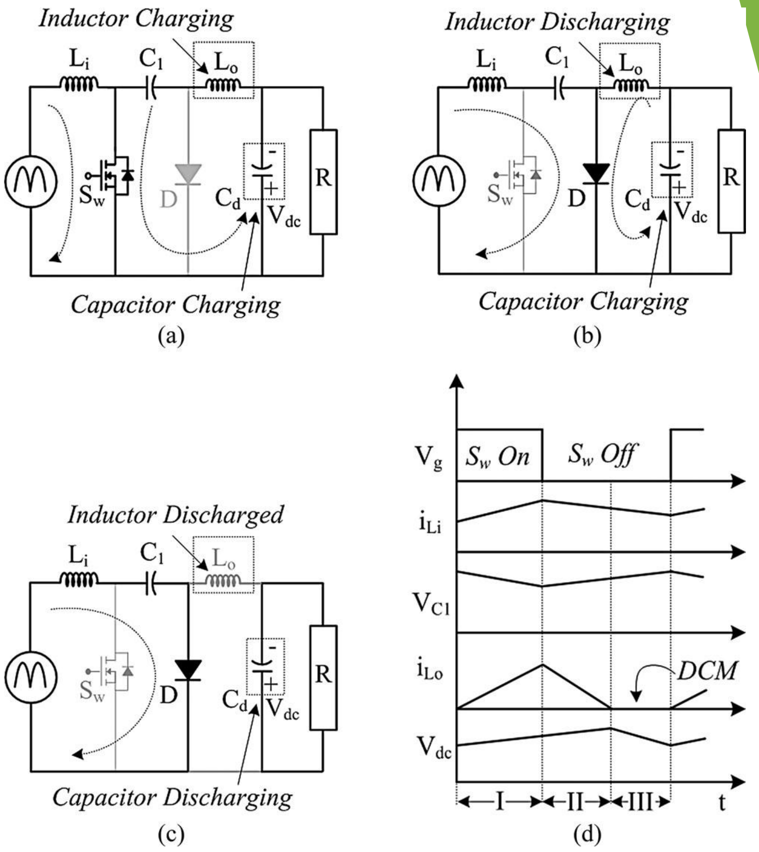


	Mode	
	CCM	DCM
L_i	4.6 mH	
L_o	2.2 mH	20 uH
C_i	3 µF	
C_o	4 mF	
C_{filter}	1 µF	

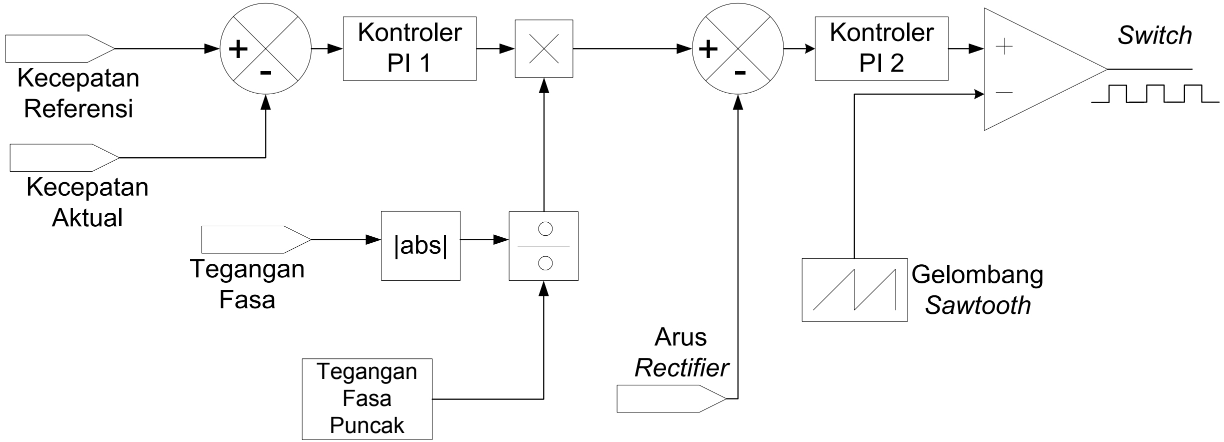
Mode CCM



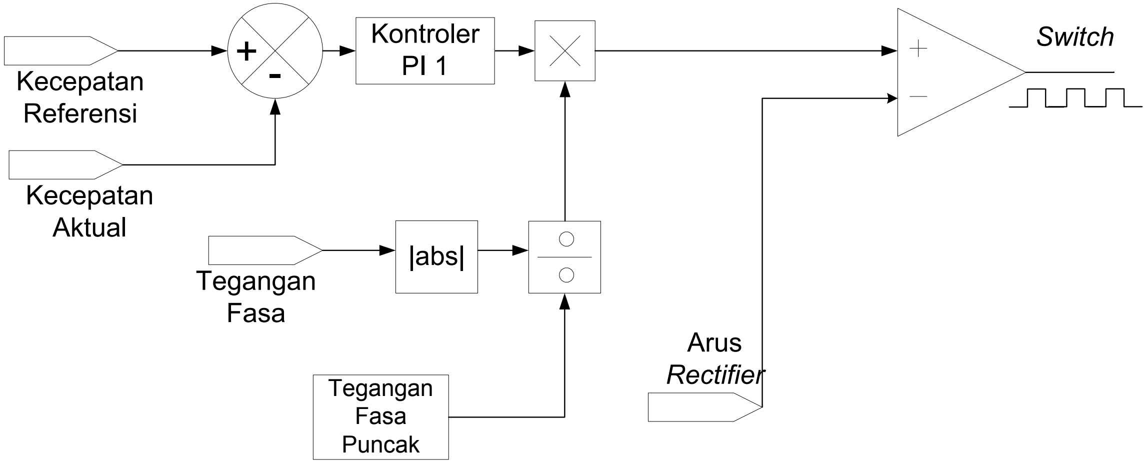
Mode DCM pada Lo



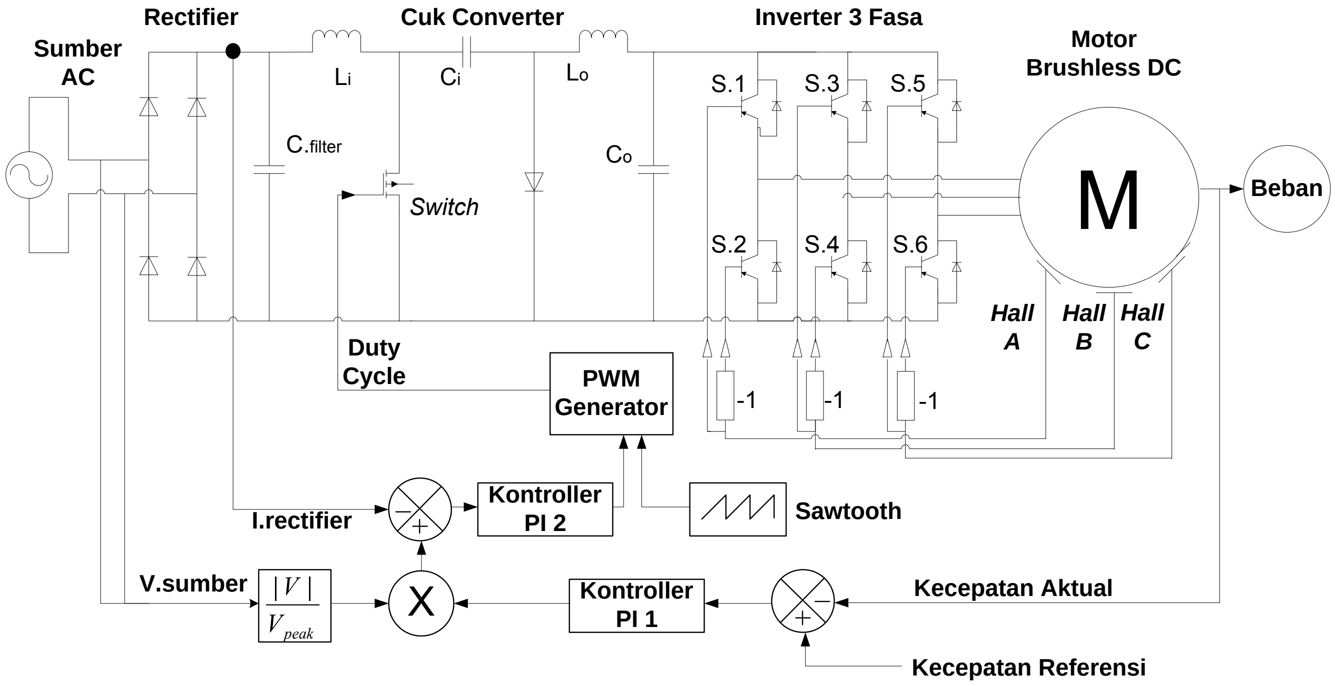
Metode Average Current Control



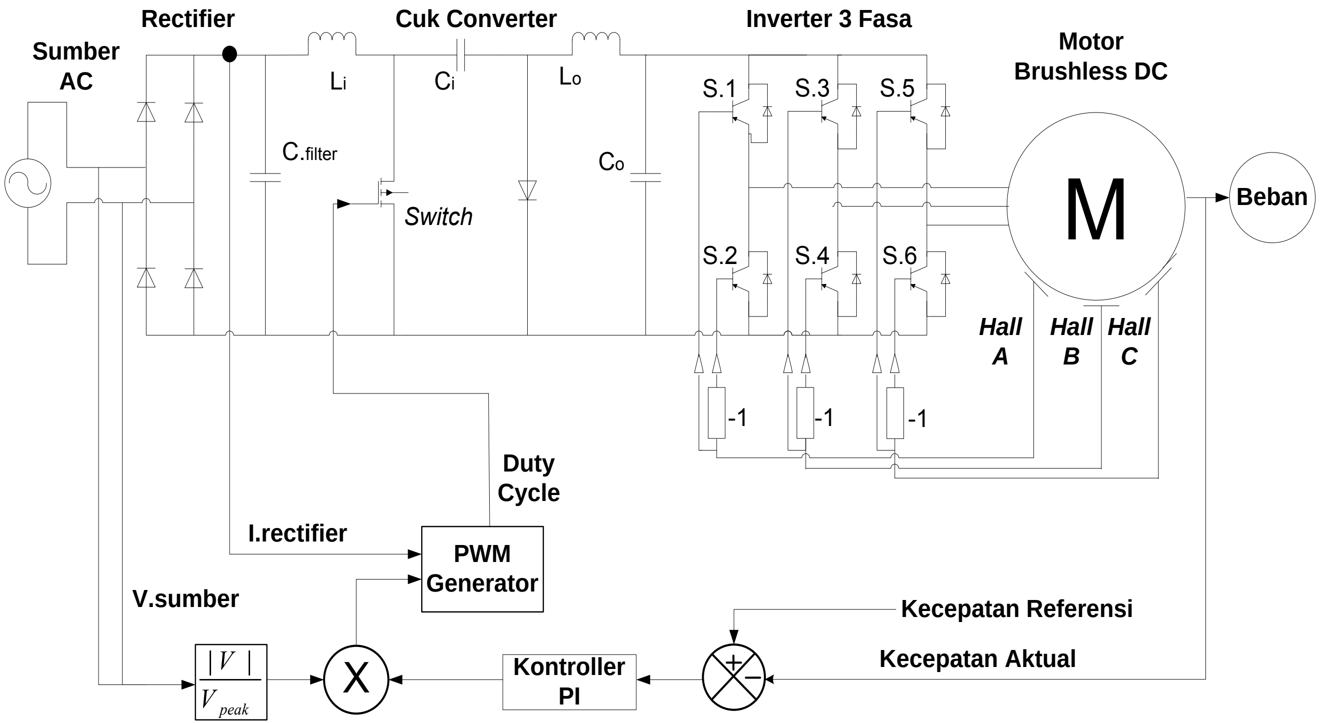
Metode Histeresis



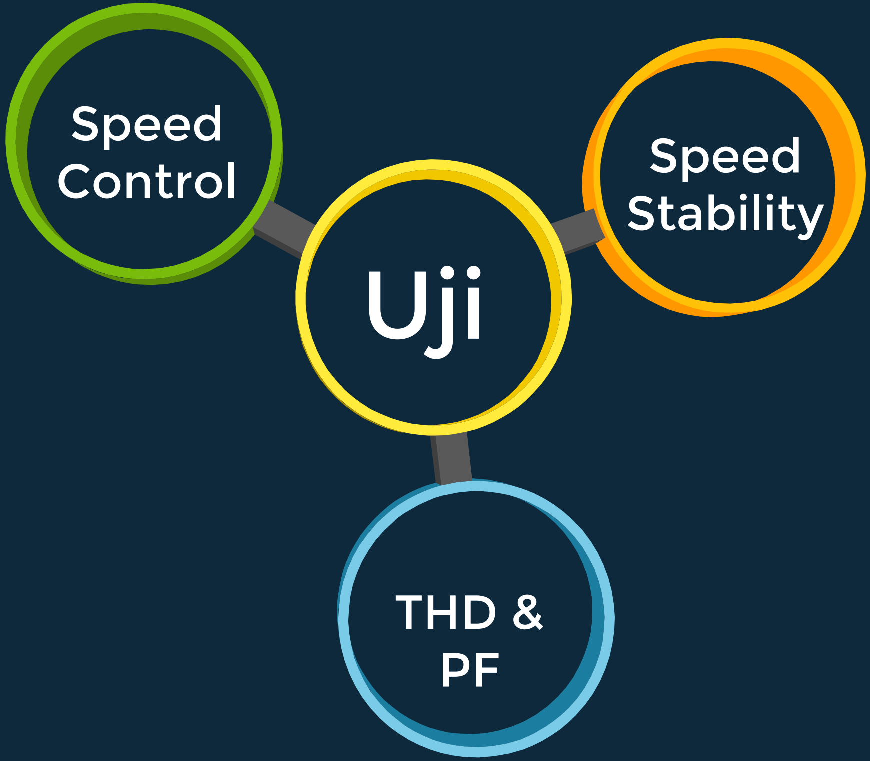
Rangkaian Lengkap dengan Average Current Control



