Moteur Asynchrone

S. Dufour

2A Energie - ENRS8AB

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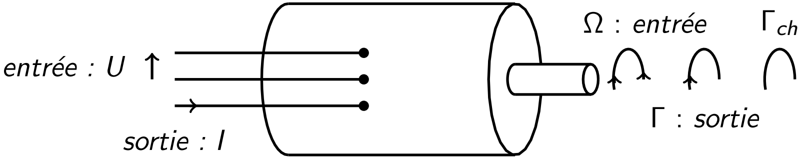
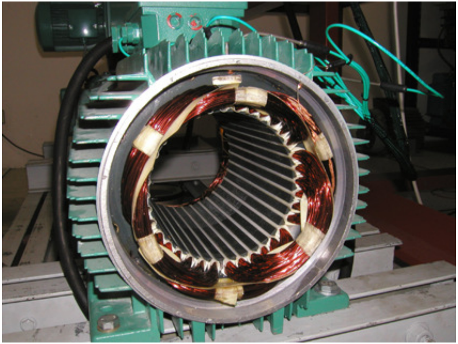
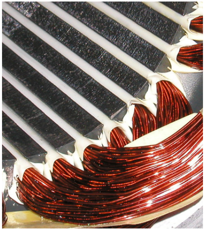
Moteur asynchrone



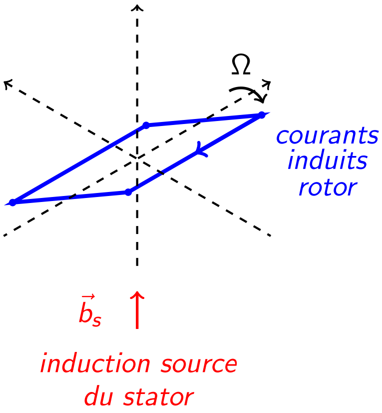


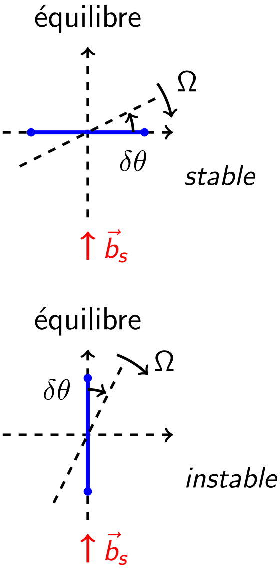


Stator

Rotor

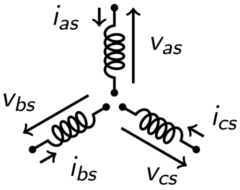
Moteur asynchrone : principe de fonctionnement





Moteur asynchrone : stator

système triphasé direct équilibré de pulsation $\omega = 2\pi f$



Tensions de phase :

$$[v_s] = \begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = \sqrt{2}\ \Re e \left(\overline{V}_1 e^{j\omega t} \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix} \right)$$

Courants de phase :

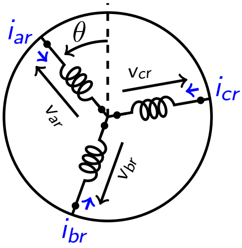
$$[i_s] = \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} = \sqrt{2}\ \Re e \left(\overline{I}_1 e^{j\omega t} \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix} \right)$$

Flux de phase :

$$[\varphi_s] = \begin{bmatrix} \varphi_{as} \\ \varphi_{bs} \\ \varphi_{cs} \end{bmatrix} = \sqrt{2}\ \Re e \left(\overline{\varphi}_1 e^{j\omega t} \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix} \right)$$

$$[v_s] = R_1 [i_s] + \frac{d}{dt}[\varphi_s] \qquad \overline{V}_1 = R_1 \overline{I}_1 + j\omega\overline{\varphi}_1$$

