Grid Connected Building Load Operation

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Introduction and Motivation

- Building electrical loads display nonlinear interactions with thermostatic setpoints, ambient temperature and electrical bus voltages.
- It is imperative that an adequate representation of this nonlinear behavior be incorporated into load models to effectively control buildings under demand side load management.
- Building load modeling traditionally focuses on electric heating with cycling and aggregate load variations which fail to effectively capture inherent electrical-thermal coupling.
- Standalone software packages such as DOE-2 are primarily used for building design purposes and are not easily integrated into electrical grid studies.
- The present work discusses a model that captures the building electro-thermal and building-grid coupling to improve understanding of grid connected building load operation.

Problem Formulation

- Building loads are primarily controlled through thermostatic temperature setpoint variations and are subject to operating limits determined by the HVAC equipment capacities.
- Load variations correspondingly cause variations in the electrical bus voltages, and hence, form a temperature-load-voltage coupling that constrain the building – grid operation.
- Operating without regard for such behavior could bring about inefficiencies and even have potentially detrimental effects on the power system.
- The following discussion will present a building load model that incorporates the efforts in [1,2,3] to capture the necessary temperature-load-voltage relationships.

Methodology

- The building-grid energy interaction is described through an Energy Hub [2], E2MT, with building controllable and uncontrollable load components (1).
- The thermostatically controllable load portion, primarily the HVAC equipment load, is presented with a corresponding conversion efficiency $\left(P_B^{th}, \eta^{eq}\right)$.

$$P_{in}^{elec} = P_{UC}^{elec} + \frac{1}{\eta^{eq}} P_B^{th} \qquad (1)$$

P_{UC}^{elec} – Building uncontrollable electric load/controllable thermal load

P_B^{th} – Building uncontrollable electric load/controllable thermal load

η^{eq} – Equivalent efficiency of conversion

$$P_{UC}^{elec} = P_0\left[Z_p\left(\frac{|V|}{|V_0|}\right)^2 + I_p\left(\frac{|V|}{|V_0|}\right) + P_p\right] \qquad (2)$$

Z_p, I_p, P_p – ZIP coefficients $(\text{also}, Z_q, I_q, P_q)$

P_0 – Nominal uncontrollable electrical load (kW)

V_0 – Nominal bus voltage (p.u.)