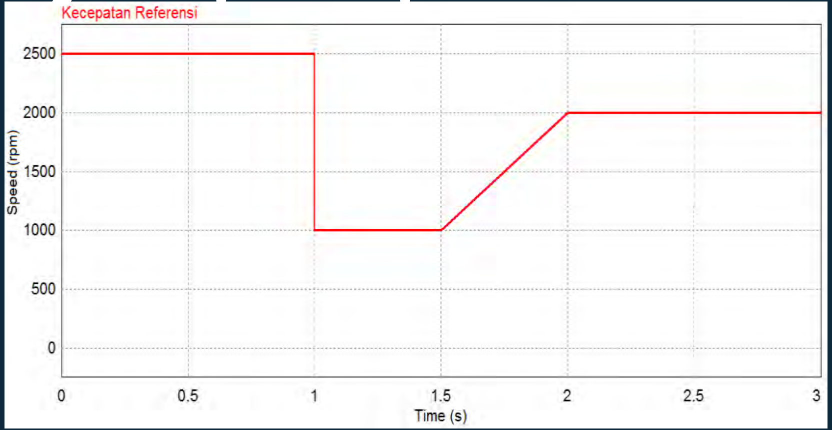
Rangkaian Lengkap dengan Histeresis



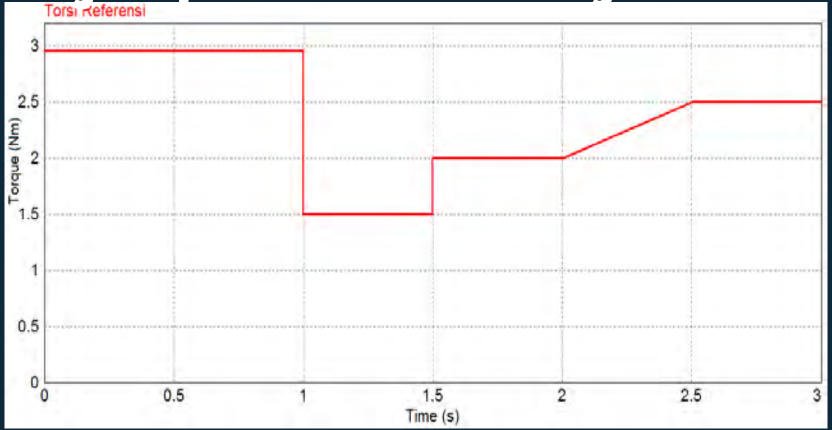
HASIL SIMULASI & PEMBAHASAN


Speed Control
Uji
Speed Stability
THD & PF

Uji respon Speed Control



Uji Speed Stability

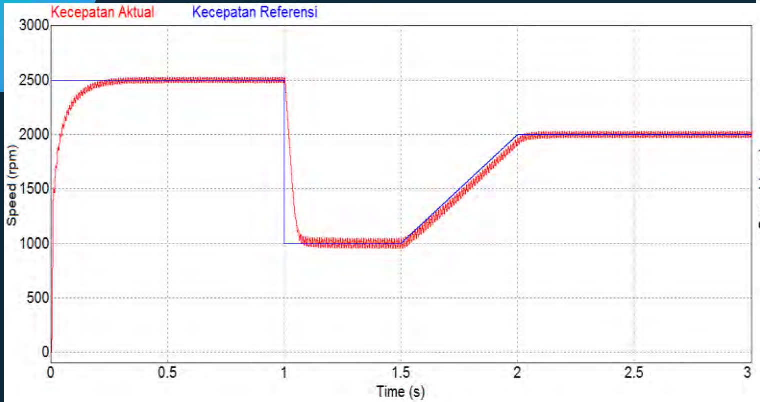


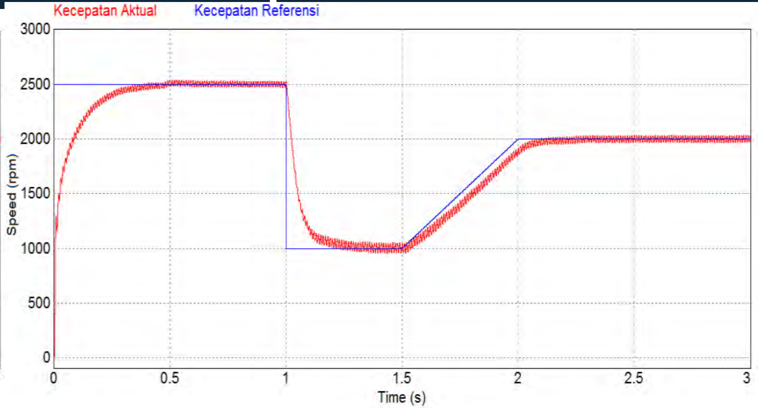
Hasil Uji Speed Control

Mode CCM

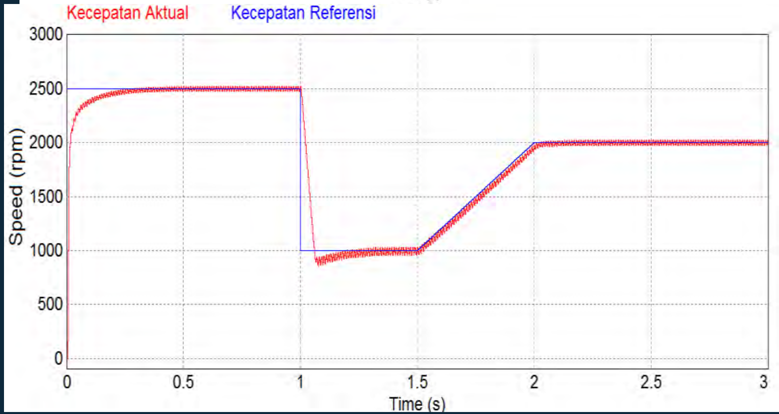
Mode DCM pada Lo

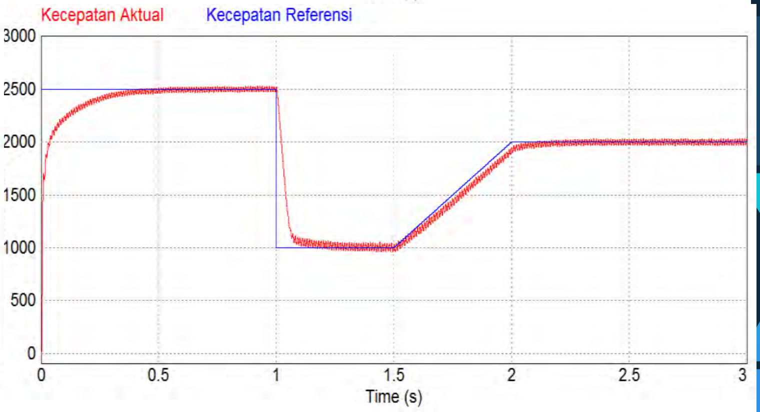
Average Current Control





Histeresis



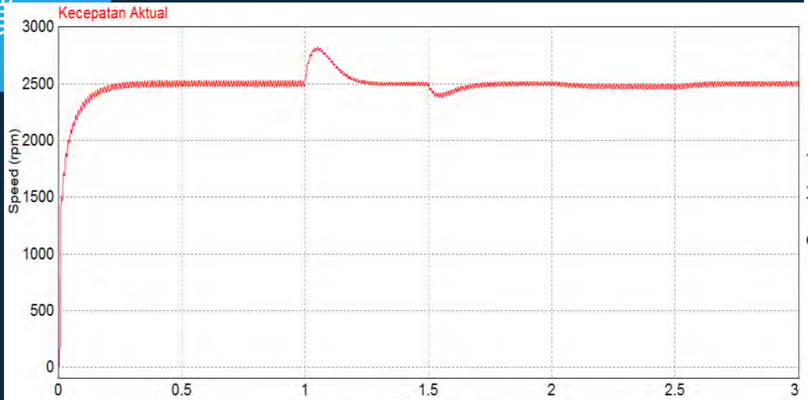


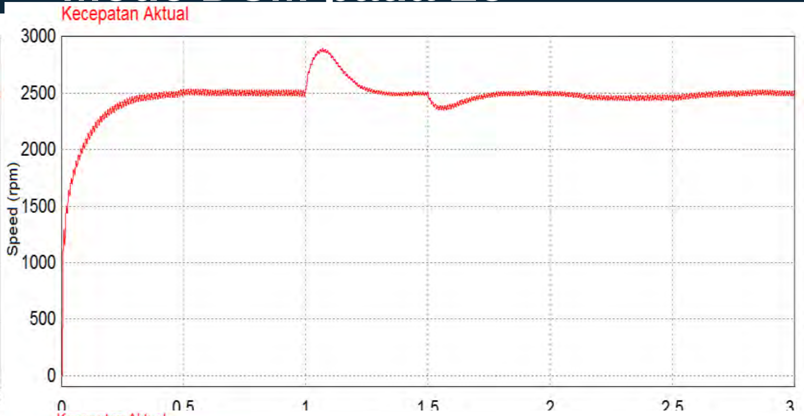
Hasil Uji Speed Stability

Mode CCM

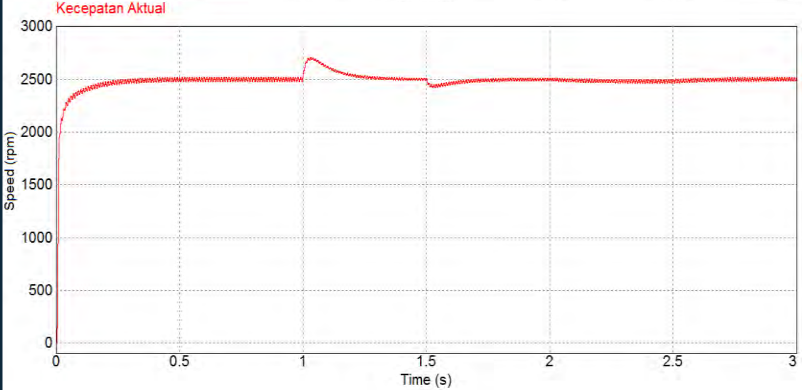
Mode DCM pada Lo

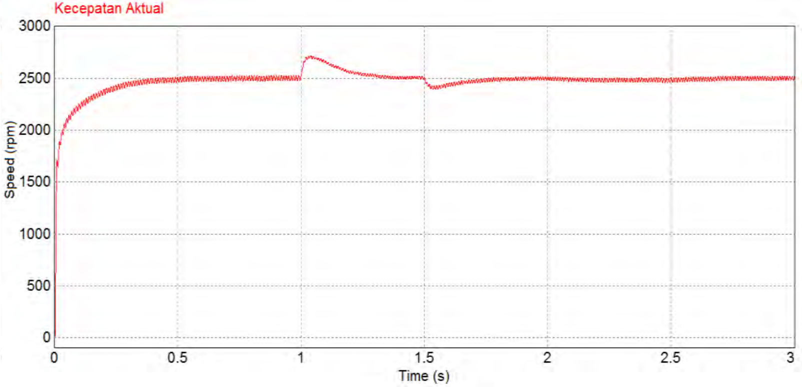
Average Current Control





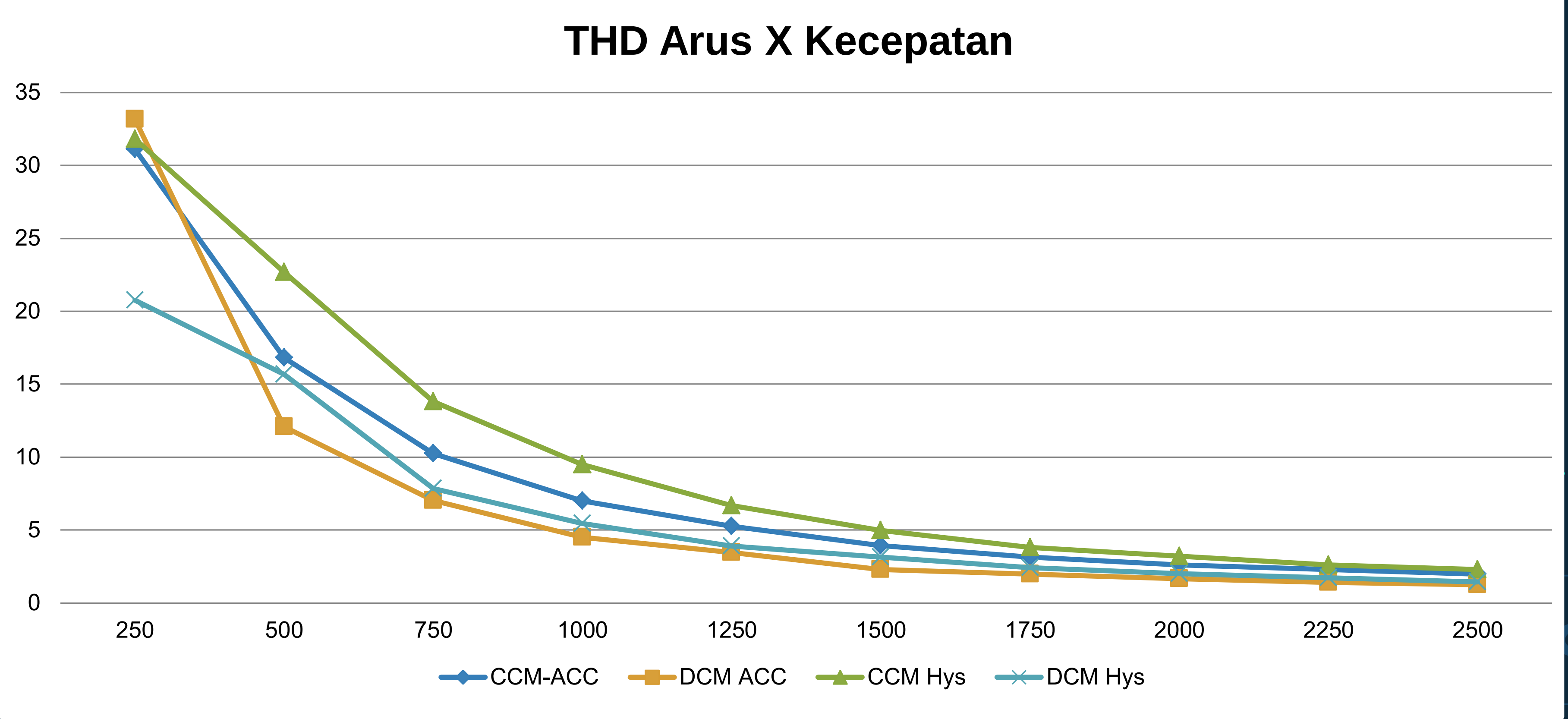
Histeresis

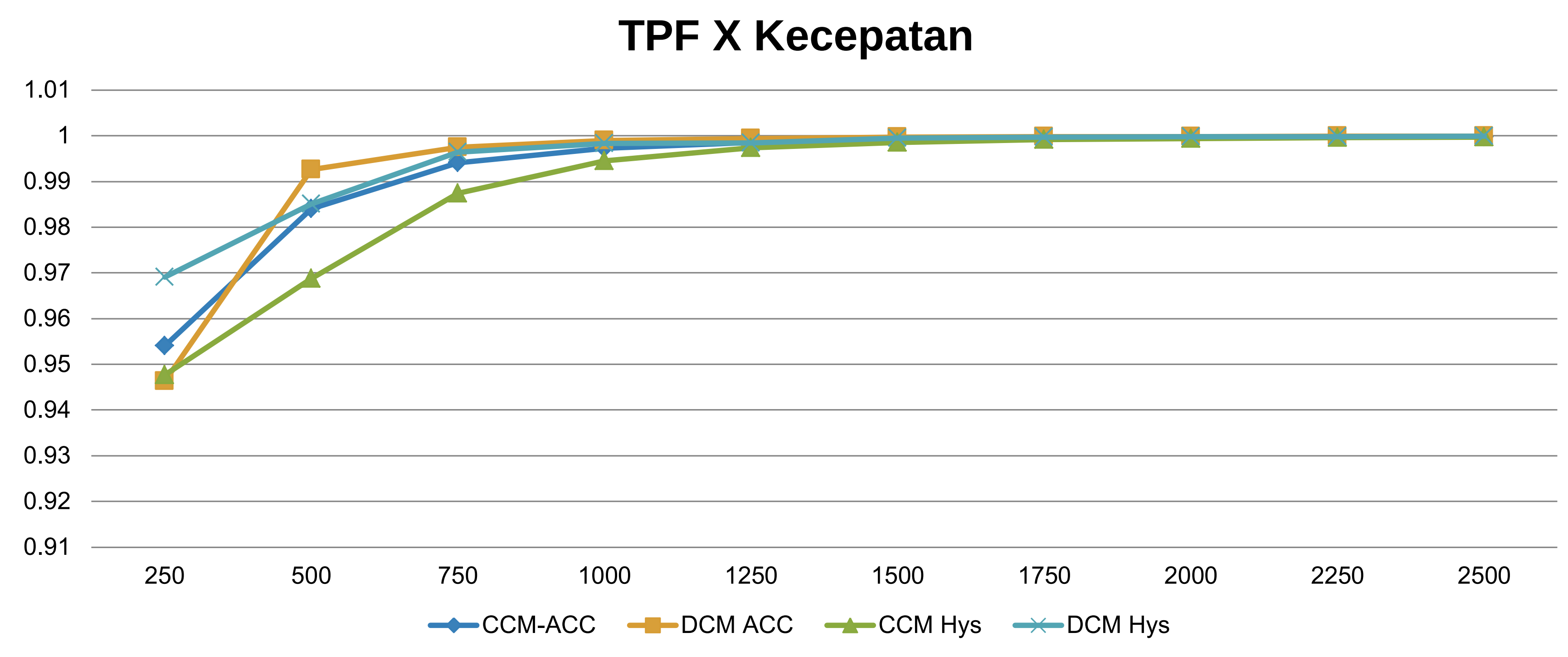




