

**DESAIN KALKULASI
PROTEKSI KATODIK ARUS PAKSA
STRUKTUR LEPAS PANTAI**

Parameter Proteksi Katodik

Umur Layan (t)	40	tahun
Tahanan Air Laut (ρ_{seawater})	0.19	Ohm.m
Tahanan Tanah Bawah Laut (ρ_{soil})	1.3	Ohm.m
Kedalaman Laut	>30-100	m
Safety Factor (S_f)	25%	
Temperatur Air Laut	> 20	°C
Desain Potensial Protektif (E_p°)	-800	mV
Desain Closed Circuit (E_a°)	-1050	mV

Faktor Kerusakan Cat (C_d)

	Initial	Mean	Final	
Kedalaman Laut 0-30	2.00%	26.00%	50%	%
Kedalaman Laut > 30	2.00%	18.00%	34%	%
Coating Category (DNV-RP-B401)	III			

Rapat Arus (C_b)

Zona Terendam	Initial	Mean	Final	
Kedalaman Laut 0-30	0.15	0.07	0.1	Amp/m ²
Kedalaman Laut 30-100	0.12	0.06	0.08	Amp/m ²
Kedalaman Laut 100-300				Amp/m ²
Kedalaman Laut >300				Amp/m ²
Zona Terkubur	0.02	0.02	0.02	Amp/m ²

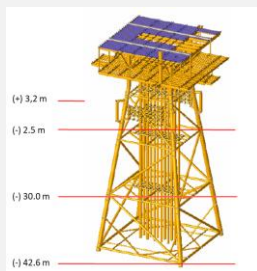
Spesifikasi Anoda

Tipe Anoda	Tubular Ti-MMO anode, min. dimension: 1.25" dia x 48" length		
Radius Anoda (r_a)	15.875	mm	
Panjang Anoda (L_A)	1219.2	mm	
Kapasitas Arus Anoda (I_A)	600	Amp/m ²	
Tahanan Anoda(R_A)	0.12	ohm	

Spesifikasi Peralatan Listrik

Jenis Kabel DC positif (Anoda ke Junction Box)	1/C x 50 mm2 N2XB(AL)Y cable with HMWPE insulation.		
Tahanan Spesifik Kabel (R_c)	0.001075	ohm/m	Jumlah : 43 buah
Total Panjang Kabel (L_c)	10	m	
Jenis Kabe DC positif (Junction Box ke Rectifier)	3/C x 16mm2 (6 AWG) with HMWPE insulation		
Tahanan Spesifik Kabel (R_c)	0.00033456	ohm/m	Jumlah : 1 buah
Total Panjang Kabel (L_c)	10	m	
Jenis Kabe DC negatif (Struktur ke Junction Box)	3/C x 16mm2 (6 AWG) with HMWPE insulation		
Tahanan Spesifik Kabel (R_c)	0.00033456	ohm/m	Jumlah : 1 buah
Total Panjang Kabel (L_c)	5	m	
Jenis Kabe DC negatif (Junction Box ke Rectifier)	3/C x 16mm2 (6 AWG) with HMWPE insulation		
Tahanan Spesifik Kabel (R_c)	0.00033456	ohm/m	Jumlah : 1 buah
Total Panjang Kabel (L_c)	5	m	
Safety Factor (S_f)	25%		
Back Electromotive (B_{ent})	2	volt	
Tegangan Input AC	415	volt	
Transformer Rectifier Efficiency (η)	70%		
cos ϕ	0.85		

Spesifikasi Struktur Lepas Pantai



**Structural Steel Grade
Luas Permukaan (A)**

Zona Percikan	746.79	m ²	coated
Zona Terendam	3452.80	m ²	coated
Zona Terkubur	1850.90	m ²	coated

Coating Type III

Two or more layers of marine paint coating (epoxy, polyurethane or vinyl based), total nominal DFT min. 350 μm .

DESAIN KALKULASI PROTEKSI KATODIK ARUS PAKSA STRUKTUR LEPAS PANTAI

Perhitungan Kebutuhan Arus

$$I_t = \left[\left(A_1 \cdot \frac{C_b \cdot C_{d1}}{1000} \right) \times (1 + S_f) \right] + \left[\left(A_2 \cdot \frac{C_b \cdot C_{d2}}{1000} \right) \times (1 + S_f) \right] + \left[\left(A_3 \cdot \frac{C_b \cdot C_{d3}}{1000} \right) \times (1 + S_f) \right]$$

	initial	mean	final	
Kebutuhan Arus Zona Percikan	2.80	16.99	46.67	A
Kebutuhan Arus Zona Terendam	12.95	78.55	215.80	A
Kebutuhan Arus Zona Terkubur	0.93	12.03	23.14	A
Total Kebutuhan Arus (I _t)	16.67	107.57	285.61	A

