HYSTERESIS-BASED CONTROL OF ELECTRICAL LOADS

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INTRODUCTION

❑Different types of electrical loads, e.g. thermostatically controlled loads (TCLs) and plug-in electric vehicles (PEVs) are being considered for the task of generation-balancing (e.g. following fluctuations in wind power)

- ❖Electrical loads offer faster response time than conventional generators
- ❖Fast ramping up/down a generator is expensive and environmentally more damaging

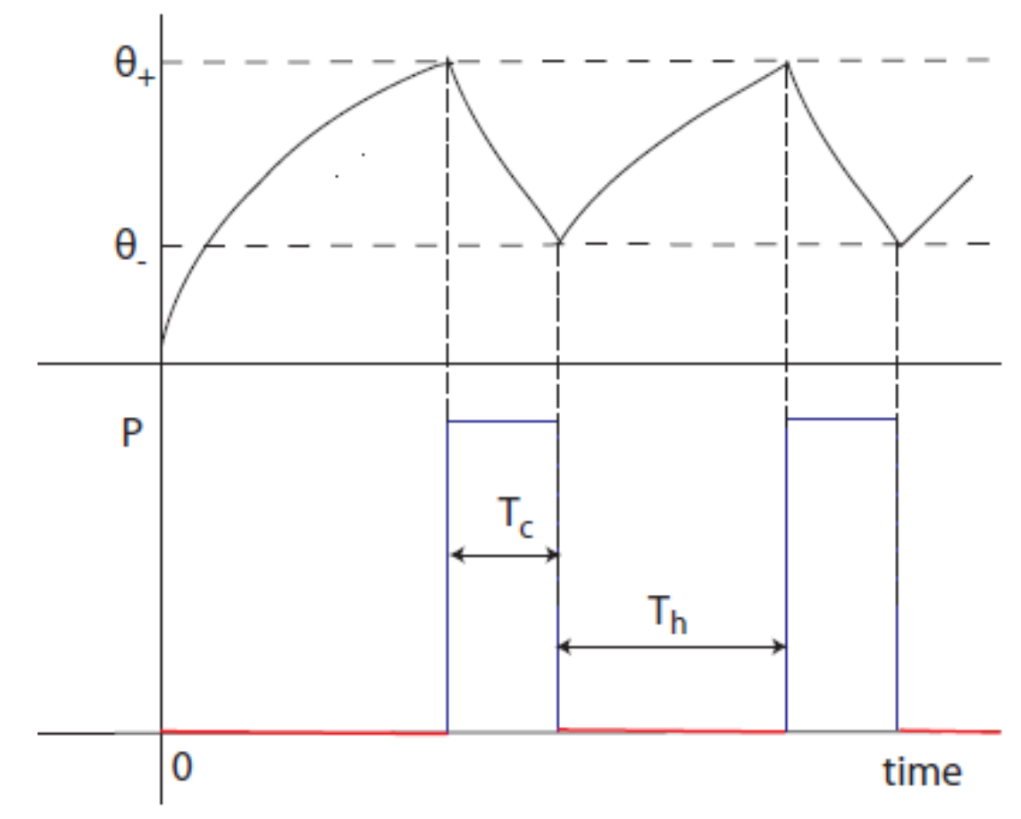
❑One way of approaching this load-control problem is to develop hysteresis-based response model of aggregate power demand of the population of electrical loads and dispatch a centralized control signal to all the participating loads.

❑This poster focuses on such centralized methods

- ❖A detailed hysteresis-based control method is discussed in connection to TCLs and a feedback control law is tested.
- ❖A hysteresis-based for PEV charging scheme is briefly discussed.