THD & TPF pada Kecepatan Uji

No.	Speed (rpm)	CCM Average Current Control		DCM pada Lo Average Current Control		CCM Histeresis		DCM pada Lo Histeresis	
		THD (%)	TPF	THD (%)	TPF	THD (%)	TPF	THD (%)	TPF
1	250	31.108	0.95405	33.17	0.94628	31.82	0.9477	20.767	0.96909
2	500	16.805	0.98402	12.076	0.99267	22.675	0.96881	15.67	0.98508
3	750	10.247	0.99409	7.041	0.99751	13.814	0.98747	7.834	0.99649
4	1000	6.997	0.99732	4.4939	0.99897	9.505	0.9945	5.44	0.99835
5	1250	5.266	0.99854	3.4748	0.99939	6.683	0.99735	3.888	0.9984
6	1500	3.924	0.99918	2.286	0.99973	4.986	0.99853	3.142	0.99946
7	1750	3.128	0.99946	1.9697	0.9998	3.815	0.99915	2.429	0.99968
8	2000	2.62	0.99961	1.645	0.99985	3.211	0.99941	2.021	0.99978
9	2250	2.285	0.99969	1.408	0.99989	2.614	0.99962	1.716	0.99983
10	2500	1.967	0.99976	1.2618	0.99991	2.286	0.99971	1.428	0.99989