Perhitungan Jumlah Anoda

$$\log (id) = [(2.3) - \log L] \times 2.5$$

$$\text{Kapasitas Output Arus Anoda (I_a)}$$

$$\text{Luas Permukaan Anoda (per buah)}$$

$$\text{Ian} = I_d \times \text{Aan}$$

$$\text{Keluaran Arus Anoda (per buah)}$$

	initial	mean	final	
Jumlah Kebutuhan Anoda	3	16	43	buah

Perhitungan Kapasitas Transformer/Rectifier

$$E_T = \{ I_t \times R_T \times (1 + S_f) \} + B_{emf}$$

	initial	mean	final	
Output Tegangan DC yang dibutuhkan	3.31	5.17	7.13	Volt

Perhitungan Kebutuhan Arus AC

$$I_{AC} = \frac{E_T \cdot I_t}{E_{AC} \cdot \eta \cdot \sqrt{3} \cdot \cos \phi}$$

	initial	mean	final	
Output Arus AC yang dibutuhkan	0.12	1.20	4.39	A

Perhitungan Kapasitas Daya Transformer-Rectifier

$$P_{AC} = \sqrt{3} \times I_{AC} \times E_{AC}$$

	initial	mean	final	
Kapasitas Trafo 3-phase (VA)	0.09	0.86	3.15	kVA

NOMENKLATUR:

I _t	= Kebutuhan Arus (A)
A ₁	= Luas Permukaan Area Percikan (m ²)
Cd ₁	= Rapat Arus Area Percikan (mA/m ²)
A ₂	= Luas Permukaan Area Terendam (m ²)
Cd ₂	= Rapat Arus Area Terendam (mA/m ²)
A ₃	= Luas Permukaan Area Terkubur (m ²)
Cd ₃	= Rapat Arus Area Terkubur (mA/m ²)
Cb	= Faktor Kerusakan Cat Pelindung (%)
S _f	= Faktor Pengaman (25 %)
L	= Umur Layan (tahun)
I _d	= Kapasitas Arus Individual Anoda (Amp/m ²)
I _{an}	= Kapasitas keluaran arus anoda (Amp)
A _{an}	= Luas Area Anoda (m ²)
Q _a	= Jumlah kebutuhan anoda (buah)
I _t	= Kebutuhan Arus (A)
I _d	= Rapat Arus Anoda (A)
ρ _{seawater}	= Tahanan Air Laut (Ohm.m)
ρ _{soil}	= Tahanan Tanah (Ohm.m)
L _a	= Panjang Anoda (m)

r _a	= radius anoda (m)
L _c	= Panjang kabel (m)
N	= Jumlah kabel(buah)
R _a	= Tahanan spesifik kabel (Ohm/m)
R _{rectifier}	= Tahanan rectifier (ohm)
R _{cable}	= Tahanan kabel (ohm)
I _t	= Total Kebutuhan Arus (Ampere)
R _T	= Total Tahanan Sirkuit (Ohm)
S _f	= Safety factor (25%)
B _{emf}	= Back Electromotive Force (2 Volt)
E _T	= Output Tegangan DC yang dibutuhkan (Volt)
E _{AC}	= Input Tegangan AC (415 Volt)
E _T	= Output Tegangan DC yang dibutuhkan (Volt)
I _t	= Total Kebutuhan Arus (Ampere)
η	= Transformer Rectifier Efficiency (70 %)
Cos φ	= Sudut fase listrik AC (0.85)
P _{AC}	= Kapasitas daya transformer rectifier (VA)
E _{AC}	= Input Tegangan AC (415 Volt)
I _{AC}	= Input Arus AC (Ampere)

Tahanan Sirkuit

$$R_{anoda} = \frac{\rho_{seawater}}{2\pi L_a} \times \left[\ln \left(\frac{4L_a}{r_a} \right) - 1 \right]$$

Submerged

Jarak antar anoda	:	1 m			
		initial	mean	final	
Tahanan individu Anoda R _a	:	0.117	0.117	0.117	Ohm
InterferenceFactor F	:	1.349	2.213	2.723	
Total Tahanan Anoda	:	0.0527	0.0162	0.0074	Ohm

$$R_{anoda} = \frac{\rho_{seawater}}{2\pi L_a} \times \left[\ln \left(\frac{4L_a}{r_a} \right) - 1 \right]$$

$$R_{anoda} = \frac{\rho_{seawater}}{Q_a 2\pi L_a} \times \left\{ \left[\ln \left(\frac{4L_a}{r_a} \right) - 1 \right] + \frac{2L_a}{s} \ln(0.656 Q_a) \right\}$$

$$R_{cable} = \frac{L_c \times R_e}{N}$$

Jenis Kabel DC positif (Anoda ke Junction Box)

