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AN ANALYTICAL METHOD FOR QUANTIFYING THE ELECTRICAL SPACE HEATING COMPONENT OF A COLD LOAD PICK UP

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ABSTRACT

After an extended cold weather outage on a distribution circuit supplying a high saturation of electrical space heating, large transient overcurrents persist for several hours because of the undiversified heating load. In this paper, the electrical space heating component of enduring demand is characterized by a smooth curve. Expressions are derived for the parameters of the curve in terms of the outage conditions and a statistical description of the residences. A method is suggested for using this characterization to determine the effects of a cold load pick up on the distribution circuit components.

INTRODUCTION

Electrical distribution components such as cables, transformers and fuses are rated according to their capacity to transmit power. For feeder circuits serving predominantly residential loads, selection of such equipment is often based on the peak diversified load. If power is not available to the residential appliances which are automatically controlled, their tasks accumulate. As a result, when power is restored, many of the appliances will be energized simultaneously; thus loss of diversity occurs and the demand may rise above component ratings. The accompanying excess currents flowing through the distribution equipment can cause overheating and large voltage drops.

Restoring power to a circuit after an outage, an old problem, is commonly called a cold load pick up (CLPU). In 1949, Audlin et al. (3) delineated four time phases of a residential circuit CLPU. The first three phases, lasting about 15 seconds, are characterized by inrush currents. In the fourth phase, excess currents are attributed to an undiversified appliance load which persists for several hours.

Regarding the first three phases, the problem is to design the circuit to allow CLPU inrush currents without sacrificing coordination and fault current protection.

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Solutions include the use of relays with 'extremely' inverse characteristics (3), proper relay settings (5, 6) and proper fuse selection (7, 8). Often the circuit must be restored one section at a time (9).

Recently, fourth phase CLPU problems have occured after cold weather outages on feeders serving a high saturation of electrical space heating (10). These circumstances have received some attention. Bruning (14) describes the effect on fuse coordination and design. McDonald et al. (4) present curves for quantifying the electrical space heating component (ESHC) of fourth phase load. Butts (10) compiles most of the available cold weather CLPU information together with case histories. He also described a simulated CLPU on some Illinois Power Company feeders in which the McDonald curves were used to determine the fourth phase load.

The McDonald curves quantify the ESHC as a function of only two variables--outside temperature and outage duration. No distinction is made as to types of construction and heating systems that might be peculiar to a particular locality. On the other hand, detailed simulations that account for many variables require large data bases and considerable computer effort. The contribution described in this paper is a characterization of the ESHC in terms of a statistical profile of the residences as well as the outage conditions. However, unlike the computer simulations, functional dependence on the variables is defined by simple analytical expressions.

SCOPE OF THE ANALYSIS

A utility would want to quantify the excess currents of a CLPU for such purposes as sizing distribution equipment, predicting potential restoration problems, evaluating restoration strategies, or assessing insulation loss of life. The concern is, of course, overheating of equipment which have relatively large thermal capacitances. Apparently, the quantification should be a worst case prediction accounting for a minimum number of significant variables.

Overheating is properly a function of the current passing through a device. For convenience, however, some distribution equipment is rated according to the load carried. Along the same lines, the quantification in this paper is of load power rather than load currents. Actually only the ESHC of load power is quantified. The total fourth phase load can be found by adding the non-ESHC to the ESHC.