THD Arus X Kecepatan
35
30
25
20
15
10
5
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
CCM-ACC
DCM ACC
CCM Hys
DCM Hys


TPF X Kecepatan
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
250
500
750
1000
1250
1500
1750
2000
2250
2500
CCM-ACC
DCM ACC
CCM Hys
DCM Hys

KESIMPULAN

1. Mampu mengurangi harmonisa hingga **1.262%** & memperbaiki PF hingga **0.99991**.

2. Mitigasi Harmonisa & PFC, **CCM < DCM pada Lo**

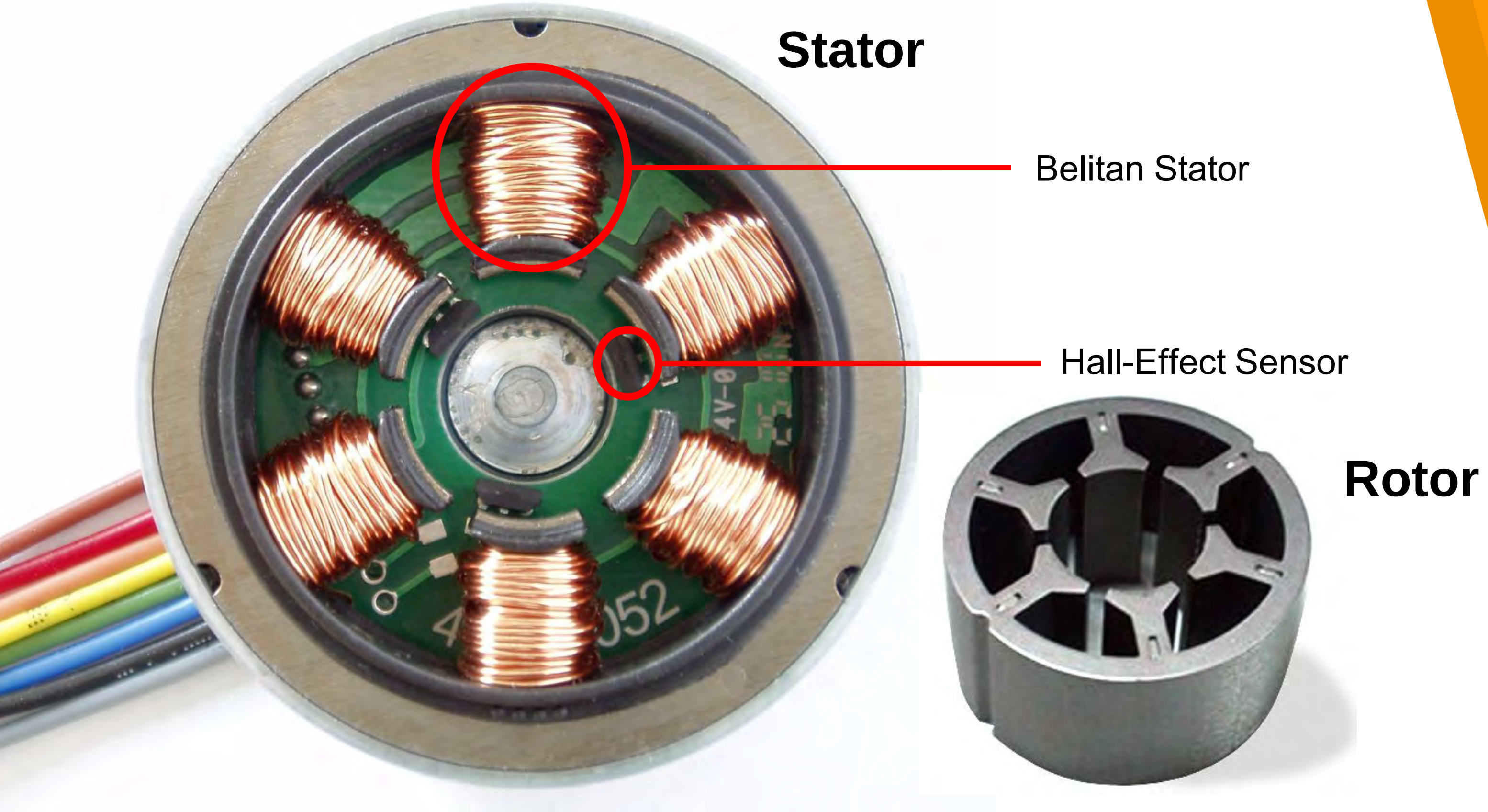
3. Speed Response, **CCM > DCM pada Lo**

4. Speed Control, **Average Current Control > Histeresis**

5. Speed Stability, **Average Current Control < Histeresis**

Thank You For Your Attention

Konstruksi BLDC



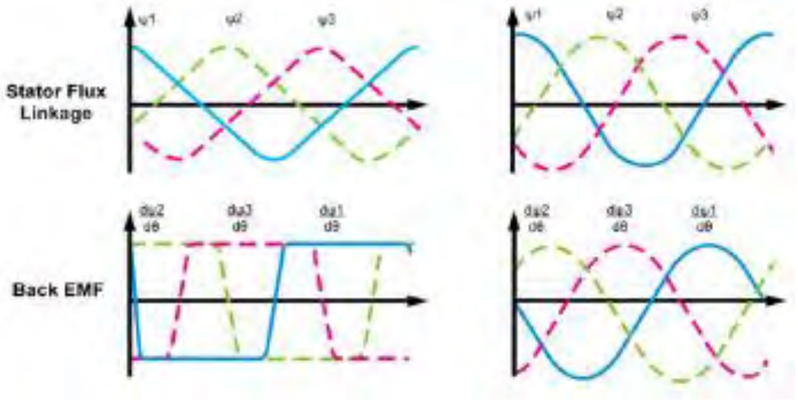
Perbedaan BLDC dengan Motor DC Konvensional

	Motor DC Konvensional	Motor Brushless DC
Struktur Mekanis	Medan magnet ada di stator	Medan magnet ada di rotor, seperti motor AC sinkron.
Kelebihan	Respon cepat dan mudah dalam kemudi	Lifetime panjang, mudah dalam maintenance
Metode Komutasi	Kontak mekanis antara sikat dan komutator	Switching elektronis dengan rangakaian VSI
Metode Deteksi Posisi Motor	Secara otomatis dideteksi oleh sikat	Sensor Hall-effect, optical encoder, dll.
Metode Pembalikkan	Dengan membalik tegangan terminal	Mengatur logika pada VSI

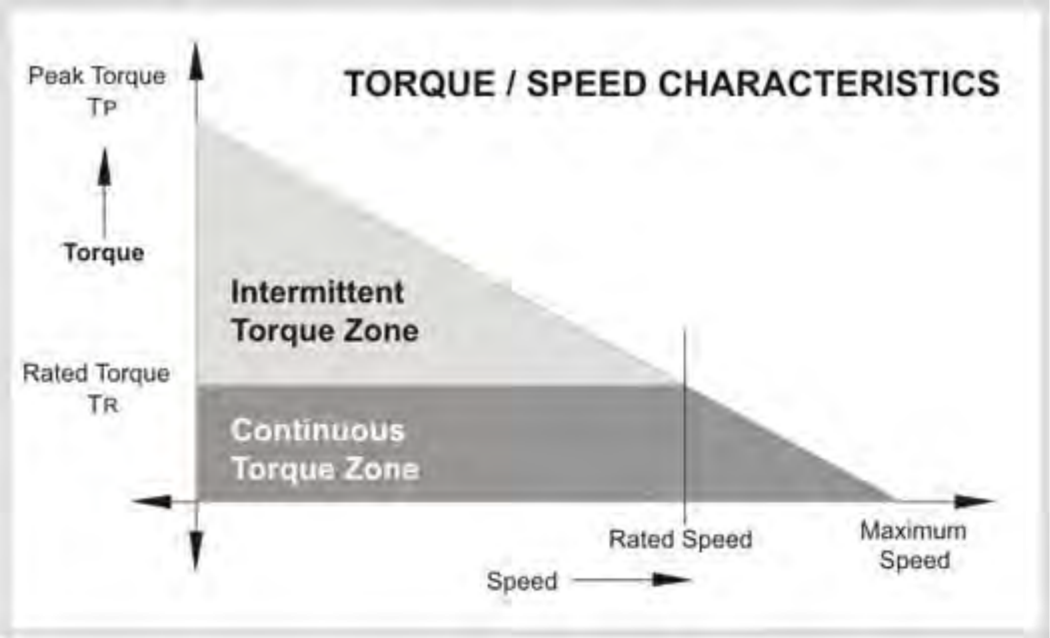
[3]

Perbedaan BLDC dengan PMSM

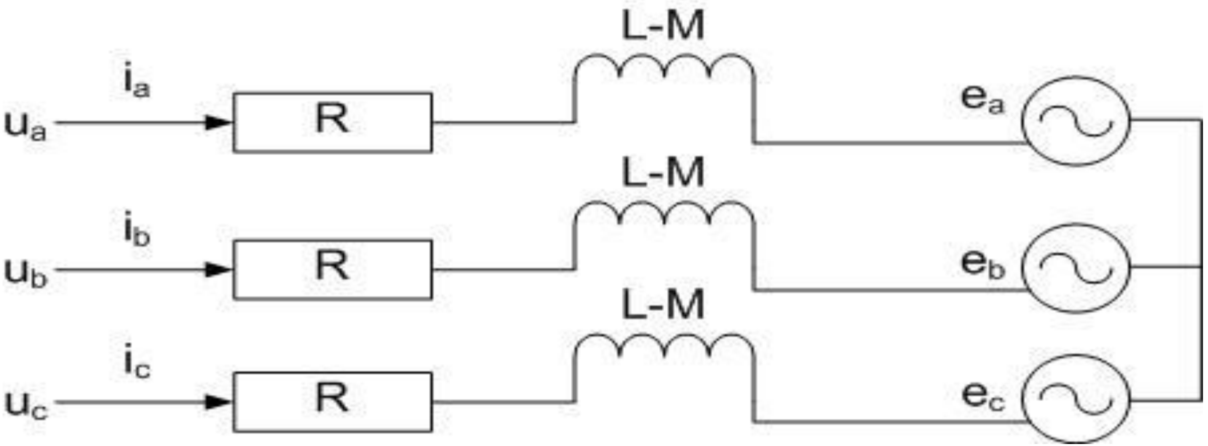
	BLDC	PMSM
Arus fasa	Trapezoidal	Sinusoidal
Flux	Kotak	Sinusoidal
Back-EMF	Trapezoidal	Sinusoidal
Daya dan Torsi	Konstan	Konstan