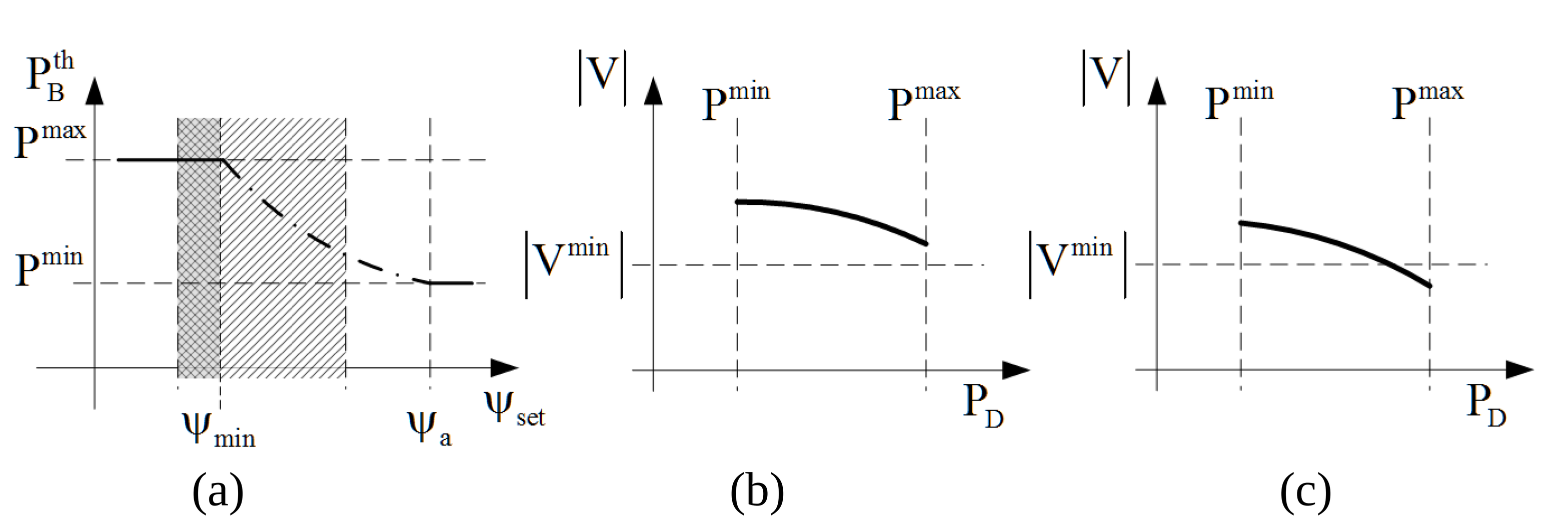

Figure 1: Building – grid limiting operation

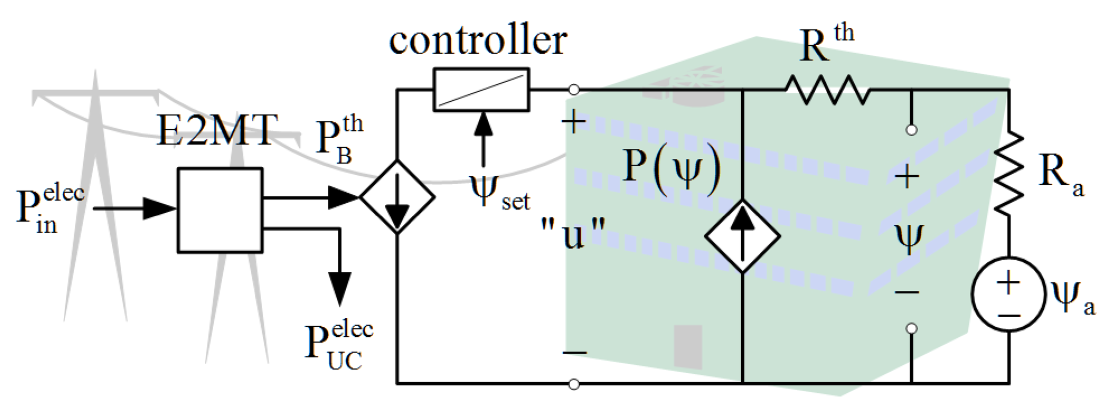

Figure 2: Building steady state circuit model

$$0 = -\left(R^{th} + R_a\right)\psi + R_a u + R^{th}\psi_a \qquad (3a)$$

$$P_B^{th} = P_n^{th}\left(\frac{\psi}{\psi_n}\right)^{\alpha} + \frac{\psi_a - \psi}{R_a} \qquad (3b)$$

ψ – Building internal temperature (°F)

ψ_{set} – Building internal temperature setpoint (°F)

u – Building management system control setpoint (°F)

ψ_a – Ambient temperature (°F)

R^{th} – Building internal thermal resistance (°F/kW)

R_a – Building envelope thermal resistance (°F/kW)

P_B^{th} – Building equivalent thermal load (kW)

P_n^{th} – Nominal controllable thermal load (kW)

ψ_n – Building nominal internal temperature (°F)

α – Building thermal load sensitivity

- The electro-thermal load is subject to P^{max} and P^{min} limits that are sensitive to temperature conditions as shown in Figure 1 (a).
- The thermostatically uncontrollable load portion, lighting, appliance load, etc., is represented through a ZIP load (2), where the coefficients can be estimated from meter data as in [3].
- The thermal load is described through an equivalent circuit. The steady state circuit is given in Figure 2 and is accompanied by (3).
- The building load equation (1) can be written as (4) for real power and (5) for reactive power, with a constant power factor assumption.
- The multiplier $k_{Load} = \tan(\cos^{-1} PF)$ is defined for each building.