$$\overline{I}_1 = |\overline{I}_1| e^{-j\varphi}$$



rotor en court-circuit

θ_m angle mécanique $\quad \dot{\theta}_m = \Omega$

p nombre de paires de pôles *(symétrie géométrique)*

θ angle électrique $\quad \theta = p\,\theta_m \quad \dot{\theta} = p\,\Omega$

entre bobinage a stator et bobinage a rotor

$\omega_r = \omega - p\Omega = g\omega$ pulsation rotorique

$g = \dfrac{\omega/p - \Omega}{\omega/p}$ glissement

$$\begin{bmatrix} v_{ar} \\ v_{br} \\ v_{cr} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$[i_r] = \begin{bmatrix} i_{ar} \\ i_{br} \\ i_{cr} \end{bmatrix} = \sqrt{2}\,\Re e\left(-\overline{I}_2 e^{jg\omega t}\begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}\right)$$

$$[0] = R_2[i_r] + \frac{d}{dt}[\varphi_r] \qquad 0 = -R_2\overline{I}_2 + jg\omega\overline{\varphi}_2$$

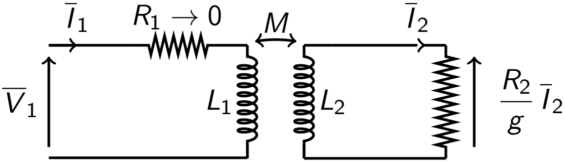
couplage stator/rotor

$$\overline{\varphi}_1 = L_1\overline{I}_1 - M\overline{I}_2$$

$$\overline{\varphi}_2 = M\overline{I}_1 - L_2\overline{I}_2$$

Modèle du transformateur à champ tournant

Schéma monophasé équivalent



$$\left\{\begin{array}{lcl} \overline{V}_1 & = & (\cancel{R_1} + jL_1\omega)\overline{I}_1 - jM\omega\overline{I}_2 \\ 0 & = & jM\omega\overline{I}_1 - (\dfrac{R_2}{g} + jL_2\omega)\overline{I}_2 \end{array}\right.$$

$$\overline{I}_2 = \frac{jM\omega}{\dfrac{R_2}{g} + jL_2\omega}\,\overline{I}_1 \qquad\qquad \overline{I}_1 = \frac{\overline{V}_1}{jL_1\omega}\,\frac{\dfrac{R_2}{g} + jL_2\omega}{\dfrac{R_2}{g} + j\sigma L_2\omega}$$

$\sigma = 1 - \dfrac{M^2}{L_1 L_2}$ *coeff. de dispersion* $\qquad \dfrac{M}{L_1}$ *rapport de transformation*

Machine asynchrone : puissances

$$\overline{S} = 3\overline{V}_1\overline{I}_1^* = 3\frac{R_2}{g}|\overline{I}_2|^2 + j3\left(L_1\omega|\overline{I}_1|^2 - L_2\omega|\overline{I}_2|^2\right)$$

$$P_a = \Re e(\overline{S}) = 3\,\frac{R_2}{g}\,|\overline{I}_2|^2$$

puissance active

$$P_m = \Gamma\,\Omega$$

puissance mécanique

pertes Joule

$$P_{jr} = 3\,R_2\,|\overline{I}_2|^2 = gP_a$$

$$P_m = (1-g)P_a$$

$$\overline{I}_2 = \frac{\dfrac{M}{L_1}\,\overline{V}_1}{\dfrac{R_2}{g} + j\sigma L_2\omega} \qquad \rightsquigarrow \quad P_a = 3\,\frac{R_2}{g}\,\frac{\left[\dfrac{M}{L_1}\right]^2 |\overline{V}_1|^2}{\left[\dfrac{R_2}{g}\right]^2 + (\sigma L_2\omega)^2}$$

$$P_m = (1-g)\,P_a = \Gamma\,\Omega = \Gamma\,\frac{\omega}{p}\,(1-g)$$

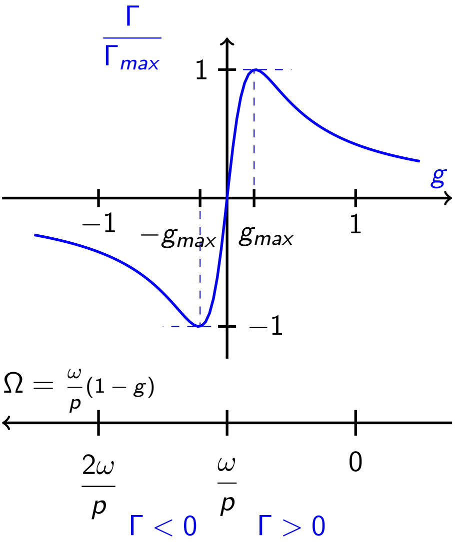
Couple

$$\Gamma = \frac{3p}{\omega}\,\frac{R_2}{g}\,\frac{\left[\dfrac{M}{L_1}\right]^2 |\overline{V}_1|^2}{\left[\dfrac{R_2}{g}\right]^2 + (\sigma L_2 \omega)^2}$$