TCLs: MECHANISM

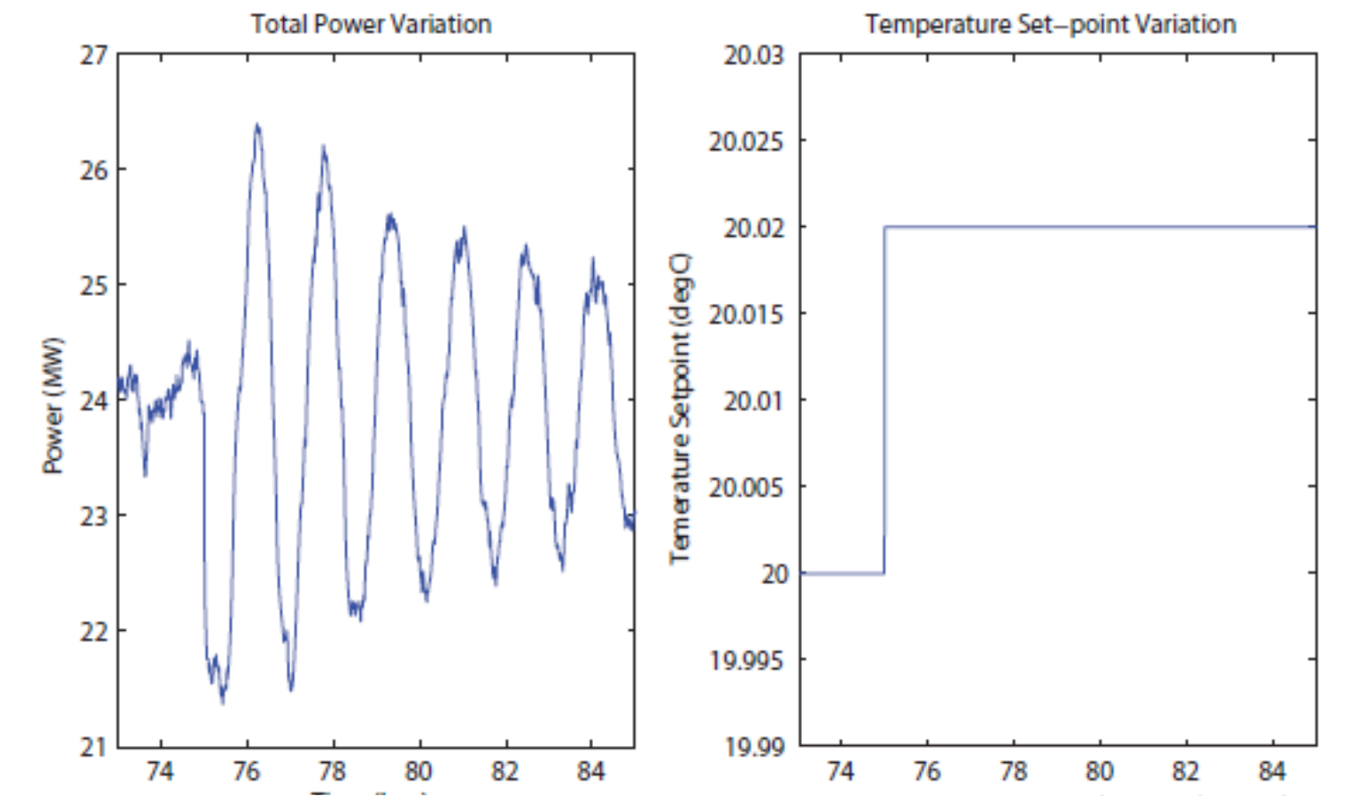
❑Thermal dynamics of a TCL forces its temperature to lie within a hysteresis deadband around the setpoint

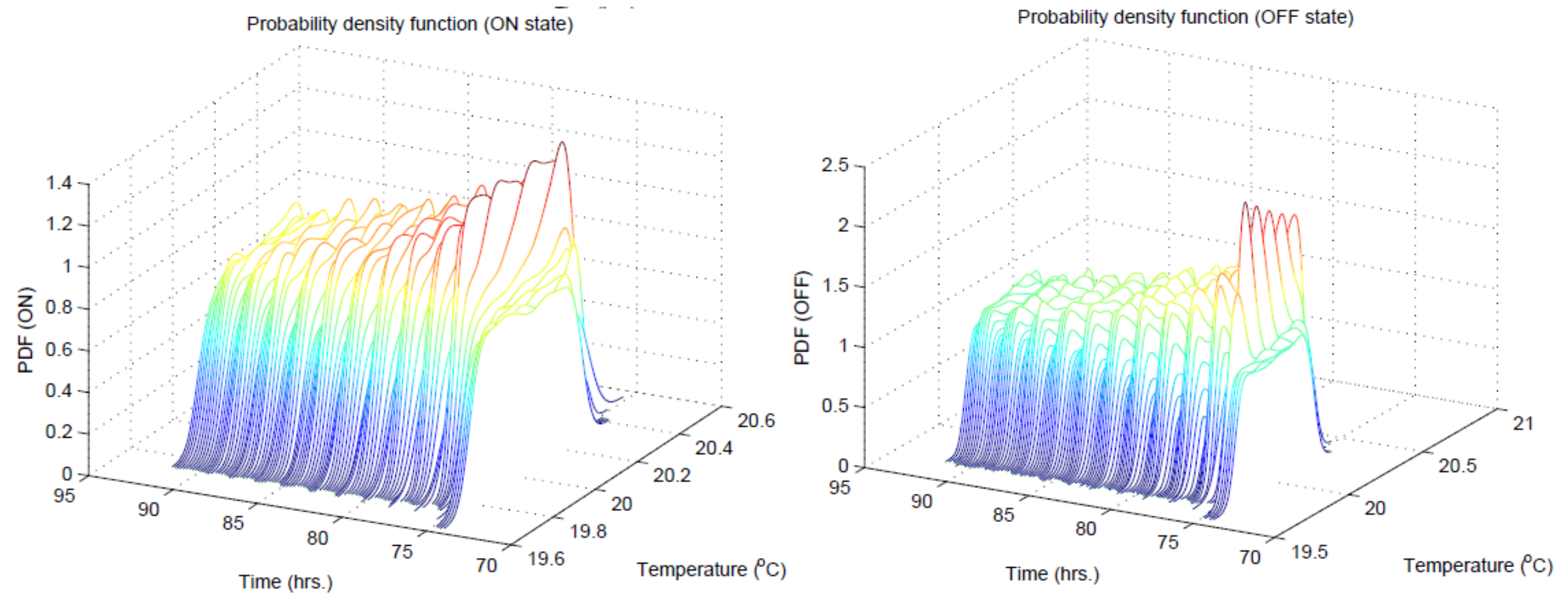


$$\dot{\theta} = \begin{cases} -\frac{1}{CR}\left(\theta - \theta_{amb} + PR\right), & \text{ON state} \\ -\frac{1}{CR}\left(\theta - \theta_{amb}\right), & \text{OFF state} \end{cases}$$

