

Errata Sheet for
Modeling and High-Performance Control of Electric Machines
by
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Preface, page xviii. Change “Chapter 4, Sections 4.1–4.5” to “Chapter 4, Sections 4.1–4.6”

Preface, page xviii. First line in **Acknowledgements** section. Change “I would to” to “I would like to”.

Chapter 1, page 22, Figure 1.19. Replace “ V_b ” with “ ξ ” in Figure 1.19.

Chapter 1, problem 3, page 58, line 2. Remove the word "taken".

Chapter 1, problem 13, page 65, line 1. Replace “(1.22), (1.23), and (1.24)” with “(1.25), (1.26), and (1.27)”.

Chapter 1, problem 14, page 66, line 1. Replace “(1.22), (1.23), and (1.24)” with “(1.25), (1.26), and (1.27)”.

Chapter 2, page 94. Second line from bottom. Remove the period “.”

Chapter 2, page 105. Just following equation (2.43), remove “with respect to δK and λ .”

Chapter 2, page 123, 7th line from the bottom. Replace the “,” with “.”

Chapter 2, page 145. Last sentence in the remark. Replace “got to” with “go to”.

Chapter 2, page 150. The fourth row of the Routh-Hurwitz table. Change

$$\frac{-K(K+1) - \alpha K}{-K} = \frac{K(K+1 + \alpha K)}{K}$$

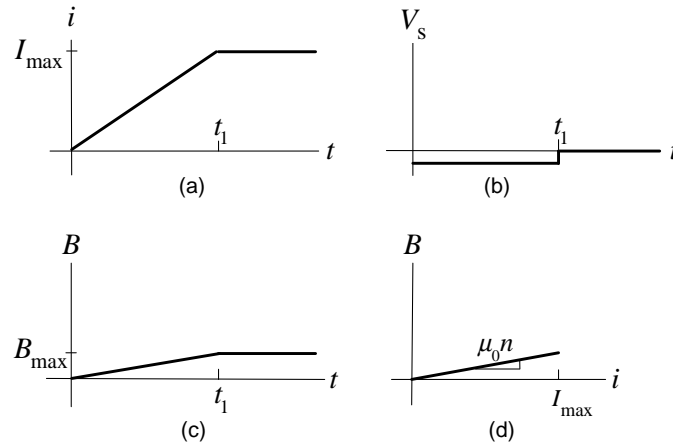
to

$$\frac{-K(K+1) - \alpha K}{-K} = \frac{K(K+1 + \alpha)}{K}.$$

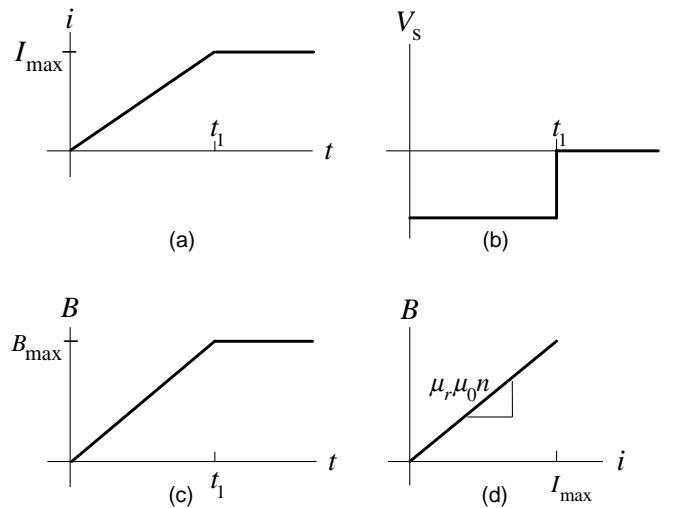
Chapter 2, page 154, problem 13. Replace “so that $e_2(t) \rightarrow 0$, $e_3(t) \rightarrow 0$ as $t \rightarrow \infty$ but that $e_1(t) \not\rightarrow 0$ ” with “so that $e_1(t) \rightarrow 0$, $e_2(t) \rightarrow 0$, and $e_3(t) \rightarrow 0$ as $t \rightarrow \infty$.”