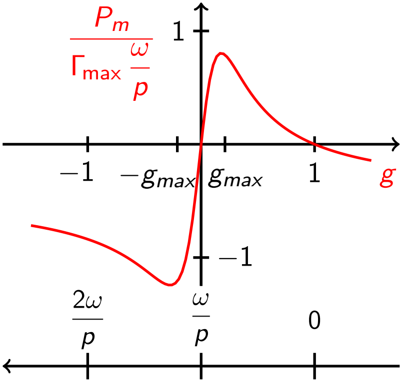
$$\Gamma_{max} = \frac{3p}{2\omega}\left[\frac{M}{L_1}\right]^2 \frac{|\overline{V}_1|^2}{\sigma L_2 \omega}$$

$$g_{max} = \frac{R_2}{\sigma L_2 \omega}$$

$$\frac{\Gamma}{\Gamma_{max}} = \frac{2}{\dfrac{g}{g_{max}} + \dfrac{g_{max}}{g}}$$



Puissance mécanique et rendement (théorique)

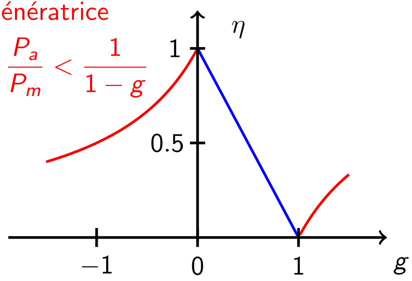


$\Omega = \frac{\omega}{p}(1-g)$

$P_m < 0$	$P_m > 0$	$P_m < 0$
$P_a < 0$	$P_a > 0$	$P_a > 0$
Génératrice	Moteur	Frein