C: thermal capacitance
R: thermal resistance
θ_{amb}: ambient temperature
P: power drawn in ON state

❑The aggregate power demand of a population of TCLs attains a steady state which responds to a "sudden" shift in temperature setpoint by a damped oscillation until reaching a new steady state





TCLs: MODELING AND CONTROL DESIGN

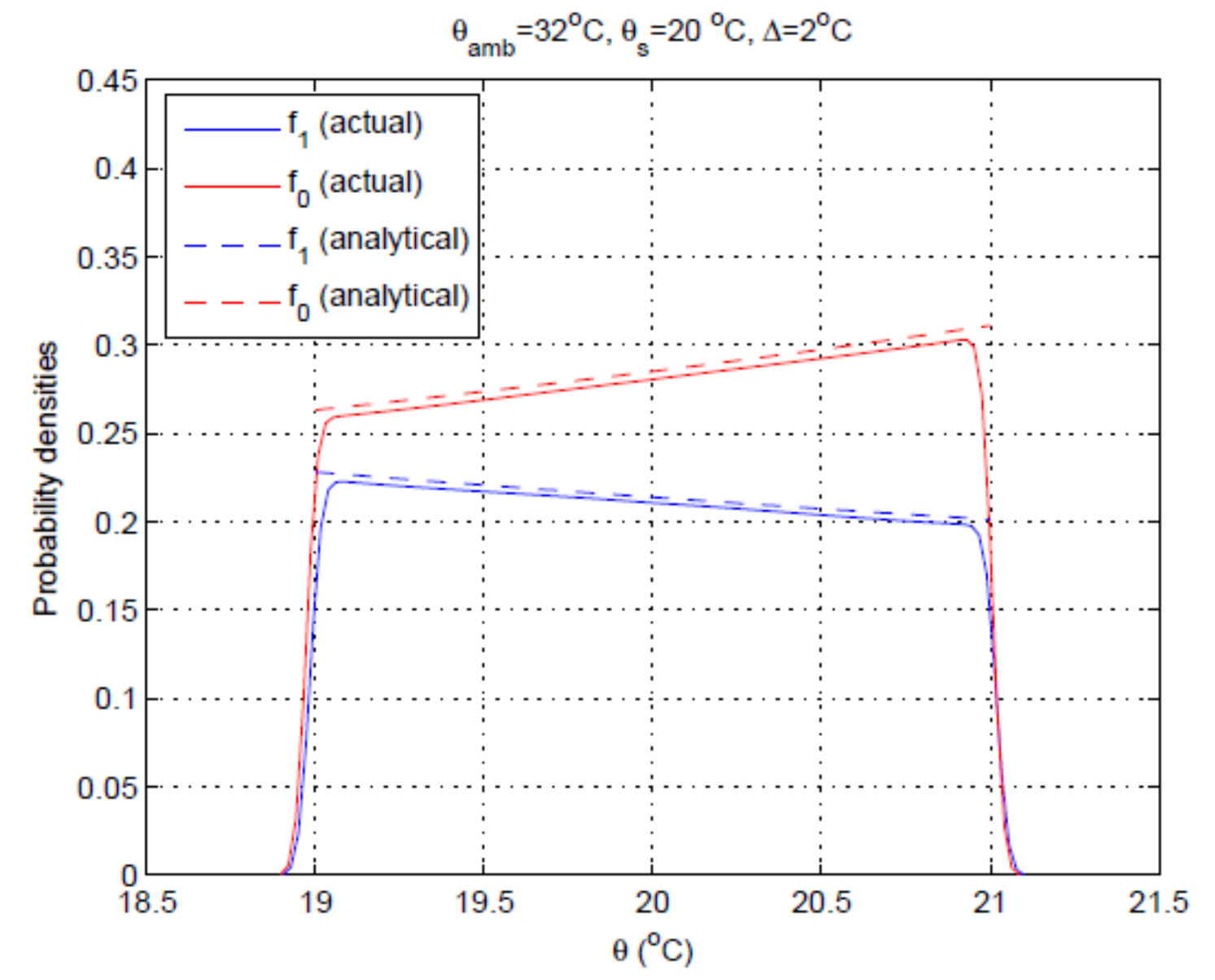
❑Step 1: Estimation of steady state probability densities of ON and OFF state loads as a function of temperature setpoint

$$f_1(\theta) = \frac{CR}{(T_c+T_h)(PR+\theta-\theta_{amb})}, \quad \forall\theta \in [\theta_-, \theta_+]$$