Chapter 2, page 158, problem 24, part b. Replace “ $K_{\omega I} \neq 0$ ” by “ $K_{\omega I} = 0$ ” and delete the question “How does your answer change if $K_{\omega I} \neq 0$?”.

Chapter 3, page 202. Replace Figure 3.30 with [compare with Figure 3.30(b)]



Chapter 3, page 203. Replace Figure 3.32 with [compare with Figure 3.32(b)]



Chapter 3, page 204, 12th line from the bottom. Replace “[see Figures 3.21 and 3.23]” with “(see Figures 3.21 and 3.23)”

Chapter 3, page 213, 2nd line. Put a “.” at the end of the equation.

Chapter 3, page 213, 9th line. Replace the “.” with a “,”.

Chapter 3, problem 9, page 231. Replace

$$-\frac{d}{dt}\lambda_1 = -\frac{d}{dt}N_1\phi = v_1$$

with

$$v_1 - \frac{d}{dt}\lambda_1 = v_1 - \frac{d}{dt}N_1\phi = 0$$

Chapter 3, problem 11, page 232. Replace the problem statement with the following:
 Problem 11 *Magnetic Force*

Consider the electromagnetic crane drawn in Figure 1. Figure 1(a) shows a movable piece a distance x below the electromagnet. The current in the wire magnetizes the iron core it is wrapped about to produce a magnetic field which crosses the air gaps to magnetize the movable piece which in turn attracts it to the electromagnet. The iron has permeability $\mu_r \gg 1$, the cross-sectional area is $S = \ell_1\ell_2$, the number of turns of the coil is N , the path length of the closed curve C in Figure 1(a) is $\ell + 2x$ and ℓ in Figure 1(b). It is assumed that B and H are both constant in the iron and (a different) constant in the air gap, and that these fields are contained within the iron and air gaps. Compute the force of the electromagnet on the moveable piece by doing the following:

(a) Use Ampère's law to compute the magnetic field B in the core (which is equal to the magnetic field strength in the air gap for small x) as a function of the current i in the winding.

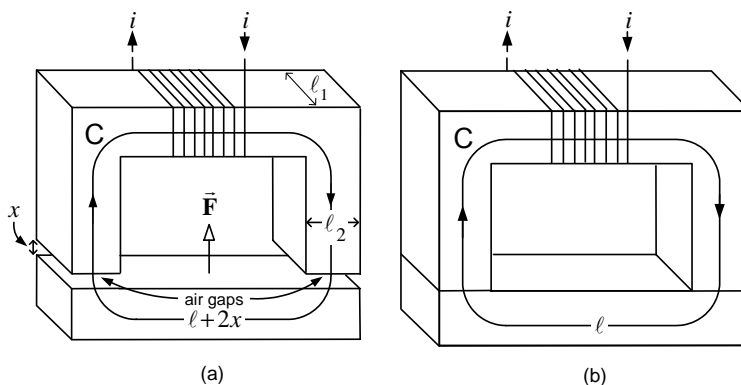


Figure 1: Electromagnet exerting a force on a rectangular-shaped iron block.

(b) Use the answer of part (a) to show that the flux linkage of the winding is

$$\lambda = N\phi = NBS = L(x)i = \frac{NS\mu_0}{(\ell/\mu_r + 2x)}i$$

where

$$L(x) \triangleq \frac{NS\mu_0}{(\ell/\mu_r + 2x)}.$$

(c) With x held constant, show that the energy W required to bring the current from 0 to i is

$$W(x, i) = \int_0^i i(t) \frac{d\lambda(t)}{dt} dt = \int_0^i id\lambda = \frac{1}{2}L(x)i^2.$$

Show that this can be rewritten in terms of x and λ as

$$W(x, \lambda) = \frac{1}{2} \frac{\lambda^2}{L(x)}.$$

This energy from the source is stored as magnetic energy in the iron core and the air gaps.