Génératrice

$$\eta_g = \frac{P_a}{P_m} < \frac{1}{1-g}$$



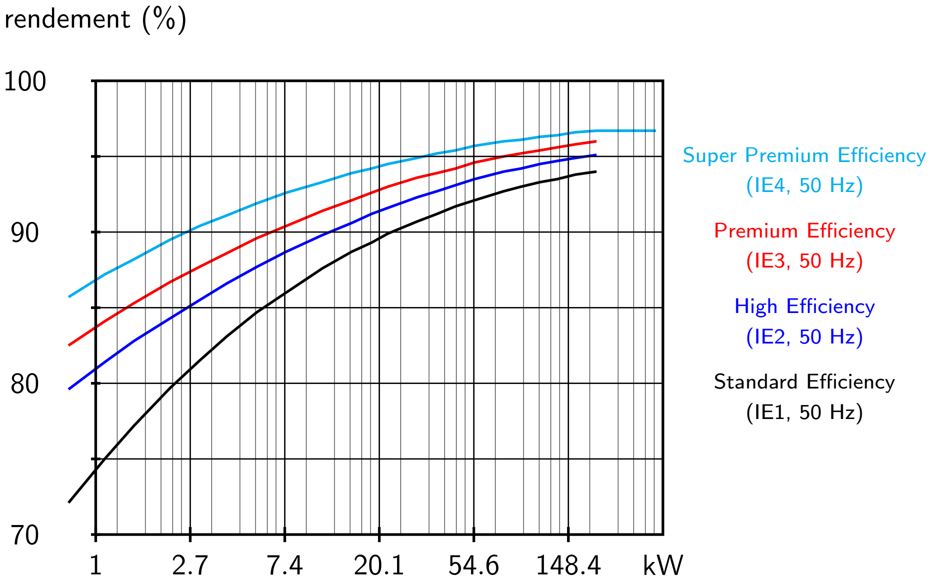
Moteur

$$\eta_m = \frac{P_m}{P_a} < 1 - g$$

Frein

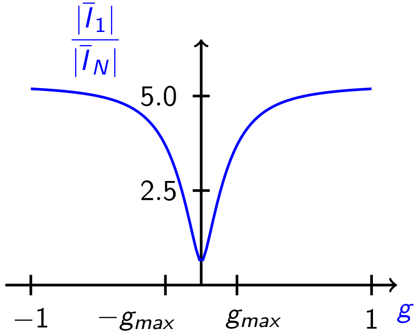
$$\eta_f = \frac{-P_m}{P_a - P_m} < 1 - \frac{1}{g}$$

Rendement d'un moteur 4 pôles 0.75kW-200kW



Courant

$$\overline{I}_1 = |\overline{I}_1| e^{-j\varphi} = \frac{\overline{V}_1}{jL_1\omega} \; \frac{\frac{R_2}{g} + jL_2\omega}{\frac{R_2}{g} + j\sigma L_2\omega} = \frac{\overline{V}_1}{j\sigma L_1\omega} \; \frac{\sigma + j\frac{g}{g_{max}}}{1 + j\frac{g}{g_{max}}} = \frac{\overline{V}_1}{\overline{Z}(g)}$$



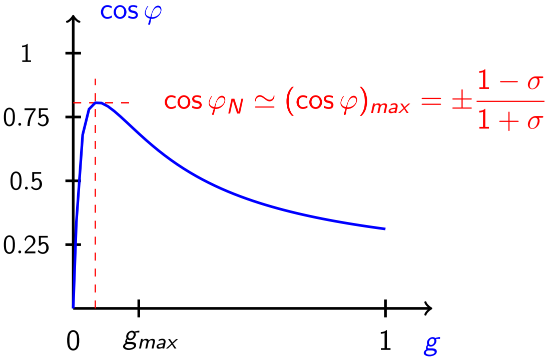
$$\overline{I}(g=1) \simeq \frac{\overline{V}_1}{j\sigma L_1\omega}$$ courant de démarrage

$$\overline{I}_N \simeq \overline{I}((cos\varphi)_{max}) = \frac{\overline{V}_1}{j\sqrt{\sigma} L_1\omega} \; \frac{\sqrt{\sigma} + j}{1 + j\sqrt{\sigma}}$$

$$\overline{I}(g \to 0) \simeq \frac{\overline{V}_1}{jL_1\omega}$$ courant à vide

Facteur de puissance

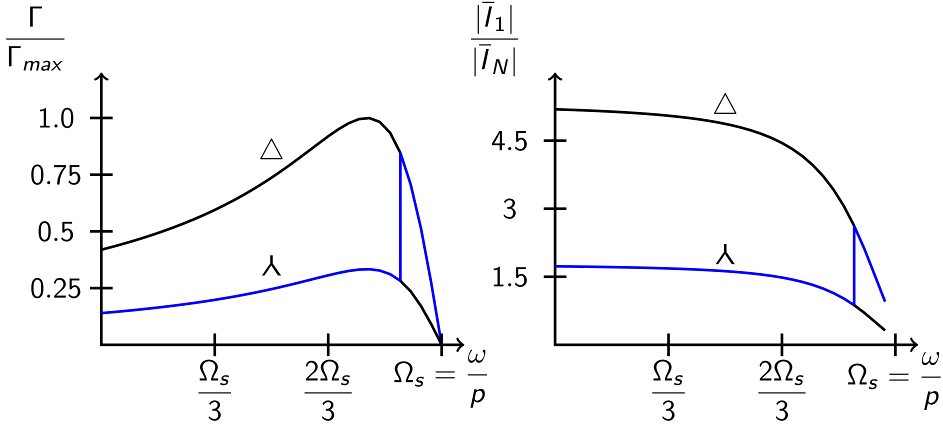
$$\cos\varphi = \frac{(1-\sigma)\dfrac{g}{\sigma g_{max}}}{\left[\left(1+\left(\dfrac{g}{g_{max}}\right)^2\right)\left(1+\left(\dfrac{g}{\sigma g_{max}}\right)^2\right)\right]^{1/2}}$$