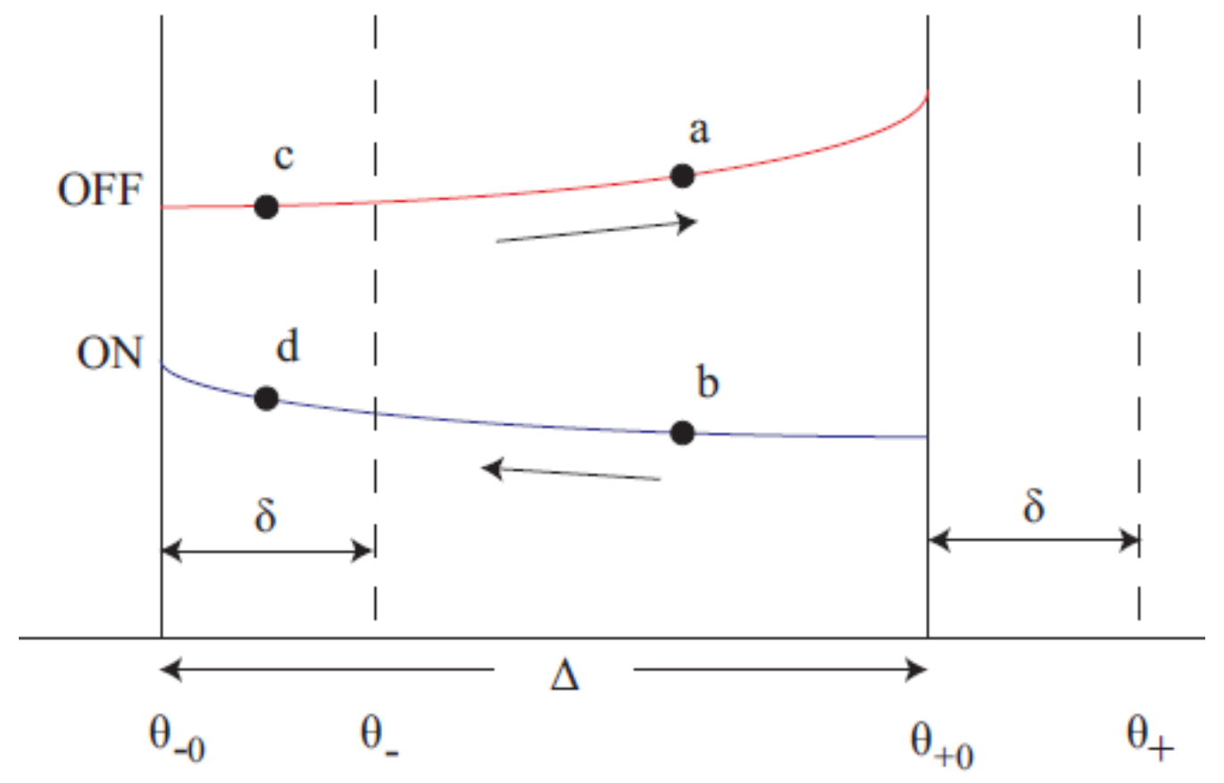
$$f_0(\theta) = \frac{CR}{(T_c+T_h)(\theta_{amb}-\theta)}, \quad \forall\theta \in [\theta_-, \theta_+]$$

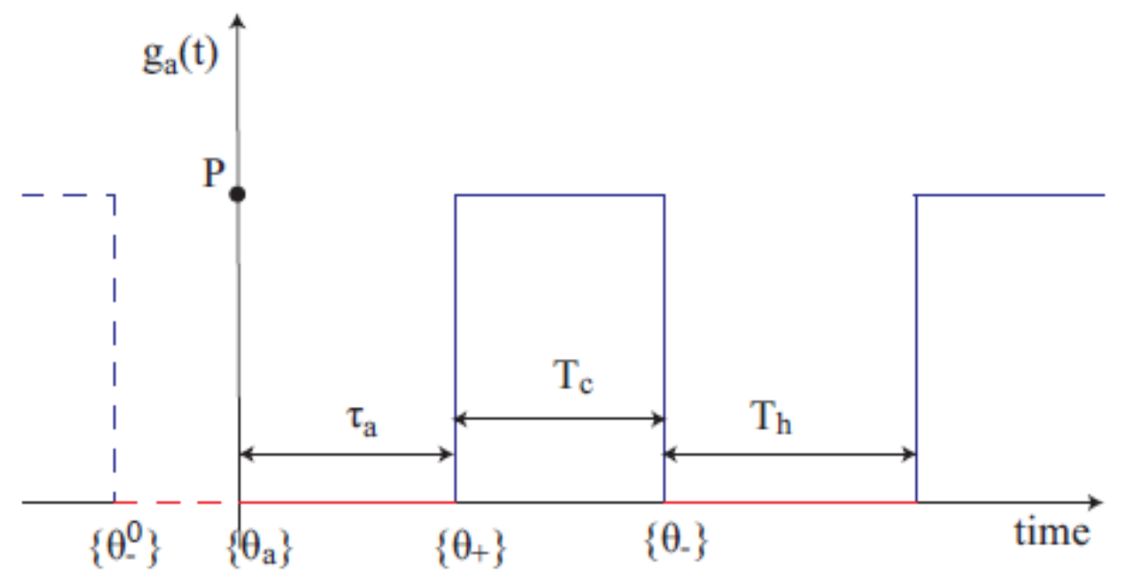
$$T_c = CR\ln\left(\frac{PR+\theta_+-\theta_{amb}}{PR+\theta_--\theta_{amb}}\right)$$

$$T_h = CR\ln\left(\frac{\theta_{amb}-\theta_-}{\theta_{amb}-\theta_+}\right)$$



❑Step 2: Computation of the aggregate response to setpoint shift by probabilistically averaging the typical response of TCLs lying in different regions on the probability density curves.