(d) With v the source voltage and R the winding resistance, let $e \triangleq v - Ri$. Explain why

$$e = -\frac{d\lambda}{dt} \quad (1)$$

$$ei + \frac{dW(x, \lambda)}{dt} + F \frac{dx}{dt} = 0, \quad (2)$$

where F is the magnetic force on the moveable bar.

(e) Substitute $e = -d\lambda/dt$ and $\frac{d}{dt}W(x, \lambda) = \frac{\partial W(x, \lambda)}{\partial \lambda} \frac{d\lambda}{dt} + \frac{\partial W(x, \lambda)}{\partial x} \frac{dx}{dt}$ into (2) to show that

$$\begin{aligned} i &= \frac{\partial W(x, \lambda)}{\partial \lambda} \left(= \frac{\lambda}{L(x)} \right) \\ F &= -\frac{\partial W(x, \lambda)}{\partial x} \left(= \frac{1}{2} \frac{\lambda^2}{L^2(x)} \frac{\partial L(x)}{\partial x} \right). \end{aligned}$$

(f) Define the co-energy to be

$$W_{co-energy}(x, i) \triangleq \lambda i - W(x, \lambda). \quad (3)$$

Use the chain rule to differentiate both sides of (3) with respect to t along with the substitution $i = \partial W(x, \lambda)/\partial \lambda$ to show that

$$\begin{aligned} \frac{\partial W_{co-energy}(x, i)}{\partial x} &= -\frac{\partial W(x, \lambda)}{\partial x} = F \\ \frac{\partial W_{co-energy}(x, i)}{\partial i} &= \lambda. \end{aligned}$$

(g) Show that in this example, where the flux linkage $\lambda = L(x)i$ is linear in the current, the co-energy equals the magnetic energy; that is,

$$W_{co-energy}(x, i) = W(x, \lambda).$$

Chapter 4, Page 265. 4th line from the bottom. Change “Section 4.6” to “Section 4.7”.

Chapter 4, Page 269. In the footnote, change “modeleded” to “modeled”.

Chapter 4, Page 271. Replace “must satisfy (9.75) in order for” by “must satisfy (4.16) in order for”.

Chapter 4, Problem 1(b). Change the statement of part (b) to

Applying Ampère's law to the path $1-2-3-4-1$ in Figure 23(a) (along with a symmetry argument that $H_2 = -H_1$) to show that $H_1 = i/(2g)$.

Chapter 5, page 323

Line 13 from the bottom, replace

$$\oint_S (\nabla \times \vec{\mathbf{E}}) \cdot d\vec{\mathbf{S}}$$

with

$$\int_S (\nabla \times \vec{\mathbf{E}}) \cdot d\vec{\mathbf{S}}.$$

Line 12 from the bottom, replace

$$\oint_S \left(-\frac{\partial \vec{\mathbf{B}}}{\partial t} \right) \cdot d\vec{\mathbf{S}}$$

with

$$\int_S \left(-\frac{\partial \vec{\mathbf{B}}}{\partial t} \right) \cdot d\vec{\mathbf{S}}.$$

Line 10 from the bottom, replace

$$\oint_C \vec{\mathbf{E}} \cdot d\vec{\ell} = \oint_S (\nabla \times \vec{\mathbf{E}}) \cdot d\vec{\mathbf{S}}$$

with

$$\oint_C \vec{\mathbf{E}} \cdot d\vec{\ell} = \int_S (\nabla \times \vec{\mathbf{E}}) \cdot d\vec{\mathbf{S}}.$$