Kurva Karakteristik BLDC



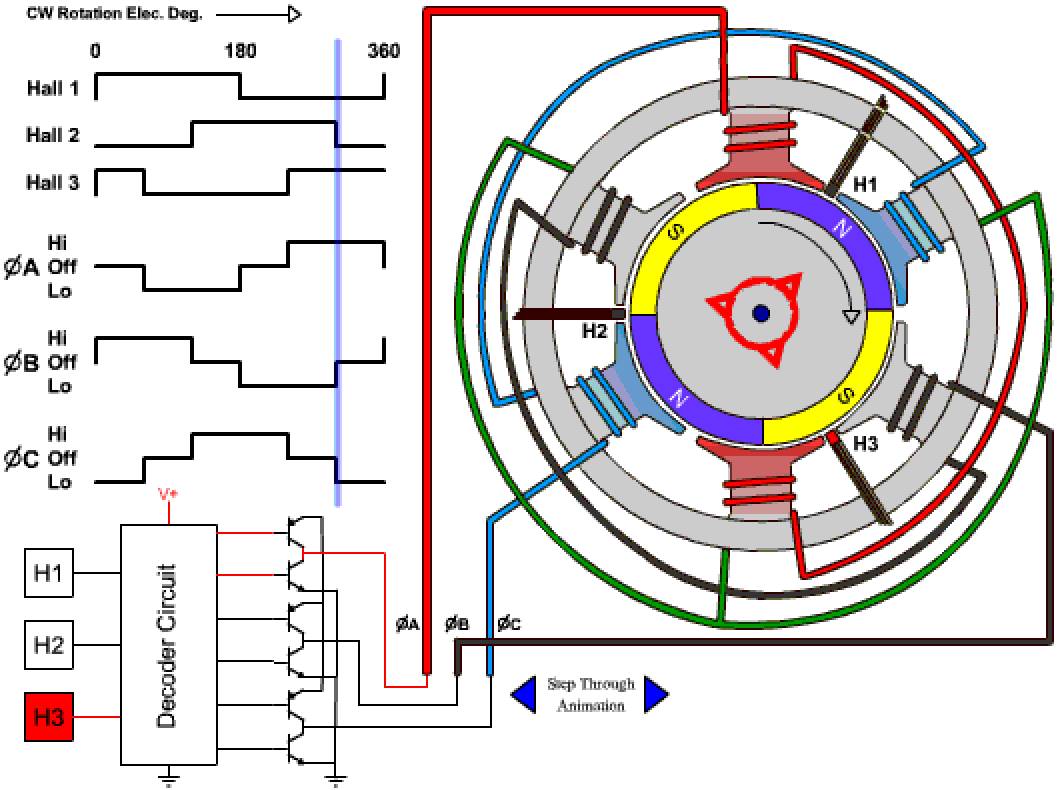
Persamaan BLDC



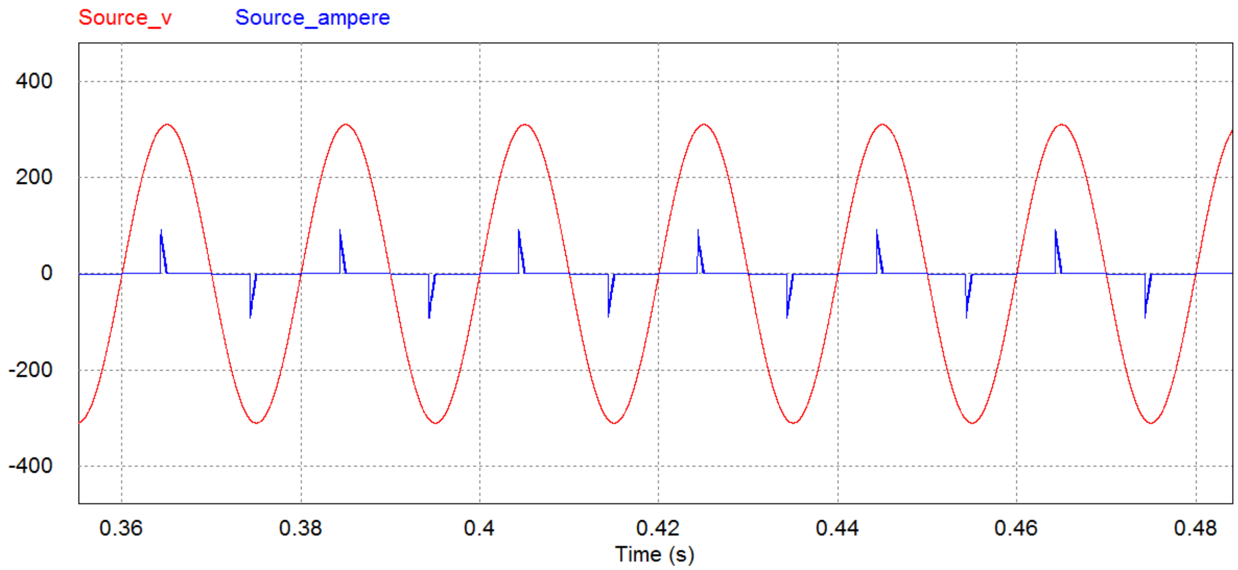
$$U_x = (L - M)\frac{di_x}{dt} + R \cdot i_x + e_x$$

$$T_e = \frac{\sum x = a, b, c\ e_x i_x}{\omega_r}$$

$$e_x = \lambda_m \cdot \cos\theta \cdot p \cdot \omega_r$$

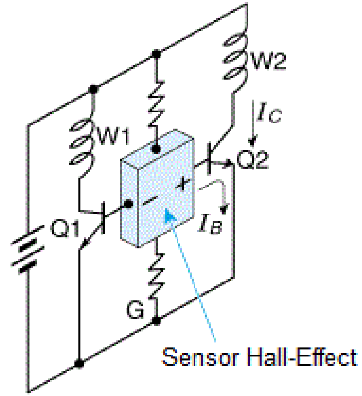

CW Rotation Elec. Deg.
0
180
360
Hall 1
Hall 2
Hall 3
Hi
ØA Off
Lo
Hi
ØB Off
Lo
Hi
ØC Off
Lo
V+
H1
H2
H3
Decoder Circuit
ØA
ØB
ØC
H1
H2
H3
S
N
N
S
Step Through Animation

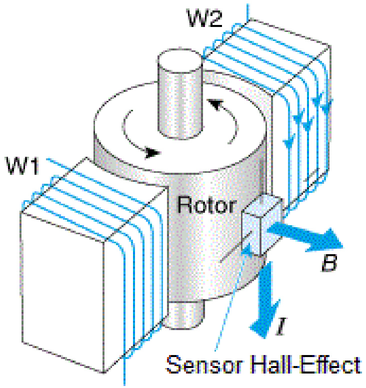
Kontrol Konvensional

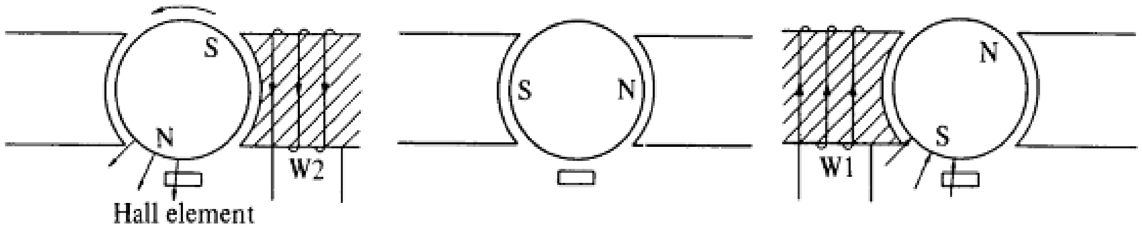


THD arus (%)	298.85
DPF	0.9792
TPF	0.3099

Hall-Effect Sensor







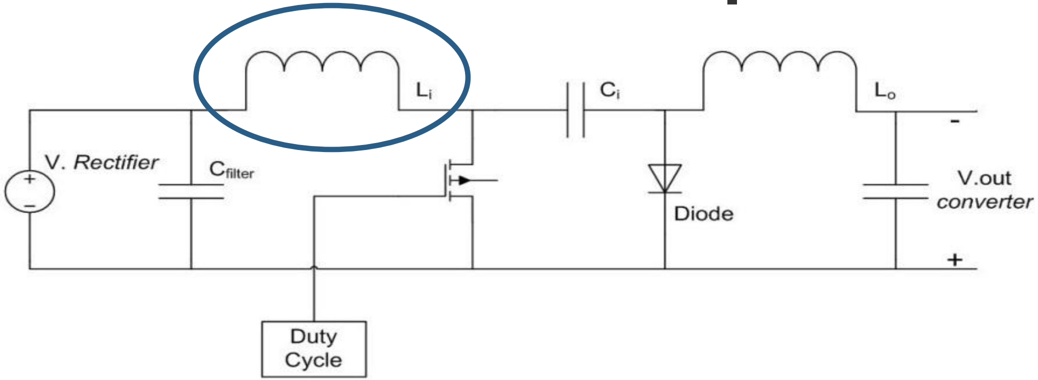
Penentuan Nilai Parameter

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T (V_m \sin \omega t)^2 \, d\omega t} = \sqrt{\frac{2}{2\pi}\int_0^\pi V_m^2 \sin^2 \omega t d\omega t} = \frac{V_m}{\sqrt{2}}$$

$$V_{avg} = \frac{1}{T}\int_0^T f\theta d\theta = \frac{2}{2\pi}\int_0^\pi V_p \sin \omega t \, d\omega t = \frac{2V_p}{\pi}$$

Tegangan Input Rms Maksimal ($V_{rms.max}$)	240 V
Tegangan Input Rms Minimal ($V_{rms.min}$)	200 V
Tegangan Input Puncak Maksimal ($V_{p.max}$)	339.14 V
Tegangan Input Puncak Minimal ($V_{p.min}$)	282.84 V
Tegangan Input Rata-Rata Maksimal ($V_{avg.max}$)	216 V
Tegangan Input Rata-Rata Minimal ($V_{avg.min}$)	180 V
Tegangan Output Optimal ($V_{out.opt}$)	100 V
Tegangan Output Maksimal ($V_{out.max}$)	110 V
Tegangan Output Minimal ($V_{out.min}$)	10 V
Daya Maksimal (P_{max})	900 Watt
Daya Minimal (P_{min})	10 Watt
Frekuensi Switching (f)	20.000 Hz

