%% Mini Project for Advanced Electrical Drives Documentation

Mini Project: Advanced Electrical Drives

Overview

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1. Machine Parameters

```
Psi_f = 90e-3;     % Field flux linkage [Vs]
L_sd = 200e-6;     % d-axis inductance [H]
L_sq = 500e-6;     % q-axis inductance [H]
i_max = 500;       % Maximum stator current [A]
U_dc = 350;        % DC link voltage [V]
u_smax = U_dc/sqrt(3);  % Maximum stator voltage [V]
p = 4;             % Number of pole pairs
```

1.1 Calculated Parameters

```
i_sc = Psi_f / L_sd;          % Short-circuit current [A]
kappa = i_sc / i_max;         % Normalized short-circuit current
chi = (L_sq - L_sd) / (2*L_sd);  % Saliency
```

Derived quantities:

$i_{sc} = \frac{\Psi_f}{L_{sd}}, \quad \kappa = \frac{i_{sc}}{i_{max}}, \quad \chi = \frac{L_{sq}-L_{sd}}{2L_{sd}}$

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2. Key Equations

2.1 Torque and Current Relations

Electromagnetic torque:

$T_e = \frac{3}{2}p\left(\Psi_f i_{sq} + (L_{sd} - L_{sq}) i_{sd} i_{sq}\right)$

MTPA current calculation:

$i_{sd}^{MTPA} = \frac{\frac{2}{3}T_e - \Psi_f i_{sq}}{i_{sq}(L_{sd}-L_{sq})}, \quad i_{sq}^{MTPA} = \text{roots of } (L_{sd}-L_{sq})^2 i_{sq}^4 + \frac{2}{3}T_e\Psi_f i_{sq} - \left(\frac{2}{3}T_e\right)^2 = 0$

2.2 Field Weakening Constraints (Constant Torque Locus)

$$(i_{sd}+i_{sc})^2+[i_{sq}(2\chi+1)]^2=\left(\frac{u_{smax}}{\omega_s L_{sd}}\right)^2$$

2.3 Maximum Current Ellipse (MA Circle)

$$\sqrt{i_{sd}^2+i_{sq}^2}=i_{max}$$

2.4 MTPF Trajectory

$$i_{sd}=\left[-\kappa+\frac{(1+2\chi)\kappa}{8\chi}-\sqrt{\frac{1}{2}\left(\frac{u_{smax}}{\omega_s L_{sd} i_{max}}\right)^2+\left(\frac{(1+2\chi)\kappa}{8\chi}\right)^2}\right]i_{max}$$

2.5 Maximum Torque Calculation

$$\begin{cases}\sqrt{i_{sd}^2+i_{sq}^2}=i_{max}\\ i_{sd}=\left(\frac{\kappa}{8\chi}-\sqrt{\frac{(\sqrt{i_{sd}^2+i_{sq}^2}/i_{max})^2}{2}+(\kappa/(8\chi))^2}\right)i_{max}\\ i_{sq}\geq 0\end{cases}$$

$$T_e^{max}=\frac{3}{2}\left(\Psi_f i_{sq}+(L_{sd}-L_{sq})i_{sd}i_{sq}\right)$$

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3. Speed-Torque Relationships

$\omega_A=$ max speed at base current, $\omega_B=$ max speed on constant torque line, $\omega_C=$ speed where MTPF line begins, $\omega_{MA}^{max}=$ maximum speed on MA circle

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4. Workflow Based on Kappa (κ)

Case 1: κ ≥ 1 (High Short-Circuit)

```
if kappa >= 1
    [i_sd_ref, i_sq_ref] = calc_reference_currents(T_e_ref, omega_s_ref, kappa);
    draw_contours;
    plot_current_trajectory(T_e_ref, omega_s_ref);
    plot_torque_over_speed_map(T_e_ref, omega_s_ref);
end
```

Case 2: κ < 1 (Low Short-Circuit)

```
if kappa < 1
    i_max = 400;  % Adjusted max current
    kappa = i_sc / i_max;
    [i_sd_ref, i_sq_ref] = calc_reference_currents(T_e_ref, omega_s_ref, kappa);
    plot_current_trajectory(T_e_ref, omega_s_ref);
    plot_torque_over_speed_map(T_e_ref, omega_s_ref);
end
```

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5. Helper Functions

Reference Current Calculation

```
function [i_sd_ref, i_sq_ref] = calc_reference_currents(T_e_ref, omega_s_ref,
kappa)
    % Determine max torque and dynamic speed thresholds
    T_e_max = calc_maximum_torque(T_e_ref);
    omega_A = get_max_omega_A(T_e_ref);
    omega_B = get_max_omega_B(T_e_ref);

    if kappa < 1
        omega_C = get_max_omega_C(T_e_ref);
    else
        omega_MA_max = get_omega_max(T_e_ref);
    end

    % Select operating region based on kappa and speed thresholds
    if kappa >= 1
        if omega_s_ref >= omega_B && omega_s_ref <= omega_MA_max
            [i_sd_ref, i_sq_ref] = calc_i_s_ref_MA(omega_s_ref);
        elseif omega_s_ref >= omega_A
            [i_sd_ref, i_sq_ref] = calc_i_s_ref_LCT(T_e_ref, omega_s_ref);
        else
            [i_sd_ref, i_sq_ref] = calc_i_ref_MTPA(T_e_ref);
        end
    else
        if omega_s_ref >= omega_C
            [i_sd_ref, i_sq_ref] = calc_i_s_ref_MPTF(omega_s_ref);
        elseif omega_s_ref >= omega_B
            [i_sd_ref, i_sq_ref] = calc_i_s_ref_MA(omega_s_ref);
        elseif omega_s_ref >= omega_A
            [i_sd_ref, i_sq_ref] = calc_i_s_ref_LCT(T_e_ref, omega_s_ref);
        else
```

```
            [i_sd_ref, i_sq_ref] = calc_i_ref_MTPA(T_e_ref);
        end
    end
end
```

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6. Flowchart for Kappa-Based Decision

```
flowchart TD
    A[Torque Request T_e_ref + Speed omega_s_ref] --> B{Check κ}
    B -->|κ ≥ 1| C[Tasks 1.1 & 1.2]
    B -->|κ < 1| D[Task 1.3]
    C --> E[calc_reference_currents() with dynamic ω_A/B/MA_max]
    D --> F[calc_reference_currents() with dynamic ω_A/B/C]
    E --> G[Select operating region based on thresholds (MTPA, LCT, MA)]
    F --> H[Select operating region based on thresholds (MTPA, LCT, MA, MTPF)]
    G --> I[Calculate i_sd_ref, i_sq_ref]
    H --> J[Calculate i_sd_ref, i_sq_ref]
```

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7. Plots for Download

This section includes MATLAB commands to generate torque-speed and current trajectory plots. Once run, figures can be saved as PNG/PDF for submission.

```
figure;
plot_torque_over_speed_map(T_e_ref, omega_s_ref);
title('Torque-Speed Map');
xlabel('Speed [rad/s]'); ylabel('Torque [Nm]');
saveas(gcf, 'TorqueSpeedMap.png');

figure;
plot_current_trajectory(T_e_ref, omega_s_ref);
title('Current Trajectory');
xlabel('i_{sd} [A]'); ylabel('i_{sq} [A]');
saveas(gcf, 'CurrentTrajectory.png');
```