$$P_D = P_0\left[Z_p\left(\frac{|V|}{|V_0|}\right)^2 + I_p\left(\frac{|V|}{|V_0|}\right) + P_p\right] + \frac{1}{\eta^{eq}}\left[P_n^{th}\left(\frac{\psi}{\psi_n}\right)^{\alpha} + \frac{\psi_a - \psi}{R}\right] \qquad (4)$$

$$Q_D = k_{Load}P_0\left[Z_q\left(\frac{|V|}{|V_0|}\right)^2 + I_q\left(\frac{|V|}{|V_0|}\right) + P_q\right] + k_{Load}\frac{1}{\eta^{eq}}\left[P_n^{th}\left(\frac{\psi}{\psi_n}\right)^{\alpha} + \frac{\psi_a - \psi}{R}\right] \qquad (5)$$

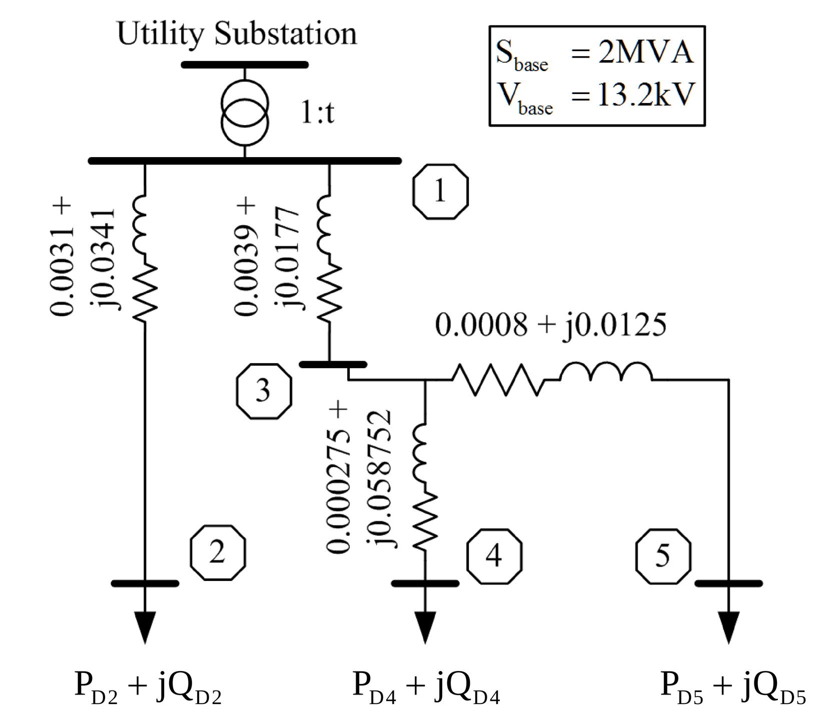

Figure 3: Example distribution system

Table 1: Building controllable load parameters

Bus	P_0	η^{eq}	P_n	P^{max}	R_a	R^{th}	α
2	600	0.8	300	700	0.0766	0.0154	-3.2
4	406	0.8	200	424	0.1393	0.0197	-5.1
5	700	0.8	400	636	0.0727	0.0449	-9.7

Table 2: Uncontrollable load parameters

Bus	Z_p	I_p	P_p	Z_q	I_q	P_q	$\lvert V_0\rvert$
2	1.21	-1.61	1.41	4.35	-7.08	3.72	0.983
4	0.40	-0.41	1.01	4.43	-7.98	4.56	0.975
5	0.76	-0.52	0.76	6.92	-11.75	5.38	0.982

(building loads values have units of kW, k_{Load}=[0.73,0.49,0.46])