Line 6 from the bottom, replace

$$\oint_S \left(-\frac{\partial \vec{\mathbf{B}}}{\partial t} \right) \cdot d\vec{\mathbf{S}} = -\frac{\partial}{\partial t} \oint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}}$$

with

$$\int_S \left(-\frac{\partial \vec{\mathbf{B}}}{\partial t} \right) \cdot d\vec{\mathbf{S}} = -\frac{\partial}{\partial t} \int_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}}.$$

Replace equation (5.41) with

$$\begin{aligned} \oint_C (\vec{\mathbf{E}} + \vec{\mathbf{v}} \times \vec{\mathbf{B}}) \cdot d\vec{\ell} &= -\frac{\partial}{\partial t} \int_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}} + \oint_C (\vec{\mathbf{v}} \times \vec{\mathbf{B}}) \cdot d\vec{\ell} \\ &= -\frac{\partial}{\partial t} \int_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}} - \oint_C \vec{\mathbf{B}} \cdot (\vec{\mathbf{v}} \times d\vec{\ell}). \end{aligned}$$

Chapter 5, page 325

In line 9 from the top, replace

$$\oint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}}$$

with

$$\int_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}}$$

In line 12 insert a $d\ell$ in the integrand on the rhs so it reads

$$\int_{\theta-\pi}^{\theta} \int_0^{\ell_1} B_r(r_R, \theta', t) (\ell_2/2) d\ell d\theta'.$$

In line 13 from the top, replace

$$\frac{\partial}{\partial t} \oint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}}$$

with

$$\frac{\partial}{\partial t} \int_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}}.$$

In line 6 from the *bottom*, replace

$$\frac{\partial}{\partial t} \oint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}}$$

with

$$\frac{\partial}{\partial t} \int_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}}.$$

In line 3 from the *bottom*, replace

$$-\frac{\partial}{\partial t} \oint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}}$$

with

$$-\frac{\partial}{\partial t} \int_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{S}}.$$

Chapter 5, last line, page 330

Put a minus sign ($-$) in front of i_{Rb} so that the last line now reads

$$\vec{\tau}'_{Rb} = -i_{Rb} \frac{\mu_0 \ell_1 \ell_2 N_S I_S}{2g} \cos(\omega'_R t) \hat{\mathbf{z}} = -i_{Rb} \frac{\mu_0 \ell_1 \ell_2 N_S I_S}{2g} \cos((\omega_S - \omega_R)t) \hat{\mathbf{z}}.$$

Chapter 5, problem 12, part (f), page 356.

Delete the two sentences “Neglecting the inductance, compute the current as $i_b = \xi_{\text{bar}}/R$ where R is the resistance of the bar. What is the net force on the bar in this coordinate system?”

Chapter 5, problem 15, page 357. Replace the statement of problem 15 with the following:

Problem 15 *Stator Electric Field*

In the derivation of the stator electric field $\vec{\mathbf{E}}_S(\theta, t)$ in the air gap due to the rotating stator magnetic field, the “constant of integration” was set to zero so that $\vec{\mathbf{E}}_S(\theta, t)$ is given by equation (5.23)

$$\vec{\mathbf{E}}_S(\theta, t) = E_{Sz}(\theta, t)\hat{\mathbf{z}} = \frac{\mu_0\ell_2 N_S I_S}{4g} \omega_S \cos(\theta - \omega_S t)\hat{\mathbf{z}}.$$

Note that $\vec{\mathbf{E}}_S(\theta, t)$ is a maximum at $\theta = \omega_S t$, a minimum at $\theta = \omega_S t + \pi$ and zero at $\theta = \omega_S t \pm \pi/2$. Similarly, the stator magnetic field

$$\vec{\mathbf{B}}_S(r, \theta, t) = \frac{\mu_0\ell_2 N_S I_S}{4gr} \cos(\theta - \omega_S t)\hat{\mathbf{r}}$$

is a maximum at $\theta = \omega_S t$, a minimum at $\theta = \omega_S t + \pi$ and zero at $\theta = \omega_S t \pm \pi/2$.