Penentuan Nilai Komponen

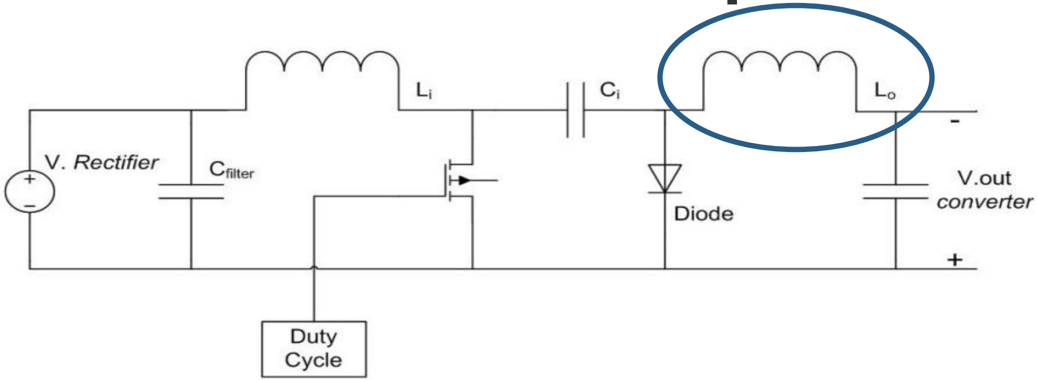


$$L_i = \frac{{V_{avg.min}}^2 \cdot V_{out.max}}{\eta_1 \cdot P_{max} \cdot f \cdot (V_{p.min} + V_{o.max})}$$

$$= \frac{180^2 \cdot 110}{0.1 \cdot 900 \cdot 20.000 \cdot (282.84 + 110)}$$

$$= 4.58\, mH$$

Penentuan Nilai Komponen

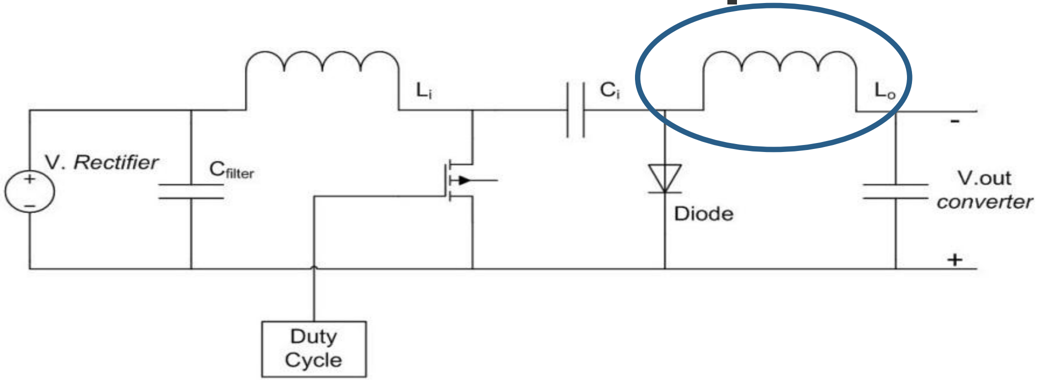


$$L_o = \frac{{V_{out}}^2 \cdot V_{avg}}{\eta_2 \cdot \sqrt{2} \cdot P_i \cdot f \cdot (V_p + V_o)}$$

$$= \frac{110^2 \cdot 180}{0.1 \cdot \sqrt{2} \cdot 900 \cdot 20.000 \cdot (282.84 + 110)}$$

$$= 2.18\, mH$$

Penentuan Nilai Komponen



$$L_{o.dcm1} = \frac{V_{out.max}{}^2 \cdot V_{avg.min}}{\eta_{crit} \cdot \sqrt{2} \cdot P_{max} \cdot f \cdot (V_{p.min} + V_{o.max})}$$

$$= \frac{110^2 \cdot 180}{2 \cdot \sqrt{2} \cdot 900 \cdot 20.000 \cdot (282.84 + 110)}$$

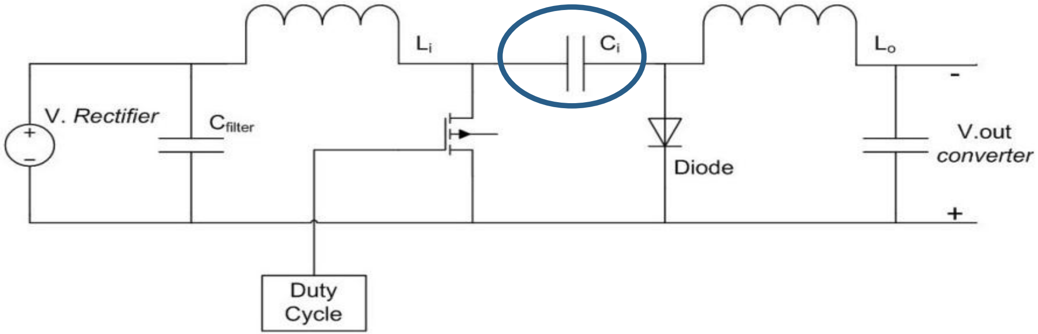
$$= 108.899\ \mu H$$

$$L_{o.dcm2} = \frac{V_{out.min}{}^2 \cdot V_{avg.min}}{\eta_{crit} \cdot \sqrt{2} \cdot P_{min} \cdot f \cdot (V_{p.min} + V_{o.min})}$$

$$= \frac{10^2 \cdot 180}{2 \cdot \sqrt{2} \cdot 10 \cdot 20.000 \cdot (282.84 + 10)}$$

$$= 108.659\ \mu H$$

Penentuan Nilai Komponen

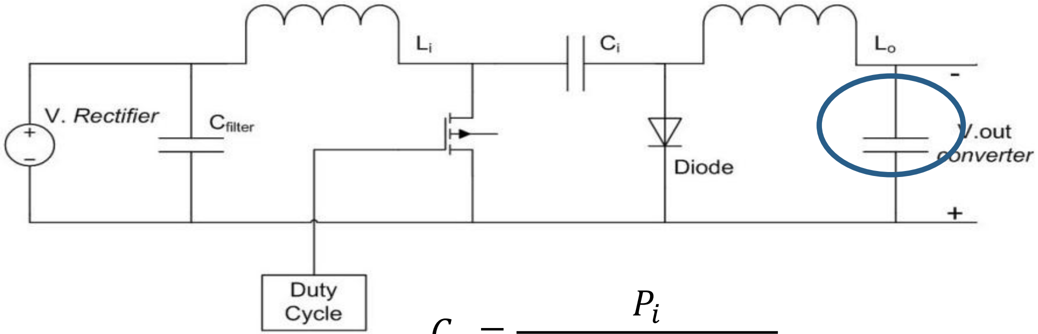


$$C_i = \frac{P_{max}}{\eta_3 \cdot (V_{o.max} + V_{p.max})^2 \cdot f}$$

$$= \frac{900}{0.1 \cdot (110 + 282.84)^2 \cdot 20.000}$$

$$= 2.92\ \mu F$$

Penentuan Nilai Komponen

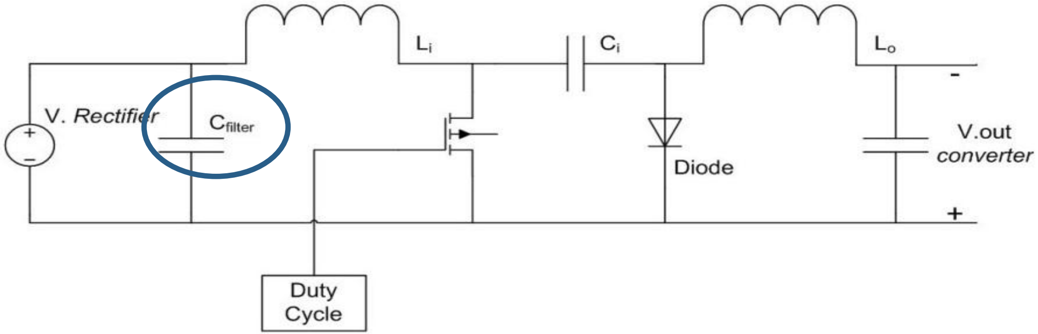


$$C_o = \frac{P_i}{2 \cdot \pi \cdot f \cdot \eta_4 \cdot {V_o}^2}$$

$$C_{o.1} = \frac{P_{max}}{2 \cdot \pi \cdot f \cdot \eta_4 \cdot {V_{o.max}}^2} = \frac{900}{2 \cdot 3.14 \cdot 50 \cdot 0.1 \cdot 110^2} = 2.37mH$$

$$C_{o.2} = \frac{P_{min}}{2 \cdot \pi \cdot f \cdot \eta_4 \cdot {V_{o.min}}^2} = \frac{10}{2 \cdot 3.14 \cdot 50 \cdot 0.1 \cdot 10^2} = 3.18\,mF$$

Penentuan Nilai Komponen



$$C_{max} = \frac{P_{max}\sqrt{2}}{V_s \cdot \omega_L \cdot V_m} \tan(1°)$$

$$= \frac{900\sqrt{2}}{220 \cdot 314 \cdot 220\sqrt{2}} \tan(1°)$$

$$= 1.03\ \mu F$$

Kelebihan Kekurangan Cuk Converter

The two inductors L_1 and L_2 are used to convert respectively the input voltage source (V_i) and the output voltage source (C_o) into current sources. Indeed, at a short time scale an inductor can be considered as a current source as it maintains a constant current. This conversion is necessary because if the capacitor were connected directly to the voltage source, the current would be limited only by (parasitic) resistance, resulting in high energy loss. Charging a capacitor with a current source (the inductor) prevents resistive current limiting and its associated energy loss.

Kelebihan
Arus in&out konstan

Kekurangan:
Tingginya current stress pada swich, dioda, dan kapasitor c1

Hubungan Harmonisa dengan PF

$$PF = \cos(\delta_1 - \theta_1)$$

Dimana δ_1 adalah sudut dari gelombang arus dan θ_1 adalah sudut dari gelomnbang tegangan. Sehingga nilai dari $(\delta_1 - \theta_1)$ adalah nilai perbedaan sudut antara gelombang arus dan gelombang tegangan.