(a) Power waveform at point a.

$$\mathbf{G}_a(s,\tau_a) = e^{-s\tau_a}\mathbf{G}(s)$$

$$\mathbf{G}(s) = \frac{P(1-e^{-sT_c})}{s(1-e^{-s(T_c+T_h)})}$$

$$\mathbf{P}_a(s) = \int_{\theta_-}^{\theta_+^0} f_0(\theta_a)\mathbf{G}_a(s,\tau_a)d\theta_a$$

$$\mathbf{P}_b(s) = \int_{\theta_-}^{\theta_+^0} f_1(\theta_b)\mathbf{G}_b(s,\tau_b)d\theta_b$$

$$\mathbf{P}_c(s) = \int_{\theta_-^0}^{\theta_-} f_0(\theta_c)\mathbf{G}_c(s,\tau_c)d\theta_c$$

$$\mathbf{P}_d(s) = \int_{\theta_-^0}^{\theta_-} f_1(\theta_d)\mathbf{G}_d(s,\tau_d)d\theta_d$$

$$\boxed{\mathbf{P}_{avg}(s) = \mathbf{P}_a(s) + \mathbf{P}_b(s) + \mathbf{P}_c(s) + \mathbf{P}_d(s)}$$

❑Step 3: Developing linearized state-space model from the step response and design feedback control.

$$\begin{aligned} \dot{x} &= \mathbf{A}x + \mathbf{B}u \\ y &= \mathbf{C}x + \mathbf{D}u \end{aligned} \qquad \mathbf{A} = \begin{bmatrix} -2\sigma & -\omega \\ \frac{\sigma^2+\omega^2}{\omega} & 0 \end{bmatrix}, \qquad \mathbf{B} = \begin{bmatrix} \omega A_\Delta \\ 0 \end{bmatrix}$$

$$\mathbf{C} = \begin{bmatrix} -1 & 0 \end{bmatrix}, \qquad \mathbf{D} = -d.$$

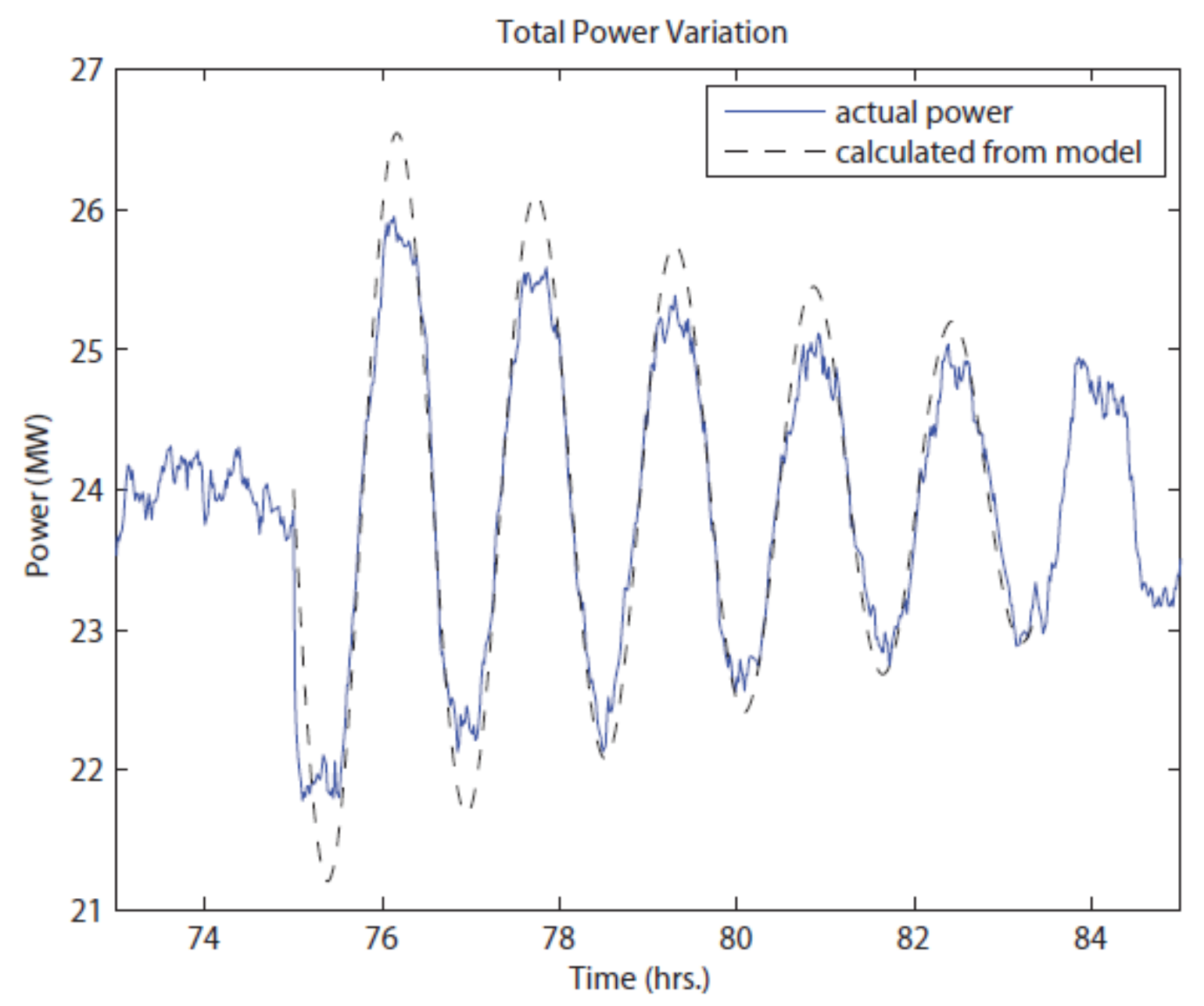
$$\boxed{u = -(\mathbf{K}\,\underline{x} + \mathbf{G}\,y_d)}$$