(a) Consider a locked rotor with one side of a loop at some fixed angle θ_0 . Show that the induced emf in a rotor loop is zero at those times t when $\theta_0 = \omega_S t + (2n + 1)\pi/2$ (the other side of the loop is located at $\theta_0 = \omega_S t - (2n + 1)\pi/2$). This is when the flux through the loop is at a maximum or a minimum [see Figure 5.15].

(b) With the rotor locked, the induced emf in the loop is also given by

$$\xi_{Ra} = V_{Ra} \triangleq \oint_{\text{rotor loop } a} \vec{\mathbf{E}}_S \cdot d\vec{\ell}.$$

Use this to explain why the stator electric field $\vec{\mathbf{E}}_S(\theta_0, t)$ must be zero for $\theta_0 = \omega_S t + (2n + 1)\pi/2$, or equivalently, why must the “constant of integration” be zero (see Figure 5.15).

Chapter 5, problem 17, page 358.

In part (c), replace “magnetic force” with “Lorentz force” and replace “ $\vec{\mathbf{v}}'_{Ra} \times \vec{\mathbf{B}}'_S$ ” with “ $\vec{\mathbf{E}}'_S + \vec{\mathbf{v}}'_{Ra} \times \vec{\mathbf{B}}'_S$ ”.

Interchange parts (d) and (e). That is, part (e) should be answered before part (d).

Chapter 5, problem 19, page 360. Replace the problem statement with the following:

Problem 19 *Synchronous Machine in the Rotor Coordinate System*

Consider a synchronous motor with a sinusoidally wound rotor in steady-state so $i_F = I_F = \text{constant}$, $i_{Sa} = I_S \cos(\omega_S t)$, $i_{Sb} = I_S \sin(\omega_S t)$, $\omega_R = \omega_S$, $\theta_S = \omega_S t$, and $\theta_R = \omega_R t - \delta$. Consider a coordinate system attached to the rotor so that it is rotating at synchronous speed; that is, it rotates at the angular speed $\omega_R = \omega_S$ with respect to the stator. Further, let the coordinate system be aligned with the stator magnetic axis so that in cylindrical coordinates,

$$\begin{aligned} r' &= r \\ \theta' &= \theta - \omega_R t \quad (\implies \theta'_S = 0, \theta'_R = -\delta) \\ z' &= z \end{aligned}$$

where (r, θ, z) are the cylindrical coordinates in the stationary coordinate system of the stator and (r', θ', z') are the cylindrical coordinates in the rotating coordinate system of the rotor. This *rotor* coordinate system is referred to as the primed ($'$) coordinate system. *In this coordinate system*, do the following:

(a) Compute the electric field $\vec{\mathbf{E}}'_S$ and the magnetic fields $\vec{\mathbf{B}}'_S$ in rotor coordinate system from the electric and magnetic fields $\vec{\mathbf{E}}_S, \vec{\mathbf{B}}_S$ in the stationary coordinate system.

(b) Compute the electric field $\vec{\mathbf{E}}'_R$ and the magnetic field $\vec{\mathbf{B}}'_R$ in the rotor coordinate system from the electric and magnetic fields $\vec{\mathbf{E}}_R, \vec{\mathbf{B}}_R$ in the stationary coordinate system.

(c) Find the velocity $\vec{\mathbf{v}}'_F$ of the charge carriers on the axial sides of the (field) rotor windings (note that in this coordinate system $\omega'_R = 0$).

(d) Find the magnetic force per unit charge $\vec{\mathbf{v}}'_F \times \vec{\mathbf{B}}'_S$ on the charge carriers in the axial sides of the rotor.

(e) Compute the torque τ_R on the rotor loop.