Beban non-linier memiliki faktor distorsi (DF), yakni faktor yang menyebabkan gelombang terdistorsi. DF dicari dengan persamaan

$$DF = \frac{1}{\sqrt{1 + (THD)^2}}$$

Dan juga memiliki faktor perpindahan (displacement power factor / DPF), yaitu faktor perbedaan antara fasa tegangan dan arus. Sehingga PF sebenarnya dicari dengan persamaan

$$TPF = DPF \ x \ DF$$

Converter X Passive Filter

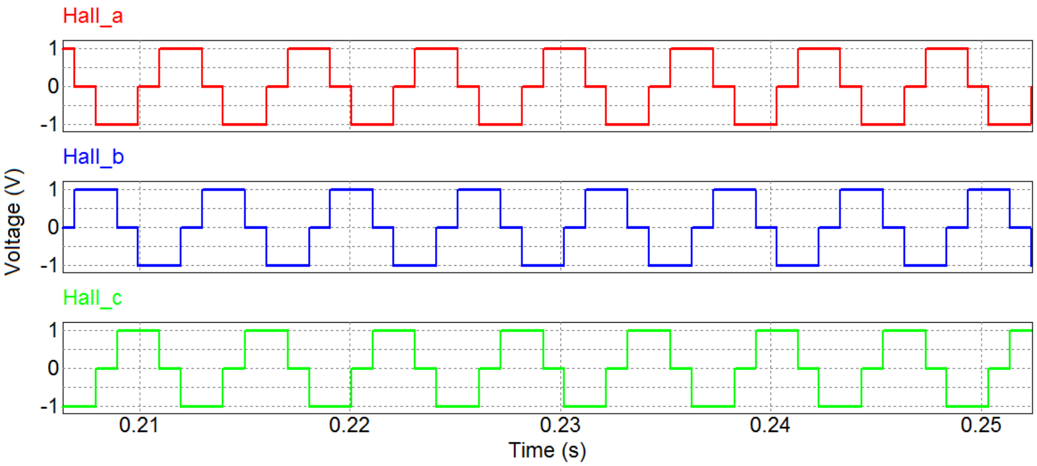
- Flexibel
- 2 in 1 (PFC + speed control)

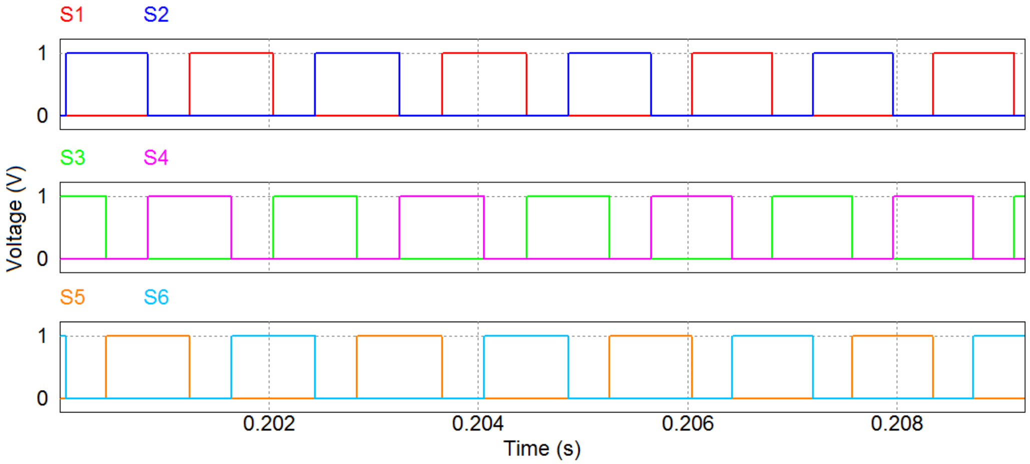
- Tidak Stabil
- Sistem harus telah ada
- Tidak flexibel
- Daya tinggi
- Cenderung mahal

Proses Komutasi

Hall-Effect Sensor			Switch Inverter					
H1	H2	H3	S1	S2	S3	S4	S5	S6
1	-1	0	1	0	0	1	0	0
1	0	-1	1	0	0	0	0	1
0	1	1	0	0	1	0	0	1
-1	1	0	0	1	1	0	0	0
-1	0	1	0	1	0	0	1	0
0	-1	1	0	0	0	1	1	0

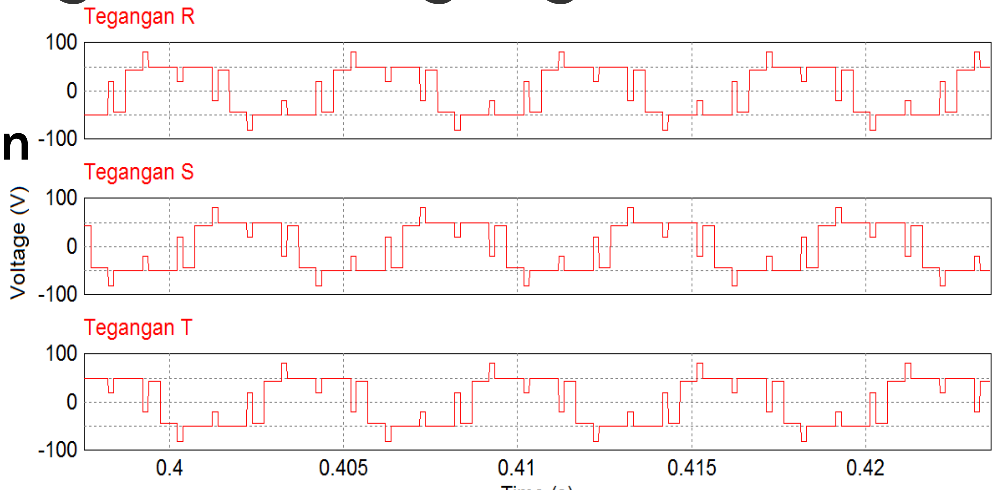
Komutasi Inverter



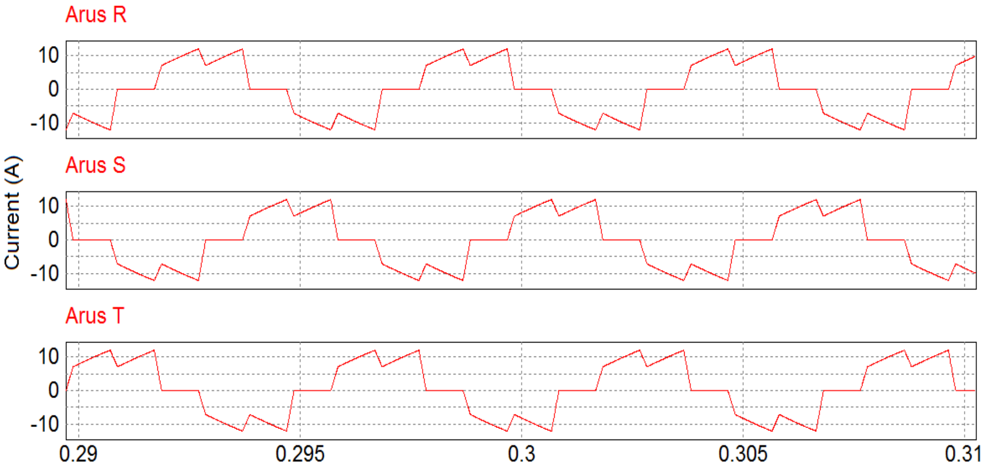


Gelombang Arus & Tegangan Motor

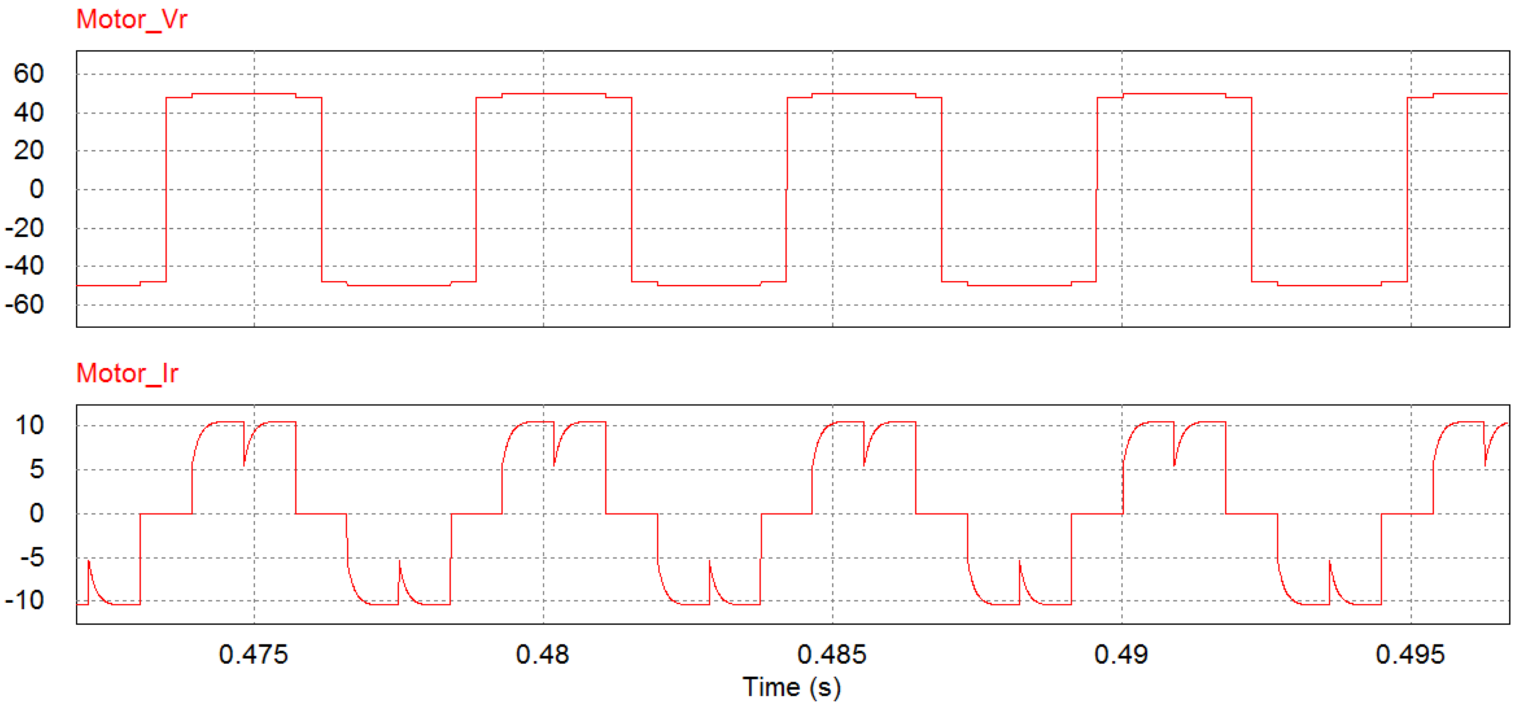
Tegangan



Arus

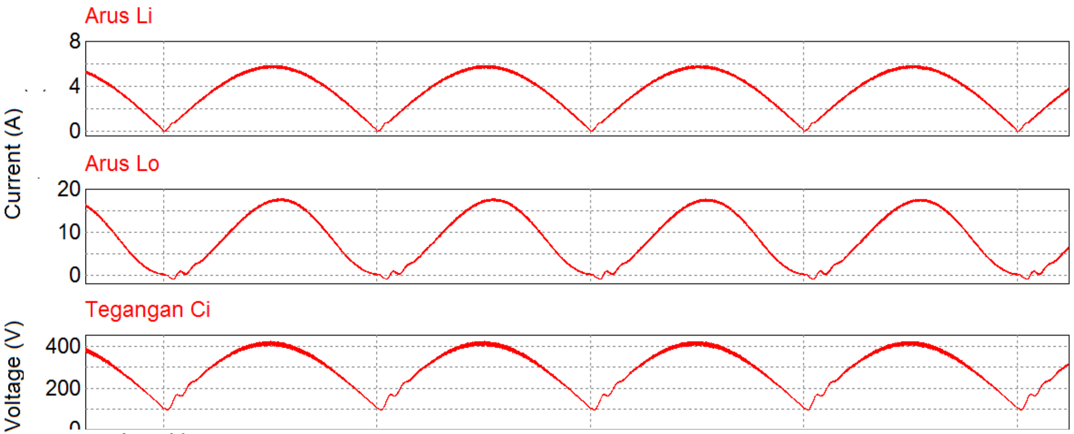


V & I motor ketika induktansi diubah (0.06mH)