Tahanan Kabel R _{cable}	:	0.00358	0.00067	0.00025	Ohm
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Tahanan Kabel R _{rectifier}	:	0.003			Ohm
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Jenis Kabe DC negatif (Struktur ke Junction Box)

Tahanan Kabel R _{rectifier}	:	0.002			Ohm
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Jenis Kabe DC negatif (Junction Box ke Rectifier)

Tahanan Kabel R _{rectifier}	:	0.002			Ohm
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$$R_{Total} = R_{anoda} + R_{cable}$$

Tahanan circuit total	:	0.063	0.024	0.014	Ohm
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**ESTIMASI HARGA
PROTEKSI KATODIK ARUS PAKSA
STRUKTUR LEPAS PANTAI**

No	Produk / Pekerjaan	Qty	Harga Satuan	Total Harga
1	Anoda			
	Tubular Ti-MMO anode, min. dimension: 1.25" dia x 48" length	43	IDR 13,300,000	IDR 571,900,000
2	Blasting & Painting			
	Type III			
	Zona Percikan	746.79	IDR 380,000	IDR 283,778,682
	Zona Terendam	3452.80	IDR 380,000	IDR 1,312,065,374
	Zona Terkubur	1850.90	IDR 380,000	IDR 703,343,685
3	Kabel (Anode to Junction Box)			
	1/C x 50 mm2 N2XB(AL)Y cable with HMWPE insulation.	430	IDR 149,500	IDR 64,285,000
4	Kabel (Junction Box to rectifier/transformer)			
	3/C x 16mm2 (6 AWG) with HMWPE insulation	20	IDR 149,500	IDR 2,990,000
5	Junction Box			
	Anode Junction Box, NEMA-4X	2	IDR 13,800,000	IDR 27,600,000
6	Transformer Rectifier			
	AC input: 415 Volt/ 3Phase/ 50Hz DC output 50 Volt - 150 Ampere	1	IDR 430,000,000	IDR 430,000,000
TOTAL				IDR 3,395,962,741

PERHITUNGAN ATENUASI ANODA PROTEKSI KATODIK ARUS PAKSA STRUKTUR LEPAS PANTAI

$$E_x = E_a e^{(-\alpha x)}$$

L	Length	42.00	m
Ea	Potential near to anode	400	mV
ρ	Steel resistivity	0.00000018	ohm.m
Rc	Coating resistivity		
	bare	10	ohm.m2
	low quality Painting	1000	ohm.m2
	High quality painting	1000000	ohm.m2
OD	Outer Diameter	1.24	m
ID	Inner Diameter	1.2019	m

Area = $\pi * [((\text{outer diameter})/2)^2 - ((\text{inner diameter})/2)^2]$
Area 0.07307061 m2

Structure resistance per meter
 $r = (\rho_{\text{steel}} * L) / \text{Area}$
Structure resistance per meter (r) 0.000103462 ohm/m

Coating resistance
 $g = \pi * OD / Rc$
bare 0.389557489 S/m
low quality Painting 0.003895575 S/m
High quality painting 3.89557E-06 S/m

α	Attenuation		
	$\alpha = \sqrt{(r * g)}$		
	bare	0.0063486	
	low quality Painting	0.0006349	
	High quality painting	0.0000201	
	Desain Potensial Protektif (Eoc)	-800	mV
	Volume anjungan	25384.07	m3

Distance (x)	Potential at x distance		
	bare	low quality Painting	High quality painting
1	-947.46	-949.75	-949.99
100	-762.00	-925.40	-949.20
200	-662.36	-902.30	-948.40
300	-609.55	-880.63	-947.60
400	-581.56	-860.29	-946.80
500	-566.72	-841.21	-946.00
600	-558.86	-823.29	-945.21
700	-554.69	-806.48	-944.42
800	-552.49	-790.71	-943.63
900	-551.32	-775.90	-942.84
1000	-550.69	-762.00	-942.05
1100	-550.37	-748.96	-941.26
1200	-550.19	-736.73	-940.48
1300	-550.10	-725.24	-939.70
1400	-550.05	-714.46	-938.91
1500	-550.02	-704.34	-938.13
1600	-550.01	-694.85	-937.36
1700	-550.00	-685.94	-936.58
1800	-550.00	-677.58	-935.80
1900	-550.00	-669.73	-935.03
2000	-550.00	-662.36	-934.26
2100	-550.00	-655.45	-933.49
2200	-550.00	-648.97	-932.72
2300	-550.00	-642.88	-931.95
2400	-550.00	-637.17	-931.18
2500	-550.00	-631.80	-930.42
2600	-550.00	-626.77	-929.66
2700	-550.00	-622.05	-928.90
	-800.05	-800.05	-941.96
	74	740	1012
	53,468,047.14	3,819,146,224.37	3,256,052,585.82

Atenuasi Anoda