(f) Compute the back emf ξ'_{Sa} induced in stator phase a by computing the rate of change of the flux due to $\vec{\mathbf{B}}'_R$ in that phase. Similarly, compute ξ'_{Sb} in stator phase b .

(g) Find the velocity $\vec{\mathbf{v}}'_{Sa}$ of the charge carriers on the axial sides of the stator phase a . Note that the stator windings are rotating with angular speed $-\omega_R$ with respect to the rotor. Similarly, find $\vec{\mathbf{v}}'_{Sb}$.

(h) Show that the back emf in stator phase a can also be computed as

$$\xi'_{Sa} = \oint_{\text{stator loops}} \left(\vec{\mathbf{E}}'_R + \vec{\mathbf{v}}'_{Sa} \times \vec{\mathbf{B}}'_R \right) \cdot d\vec{\ell}$$

Similarly, find ξ'_{Sb} .

(i) Compute the rotor emf $V_F = \oint_{\text{rotor loops}} \left(\vec{\mathbf{E}}'_S + \vec{\mathbf{v}}'_F \times \vec{\mathbf{B}}'_S \right) \cdot d\vec{\ell}$

in the rotor loops produced by the stator fields $\vec{\mathbf{E}}'_S$ and $\vec{\mathbf{B}}'_S$.

(j) Using the $\hat{\theta}$ component of $\vec{\mathbf{v}}'_{Sa} \times \vec{\mathbf{B}}'_R$, compute the torque τ_{Sa} exerted on the stator by the rotor. Similarly, compute τ_{Sb} . Is $\tau_R = -\tau_S$ where $\tau_S = \tau_{Sa} + \tau_{Sb}$?

(k) In this coordinate system, $\omega'_R = 0$ so that no mechanical power is being given to the rotor. Show that conservation of energy holds in this coordinate system, i.e., $i_{Sa}\xi'_{Sa} + i_{Sb}\xi'_{Sb} + \tau_S\omega'_S = 0$ where $\omega'_S = -\omega_S$.

Chapter 6, page 383, 14th line from the bottom. Replace “slides” with “sides”.

Chapter 7, page 413, first paragraph. In the last sentence of the first paragraph, remove “is presented”.

Chapter 7, page 416, last line, change

$$i_{S1} + i_{S2} + i_{S2} \equiv 0 \text{ and } i_{R1} + i_{R2} + i_{R2} \equiv 0.$$

to

$$i_{S1} + i_{S2} + i_{S3} \equiv 0 \text{ and } i_{R1} + i_{R2} + i_{R3} \equiv 0.$$

Chapter 7, p. 448, Figure 7.16. Replace τ_r/τ_p by τ_p/τ_r .

Chapter 7, p. 449, Figure 7.17. Replace τ_r/τ_p by τ_p/τ_r .

Chapter 7, page 454, second line. Change “for the stator and rotor currents of a *wye connected* three-phase motor become” to “for the stator currents of a *wye connected* three-phase PM synchronous motor become”.

Chapter 7, page 456

Equation (7.81), line 1, replace " $-K_m\omega_R \sin(\theta_R)$ " with " $+K_m\omega_R \sin(\theta_R)$ "

Equation (7.81), line 2, replace " $+K_m\omega_R \sin(\theta_R)$ " with " $-K_m\omega_R \sin(\theta_R)$ "

Chapter 7, page 463, 8th line from the bottom. Replace

$$V_{\max} e^{-j((i-1)\Delta\theta)}$$

by

$$V_{\max} e^{-j(\pi/4+(i-1)\Delta\theta)}$$

Chapter 7, page 464, 4th line from the bottom. Replace

$$V_{\max} e^{-j((i-1)\Delta\theta)}$$

by

$$V_{\max} e^{-j(\pi/3+(i-1)\Delta\theta)}$$

Chapter 7, page 489, problem 25. Replace

$$\tau = \frac{3}{2}(1 - \sigma)I_S^2 \frac{2}{s_p/S + S/s_p}$$

with

$$\tau = \frac{3}{2}(1 - \sigma)L_S I_S^2 \frac{2}{s_p/S + S/s_p}$$

Chapter 8, page 542, lines 11, 12, and 14 from the bottom. Replace “(8.86)” with “(8.85)”.