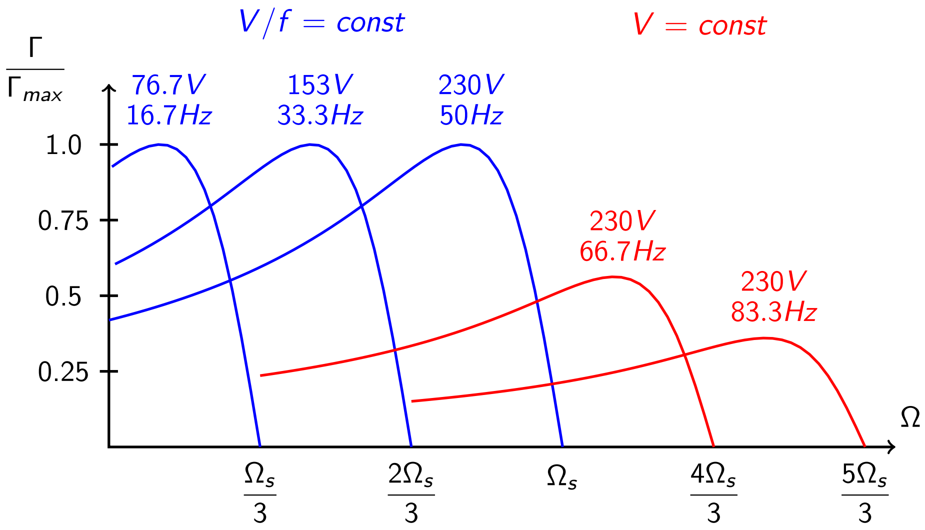
$\cos\varphi(g \to 0) \to 0$

$\cos\varphi(g = 1) \simeq (1-\sigma)g_{max}$

Démarrage étoile-triangle



Variation de vitesse à $V/f = const$



$400V \quad 50Hz \quad 0.75 - 200kW \quad$ 4 pôles

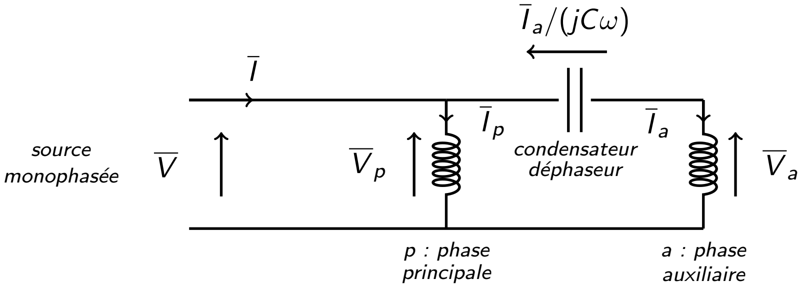
	P_N (kW)	Ω_N (tr/mn)	Γ_N $(N.m)$	Γ_d/Γ_N	I_d/I_N	I_N (A)	η $(\%)$	$\cos\varphi$
IE2	1.1	1440	7.3	1.9	6.1	2.35	82.1	0.82
	5.5	1454	36.1	2.7	7.1	11.2	88.5	0.80
	11	1460	71.9	3.1	8.4	20.9	90.6	0.84
	55	1484	354	2.3	7.3	101	94.7	0.83
	110	1488	706	3.1	7.6	200	94.8	0.84
	200	1486	1290	3.0	7.3	366	95.5	0.83
IE3	1.1	1450	7.25	2.4	6.9	2.3	84.8	0.81
	5.5	1462	35.9	2.8	8.6	10.3	90.3	0.85
	11	1466	71.7	2.3	7.3	20.5	91.6	0.85
	55	1484	354	2.3	7.3	101	94.9	0.83
	110	1488	706	3.1	7.7	198	95.6	0.84
	200	1486	1290	3.0	7.4	361	96.1	0.83