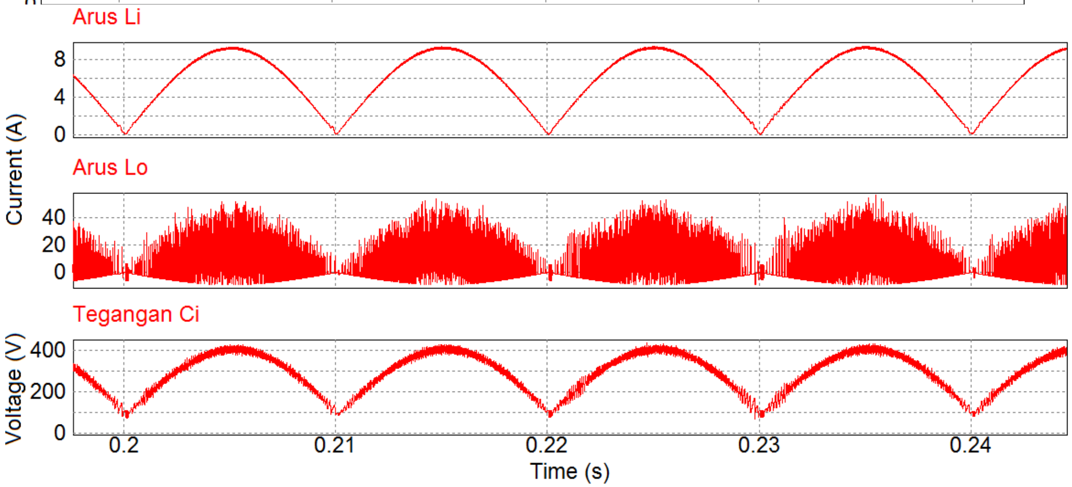


Gelombang Tegangan & Arus Komponen pada mode CCM & DCM pada Lo

CCM

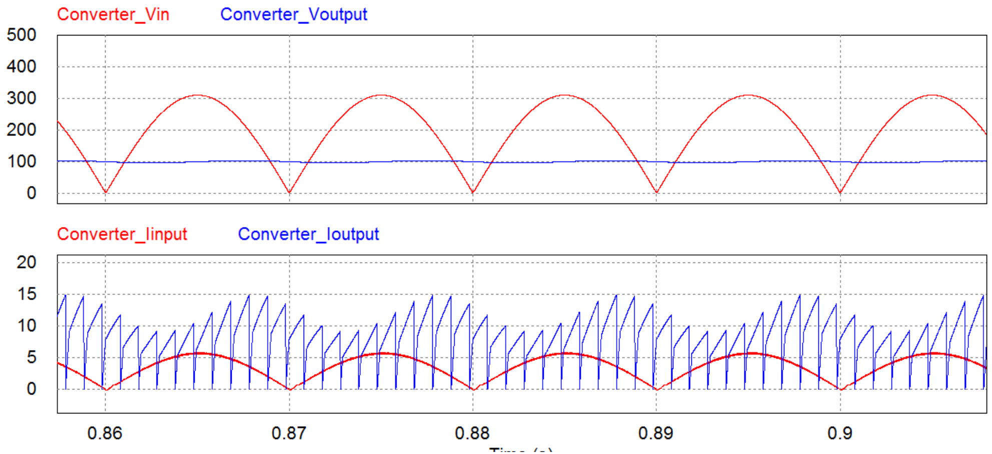


DCM pada Lo

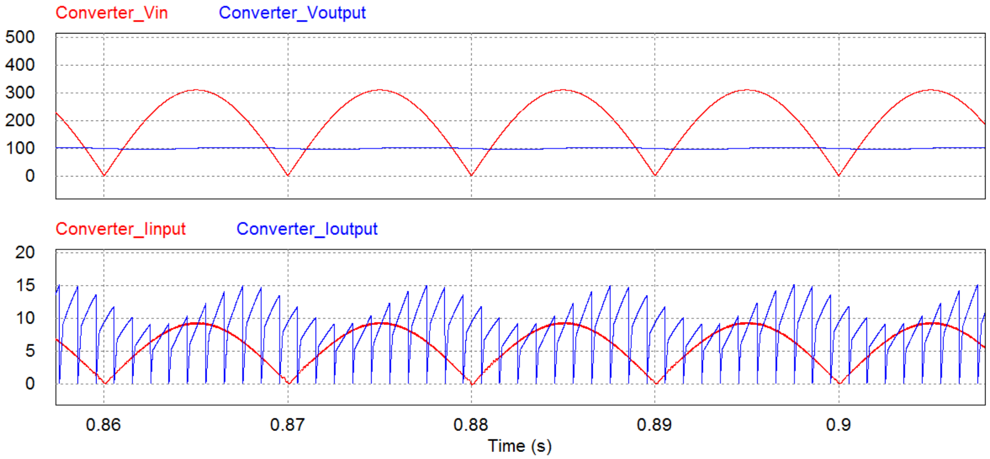


Gelombang Tegangan & Arus Komponen pada mode CCM & DCM pada Lo

CCM



DCM pada Lo



Data THD & TPF Lengkap

CCM #1					
No.	speed (rpm)	THD (%)	DF	DPF	TPF
1	250	31.108	0.95487	0.99915	0.95405
2	500	16.805	0.98617	0.99782	0.98402
3	750	10.247	0.99479	0.9993	0.99409
4	1000	6.997	0.99756	0.99976	0.99732
5	1250	5.266	0.99862	0.99992	0.99854
6	1500	3.924	0.99923	0.99995	0.99918
7	1750	3.128	0.99951	0.99995	0.99946
8	2000	2.62	0.99966	0.99995	0.99961
9	2250	2.285	0.99974	0.99995	0.99969
10	2500	1.967	0.99981	0.99995	0.99976

DCM #1					
No.	speed (rpm)	THD (%)	DF	DPF	TPF
1	250	33.17	0.94915	0.99698	0.94628
2	500	12.076	0.99279	0.99988	0.99267
3	750	7.041	0.99753	0.99998	0.99751
4	1000	4.4939	0.99899	0.99998	0.99897
5	1250	3.4748	0.9994	0.99999	0.99939
6	1500	2.286	0.99974	0.99999	0.99973
7	1750	1.9697	0.99981	0.99999	0.9998
8	2000	1.645	0.99986	0.99999	0.99985
9	2250	1.408	0.9999	0.99999	0.99989
10	2500	1.2618	0.99992	0.99999	0.99991

CCM #2					
No.	speed (rpm)	THD (%)	DF	DPF	TPF
1	250	31.82	0.95292	0.99452	0.9477
2	500	22.675	0.97524	0.9934	0.96881
3	750	13.814	0.99059	0.99685	0.98747
4	1000	9.505	0.99551	0.99898	0.9945
5	1250	6.683	0.99777	0.99957	0.99735
6	1500	4.986	0.99876	0.99977	0.99853
7	1750	3.815	0.99927	0.99988	0.99915
8	2000	3.211	0.99948	0.99993	0.99941
9	2250	2.614	0.99966	0.99996	0.99962
10	2500	2.286	0.99974	0.99997	0.99971

DCM #2					
No.	speed (rpm)	THD (%)	DF	DPF	TPF
1	250	20.767	0.97911	0.98977	0.96909
2	500	15.67	0.98794	0.9971	0.98508
3	750	7.834	0.99695	0.99954	0.99649
4	1000	5.44	0.99852	0.99983	0.99835
5	1250	3.888	0.99925	0.99915	0.9984
6	1500	3.142	0.99951	0.99995	0.99946
7	1750	2.429	0.99971	0.99997	0.99968
8	2000	2.021	0.9998	0.99998	0.99978
9	2250	1.716	0.99985	0.99998	0.99983
10	2500	1.428	0.9999	0.99999	0.99989

Fenomena Detuning

Detuning phenomenon in a Cuk converter: "Detuning phenomenon" represents the inability of a PFC converter to maintain a sinusoidal supply current at near zero-crossings of the supply voltage [38]. This distortion of the supply current at its zero crossing results in high THD of supply current and directly affects the PF at ac mains. Now, considering a case of a PFC Cuk converter-fed BLDC motor drive with the Cuk converter operating in the DCM with output inductor (L_o) is designed to operate in the DCM. During the PFC operation, the supply current is in phase with the supply voltage and it is sinusoidal in nature. The input power at zero crossings of supply voltage is very low and the duty ratio is unity. Hence, a distortion in input inductor current occurs due to inability of the input inductor to maintain a continuous current through it. Fig. 18 shows the distortion of supply current near zero crossing for a PFC Cuk converter-fed BLDC motor drive with the Cuk converter operating in the DICM (L_o).

Standar Harmonics IEC 61000-3-2

Harmonics [n]	Class A [A]	Class B [A]	Class C [% of fund]	Class D [mA/W]
		Odd harmonics		
3	2.30	3.45	30 x λ	3.4
5	1.14	1.71	10	1.9
7	0.77	1.155	7	1.0
9	0.40	0.60	5	0.5
11	0.33	0.495	3	0.35
13	0.21	0.315	3	3.85/13
15 ≤n ≤39	0.15 x 15/n	0.225 X 15/n	3	3.85/n
		Even harmonics		
2	1.08	1.62	2	-
4	0.43	0.645	-	-
6	0.30	0.45	-	-
8 ≤n ≤40	0.23 x 8/n	0.345 x 8/n	-	-

IEEE 519-1992

Current Distortion Limits for General Distribution Systems (120 V Through 69000 V)

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{sc}/I_L	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Even harmonics are limited to 25% of the odd harmonic limits above.

Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.

* All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.

Where

- I_{sc} = maximum short-circuit current at PCC.
- I_L = maximum demand load current (fundamental frequency component) at PCC.
- TDD = Total demand distortion (RSS), harmonic current distortion in % of maximum demand load current (15 or 30 min demand).
- PCC = Point of common coupling.

THDi X TDD

$$I_{THD} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + \ldots}}{I_1} \times 100\%$$

$$I_{TDD} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + \ldots}}{I_L} \times 100\%$$

	AC Line Reactor	DC Link Reactor
ADVANTAGES	Increases reliability of VFD and helps facilities to comply with utility standard	Increases reliability of VFD and helps facilities to comply with utility standard
	Provides VFD's diode bridge with some protection from voltage transient/spike caused by lighting surge or power factor capacitor switching	Does not cause voltage drop to the VFD, and suitable for cases where the VFD is installed on a power line that dips in voltage
		Less expensive than AC Line Reactor for the same impedance for harmonic mitigation
DISADVANTAGES	Causes voltage drop to the VFD due to a condition called "Overlap of Diode Conduction", which can result in nuisance tripping on undervoltage or power loss when VFD is installed on a power line that dips in voltage	Does not provide any protection to the VFD's doide bridge from possible voltage transient/spike caused by lighting surge or power factor capacitor switching
	More expensive than DC Link Reactor for the same impedance for harmonic mitigation	