Chapter 8, page 582, last sentence of the first paragraph. Change “is explored in the next two problems” to “is explored in the next three problems”.

Chapter 8, problem 28, page 583. On line 15, change

$$b_{12} = -2\mu x_2 x_3, b_{21} = 0$$

to

$$b_{12} = 0, b_{21} = -2\mu x_2 x_3$$

Chapter 8, problem 29, page 585. On the 7th line from the bottom of page 585, remove “results in two decoupled second order systems as in the d-axis case.”

Chapter 8, problem 30, page 589. On line 10, change

$$\underline{\lambda}_R = \underline{\varphi}_2(y, \dot{y}, \ddot{y}, \ddot{y})$$

to

$$\underline{\lambda}_S = \underline{\varphi}_2(y, \dot{y}, \ddot{y}, \ddot{y})$$

Chapter 9, page 595. In the remark, change “and (9.21) as the desired quadrature current” to “and (9.22) as the desired quadrature current”

Chapter 9, page 595. In equations (9.31) and (9.32) remove the factor L_S in front of v_d and v_q , respectively.

Chapter 9, page 597. In equation (9.44), left-hand side, change $\frac{de_2}{dt}$ to $\frac{d\varepsilon_2}{dt}$.

Chapter 9, page 609. 7th line from the bottom. Replace “ $V = V_{\max}$ and $V = V_{\max}, I = I_{\max}$ ” with “ $I = I_{\max}$ and $V = V_{\max}, I = I_{\max}$ ”

Chapter 9, page 609. 5th line from the bottom. Replace “ $I = I_{\max}$ and $V = V_{\max}, I = I_{\max}$ ” with “ $V = V_{\max}$ and $V = V_{\max}, I = I_{\max}$ ”

Chapter 9, page 612. 10th line. Replace “ $V = V_{\max}$ and $V = V_{\max}, I = I_{\max}$ ” with “ $I = I_{\max}$ and $V = V_{\max}, I = I_{\max}$ ”

Chapter 9, page 612. 13th line from the bottom. Replace “ $I = I_{\max}$ and $V = V_{\max}, I = I_{\max}$ ” with “ $V = V_{\max}$ and $V = V_{\max}, I = I_{\max}$ ”

Chapter 9, page 612. Replace equation (9.82) with

$$(K_m^2 + (n_p L_S I_{max})^2) \omega_1^2 + 2R_S K_m I_{max} \omega_1 + R_S I_{max}^2 = V_{max}^2.$$

Chapter 9, page 624. On the left-hand side of equation (9.103), replace “ K ” with “ J ”.

Chapter 9, page 637, Figure 9.35(d). In the figure, replace the “N” with “S” twice and also replace the “S” with “N”.

Chapter 9, problem 11, page 649. In the 8th line, replace “ $-n_p\omega L_q i_q$ ” by “ $+n_p\omega L_q i_q$ ”.

Chapter 10, page 684, problem 1. Change

$$+e_p \begin{bmatrix} e(\theta_R) \\ e(\theta_R - 2\pi/3) \\ e(\theta_R - 4\pi/3) \end{bmatrix} \omega_R$$

to

$$-e_p \begin{bmatrix} e(\theta_R) \\ e(\theta_R - 2\pi/3) \\ e(\theta_R - 4\pi/3) \end{bmatrix} \omega_R$$

Chapter 10, page 684, problem 2. Define

$$\Lambda \triangleq \begin{bmatrix} L_S & -M & -M \\ -M & L_S & -M \\ -M & -M & L_S \end{bmatrix}.$$

References, page 695, reference [63]. Replace “2003” with “2002”.