Minimizing the cost function $J = \int_0^\infty \left(\underline{x}(t)^\top Q\underline{x}(t) + u(t)^2 R\right)dt$

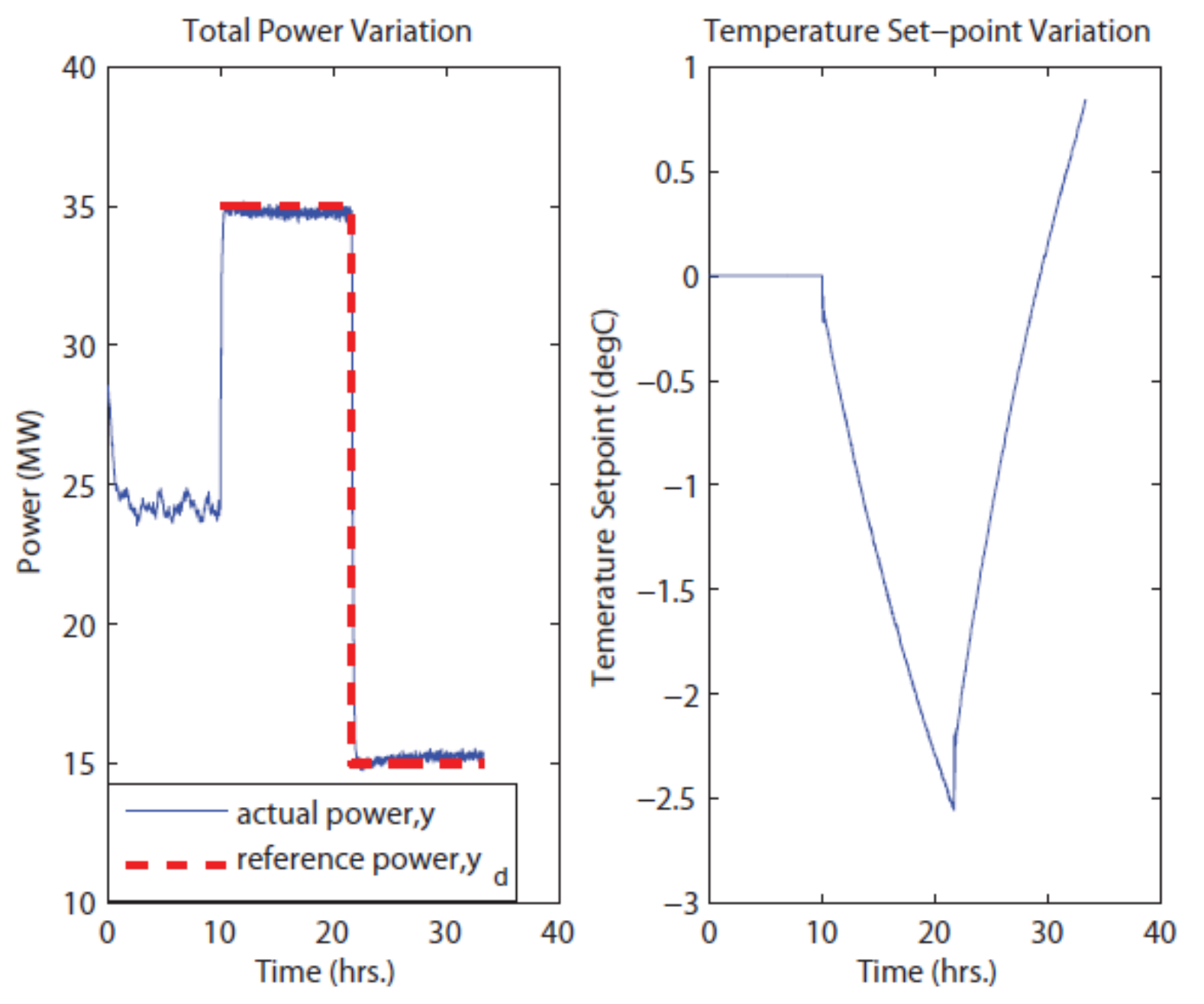
$$A_\Delta = \frac{5\sqrt{15}C(\theta_{amb}-\theta_+)(PR-\theta_{amb}+\theta_+)}{\eta\left(P^2R^2+3PR(\theta_{amb}-\theta_+)-3(\theta_{amb}-\theta_+)^2\right)^{3/2}} \times \frac{(3PR-\theta_{amb}+\theta_+)N}{(T_{c0}+T_{h0})},$$

$$\omega = \frac{2\sqrt{15}(\theta_{amb}-\theta_+)(PR-\theta_{amb}+\theta_+)}{CR\Delta\sqrt{P^2R^2+3PR(\theta_{amb}-\theta_+)-3(\theta_{amb}-\theta_+)^2}},$$