Données Nidec

$400V \quad 50Hz \quad 0.75 - 189kW \quad$ 4 pôles

	P_N	Ω_N	I_N	$\cos\varphi$	$\%\Gamma_N$	$\%\Gamma_N$	$\%\Gamma_N$	$\%\Gamma_N$	$\%\Gamma_N$
	(kW)	(tr/mn)	(A)		10Hz	17Hz	25Hz	50Hz	87Hz
IE2	1.1	1415	2.5	0.82	90	100	100	100	57
IE2	5.5	1435	11.5	0.80	90	90	100	100	57
IE2	11	1445	21.9	0.84	85	95	100	100	57
IE2	55	1480	108	0.83	85	95	100	100	57
IE2	110	1482	211	0.84	80	90	100	100	57
IE2	189	1482	356	0.83	76	85	95	95	54
IE3	1.1	1430	2.3	0.81	90	100	100	100	57
IE3	5.5	1450	11	0.85	90	90	100	100	57
IE3	11	1454	21.6	0.85	85	95	100	100	57
IE3	55	1480	108	0.83	85	95	100	100	57
IE3	110	1482	211	0.84	80	90	100	100	57
IE3	189	1482	356	0.83	80	90	90	90	57

Données Nidec



$$\overline{V} = \overline{V}_p = \overline{V}_a + \frac{\overline{I}_a}{jC\omega}$$

$$\overline{I} = \overline{I}_p + \overline{I}_a = \overline{I}_p + j\omega\overline{Q}$$

C dimensionné pour avoir :

$$\frac{P}{2} \simeq |\overline{V}_p|\,|\overline{I}_p|\cos\varphi \simeq |\overline{V}_a|\,|\overline{I}_a|\cos\varphi$$

$$|\overline{V}_d| >> |\overline{V}_i|$$

$$\begin{bmatrix} \overline{V}_p \\ \overline{V}_a \end{bmatrix} = \underbrace{\overline{V}_d \begin{bmatrix} 1 \\ -j \end{bmatrix}}_{\text{diphasé direct}} + \underbrace{\overline{V}_i \begin{bmatrix} 1 \\ j \end{bmatrix}}_{\text{diphasé inverse}}$$

Moteur Asynchrone Monophasé : performances

$230V \pm 10\%$ $50Hz$ $0.09 - 5.5kW$ $2 - 4 - 6$ pôles

Condensateur permanent

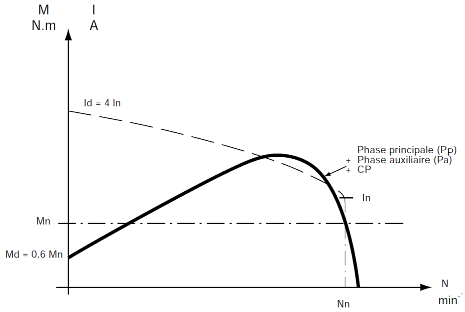
Relais de tension

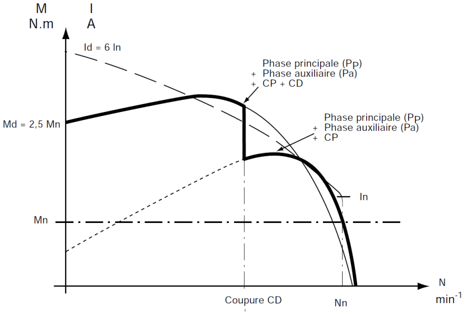
(condensateur de démarrage + relais de tension + condensateur permanent)

P_N	Ω_N	Γ_N	I_N	$\cos\varphi$	η	I_d/I_N	Γ_d/Γ_N
(kW)	(tr/mn)	$(N.m)$	(A)		$(\%)$		
0.12	1430	0.82	1.05	0.90	57	4.2	2.2
0.55	1420	3.70	4.20	0.90	65	4.5	1.9
1.1	1420	7.36	6.9	0.95	71	4.9	1.9
2.2	1445	15.0	14.0	0.93	74	5.0	1.4
5.5	1455	37.0	33.2	0.90	80	7.0	1.8

Données Nidec

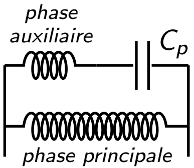
Moteur Asynchrone Monophasé : montage

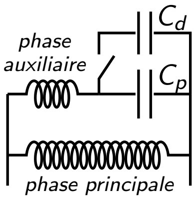




Condensateur permanent

Condensateur permanent + démarrage





Source Nidec