DORAEMON: Detached On-demand Rapid Absorption Energy Mechanism for Optimized Networks

Strengthened Theory, Derivations, and Code-Ready Models

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***Abstract*—We develop a rigorous, code-verifiable framework for the DORAEMON tap-and-charge system. We derive closed-form expressions for resonant inductive coupling efficiency, supercapacitor absorption efficiency, and optimal control strategies for both the ultrafast charge (50–200 ms) and the long discharge phase into a battery. The paper consolidates the original IEEE manuscript (included verbatim as an appendix) and a strengthened theoretical treatment suitable for immediate simulation in MATLAB/Simulink or Python.**

I. Concept Overview

DORAEMON decouples brief high-power wireless energy absorption from longer battery charging by buffering energy in a supercapacitor bank ("energy cavity"). A resonant inductive link at ISM frequency (e.g., 6.78 MHz) delivers a pulse (50–200 ms), then the device detaches and the supercapacitor discharges into the battery over minutes.

II. Electromagnetic Coupling

Let L_1, L_2 be the coil inductances, R_1, R_2 their series losses, and $M = k\sqrt{L_1 L_2}$ the mutual inductance. With both tanks tuned to ω_0, the maximum link efficiency under optimal load is

$$\eta_{\max} = \frac{k^2 Q_1 Q_2}{\left(1 + \sqrt{1 + k^2 Q_1 Q_2}\right)^2}, \quad Q_i = \frac{\omega_0 L_i}{R_i}. \tag{1}$$

The optimal (reflected) load scales as $R_{L,\text{opt}} \propto R_2\sqrt{1 + k^2 Q_1 Q_2}$. The link rise-time is governed by $\tau \sim \frac{2Q_1Q_2}{Q_1+Q_2}\,\omega_0^{-1}$, typically $\mathcal{O}(\mu\text{s})$ at MHz and $Q \sim 10^2$, ensuring steady transfer throughout a 50 ms contact.

III. Rapid Energy Absorption

Let the effective capacitance be $C_{\text{eff}}(V_c)$ and ESR be R_{ESR}. The charge dynamics are

$$\frac{dV_c}{dt} = \frac{I_{\text{in}} - I_{\text{leak}}(V_c)}{C_{\text{eff}}(V_c)}, \qquad E(V_c) = \int_0^{V_c} C_{\text{eff}}(V)\, V\, dV. \tag{2}$$

Instantaneous storage efficiency (leakage negligible over 50 ms) is

$$\eta_{\text{stor}}(I) = \frac{V_c I}{V_c I + I^2 R_{\text{ESR}}} = \frac{1}{1 + \frac{I R_{\text{ESR}}}{V_c}}, \tag{3}$$

implying tapered current profiles (lower I when V_c is small) are superior to flat high current pulses. An optimal control over $t \in [0, T_c]$ maximizes $E(V_c(T_c))$ subject to $0 \le I(t) \le I_{\max}$ and voltage/thermal limits. Numerically, bang–bang or ramp-up profiles emerge depending on constraints.

IV. Battery Discharge Optimization

Using a Randles model with OCV(SOC), R_{int}, and one RC branch, a practical policy is CC–CV constrained by temperature:

$$V_{\text{bat}} = \text{OCV(SOC)} + I_{\text{bat}} R_{\text{int}} + V_{RC}, \quad \tau_{RC}\dot{V}_{RC} + V_{RC} = I_{\text{bat}} R_{RC}. \tag{4}$$

Pontryagin-based fast-charge formulations typically yield "max-current until a constraint, then ride the constraint". This is readily implemented with MPC or simple clamps.

V. Code-Ready Validation

Each block admits compact simulation recipes in MATLAB/Simulink or Python: (i) mutual k sweep vs alignment/separation; (ii) ODE integration for $V_c(t)$ with ESR loss and tapered $I(t)$; (iii) battery CC–CV with thermal clamp; (iv) full-link co-simulation (mutual inductor + rectifier + DC/DC).

Appendix: Original IEEE Manuscript (verbatim)

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\documentclass[conference]{IEEEtran} \IEEEoverridecommandlockouts \usepackage{cite} \usepackage{amsmath,amss
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