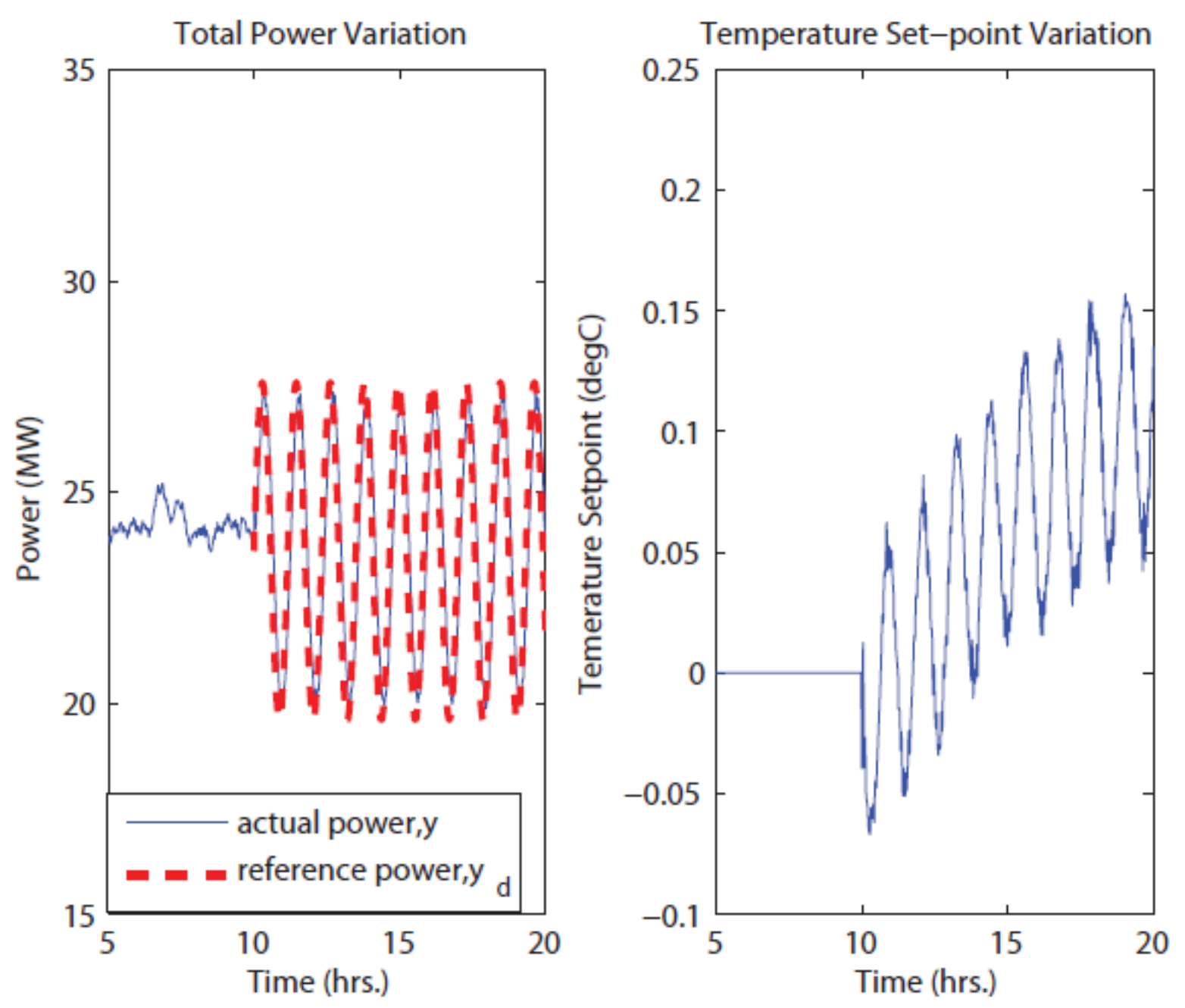
$$d = \frac{N}{\eta R}.$$



RESULTS

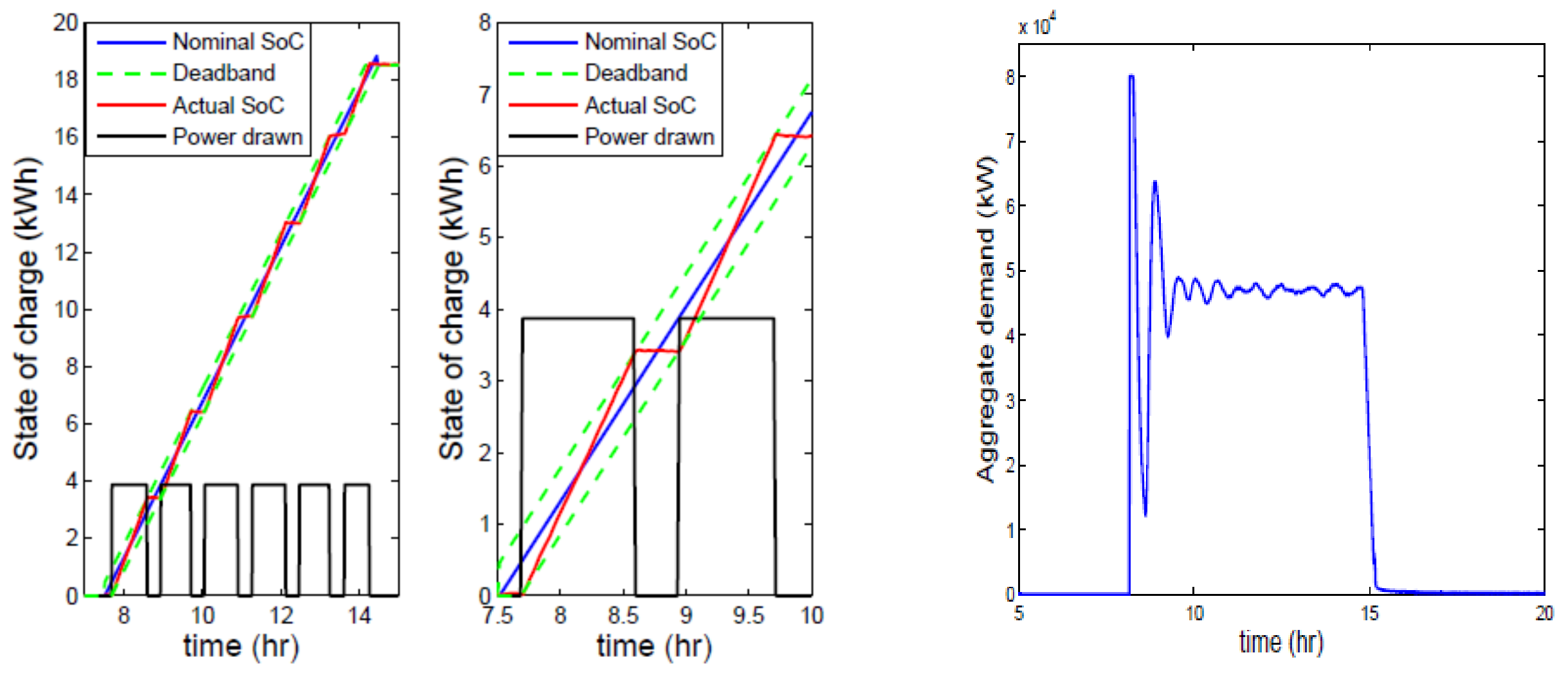


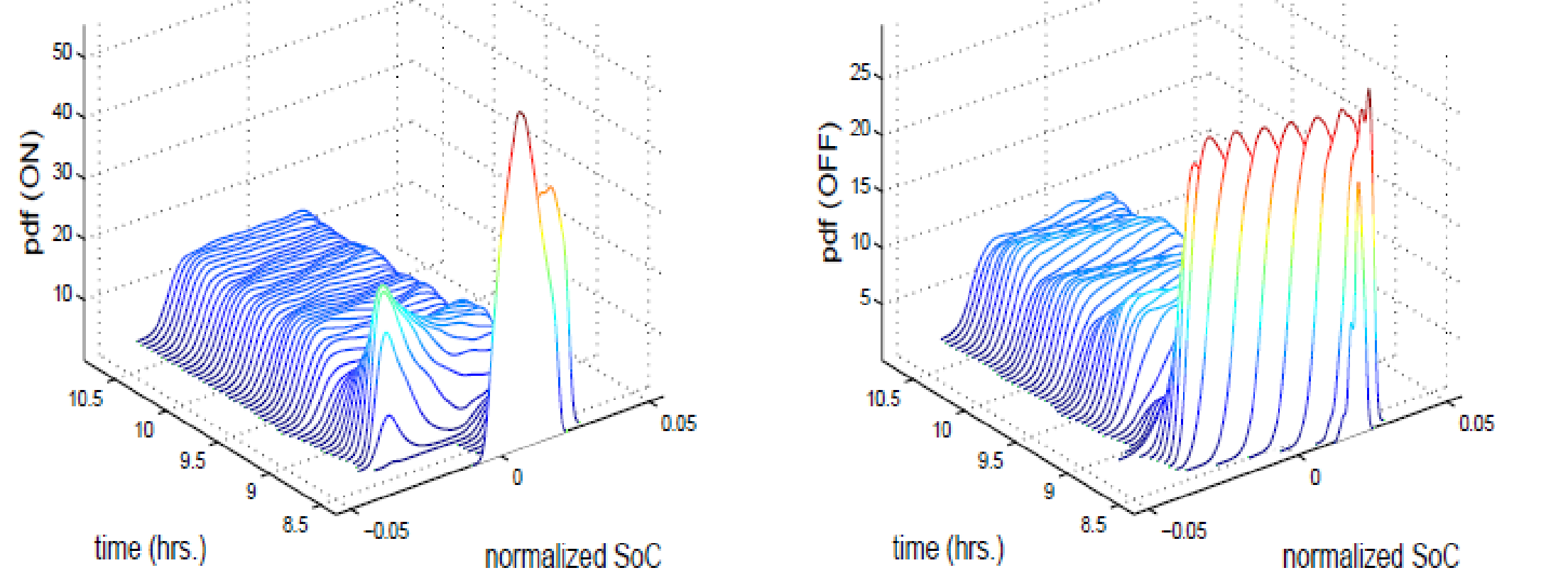
Response to step reference and the control input



Response to sinusoidal reference and the control input

PEVs: ON/OFF CHARGING





CONCLUSIONS

❑A hysteresis-based aggregate model of power demand by TCLs has been developed. It is shown that similar approach can be taken to model a ON/OFF hysteresis-based charging of a PEV fleet.

❑A feedback control law has been designed which forces the aggregate TCL demand to track reference trajectories.

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