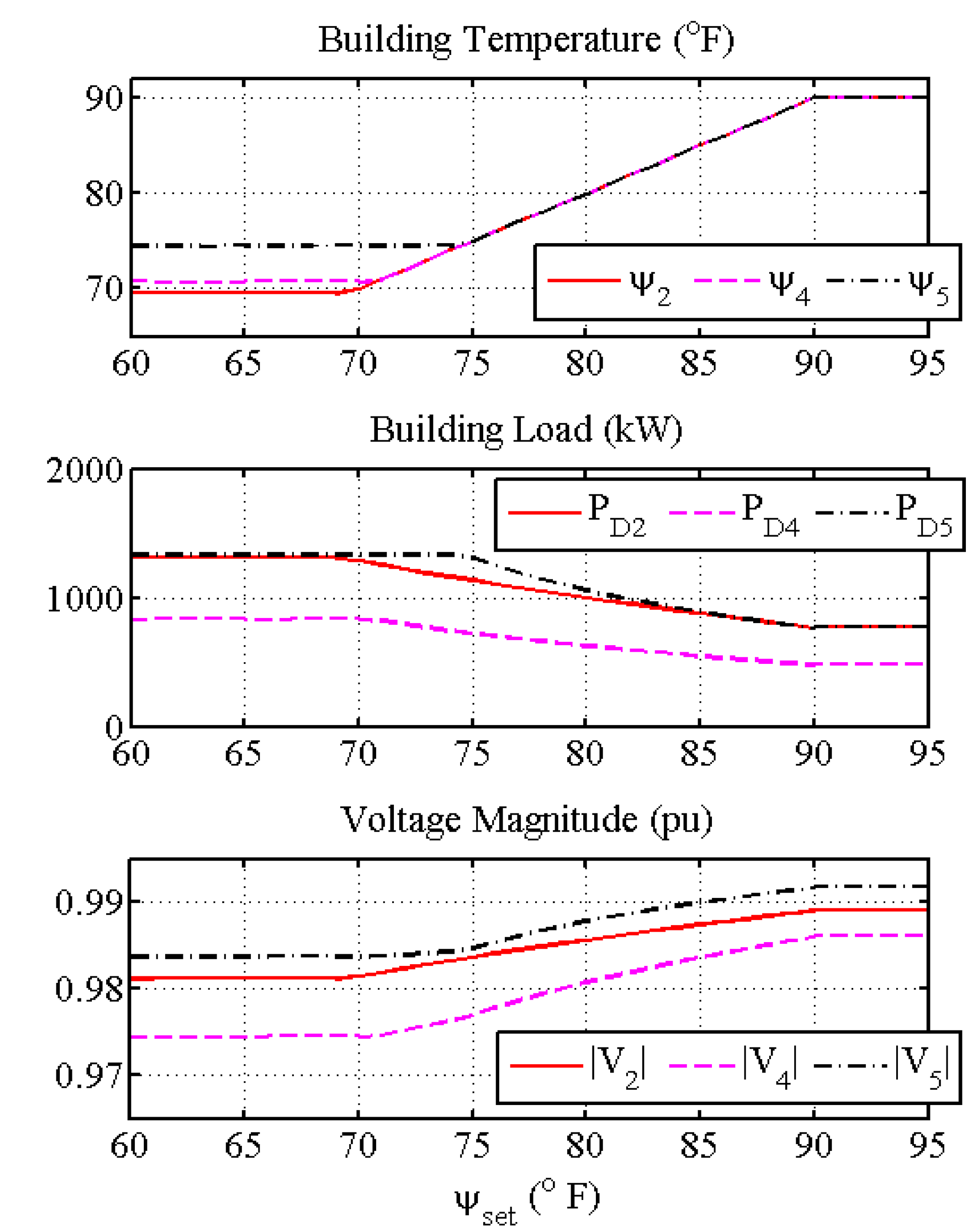

Figure 4: Results of temperature setpoint variation (60°F≤ψ_{set}≤95°F) with ambient temperature ψ_a = 90°F

Discussion of Results

- The results in Figure 4 were obtained through a load flow analysis of the network in Figure 3 by including building temperature as a state and using (4) and (5) to describe the loads.
- The circuit model parameters in Table 1 were estimated from actual building data while the ZIP parameters in Table 2 were obtained from [3] for large commercial and industrial buildings.
- The results displayed are for a unidirectional loading of the buildings with the same setpoint , ψ_{set}, while the ambient temperature, ψ_a, was held.
- As the results indicate, building internal and ambient temperature have a direct influence on load behavior.
- Building - grid operation should consider thermal operating points as well as electrical.

Conclusions

- The presented model captures the temperature-load-voltage relationship that exists between buildings and the electric grid.
- For the example network with given parameters, the bus voltages vary within allowable limits as shown in Figure 1 (b).
- In heavily loaded cases, however, it is possible that the bus voltage will violate the low voltage limit as shown in Figure 1 (c).
- Building operators should consider neighboring building operation as well as the electric grid operation to avoid grid constraint violations.
- Coordination between utility and consumer in the presence of regulatory programs such as Conservation Voltage Reduction can lead to increased efficiency of operation.

Acknowledgement

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