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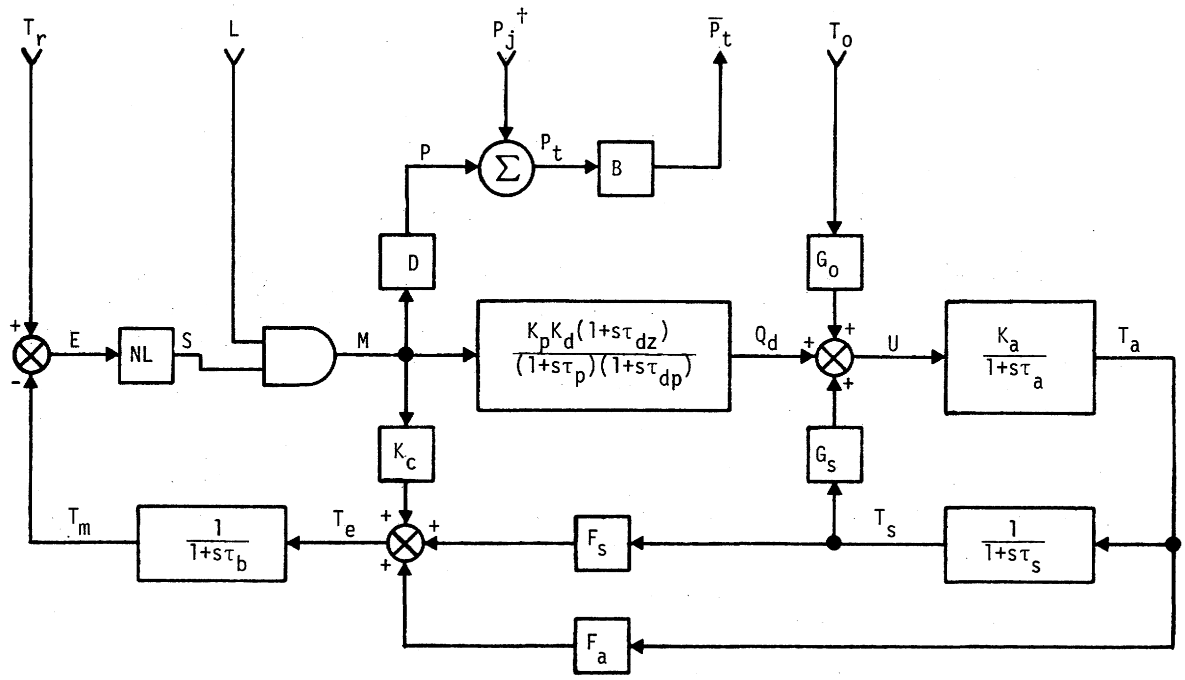

† P_j represents the demand from electrical space heaters in other residences.

Figure 1. Residential Heating System Block Diagram

In the analysis, all dwellings are treated as single zones, electrically heated by forced air furnaces, baseboard or radiant panels. It is expected that the results are also applicable to buildings with multiple heating zones. Heat pumps are not included since their incidence is not high and the most common versions revert to resistance heating at subfreezing temperatures. Regarding environmental variables, only ambient temperature is treated explicitly. No credit is given for solar heating. If required, the approximate effects of other environmental variables could be included by adjusting the ambient temperature.

THE MODEL

The analysis in this paper is based on the residential heating system model shown in Figure 1. All symbols are defined in the Appendix. The heated building itself is represented by a second order model for which an electrical equivalent is shown in Figure 2.a. A complete description of the model development is found in Reference (52). A typical set of parameter values is shown in Table 1.

THE ANALYTICAL METHOD

The ESHC of power flow into a distribution circuit, P_t, serving n electrically heated households is the sum of every heat plant demand, P_i.

$$P_t = \sum_{i=1}^{n} P_i \tag{1}$$

Immediately after an extended outage, all of the heaters operate continuously and the ESHC is constant. Eventually as the heaters begin cycling the ESHC becomes very irregular. It would be impossible to quantify the ESHC per se and fortunately unnecessary. Since the heaters do not cycle synchronously, the ESHC randomness tends to cancel when the individual demands are summed, and for a large enough number of residences, the ESHC approaches its expected value, $\overline{P}_t$. Furthermore, the cycling is additionally filtered in the distribution equipment temperature response to the CLPU overcurrents. Therefore a very smooth approximation of $\overline{P}_t$ is derived in what follows. For simplicity, the training subscript i, which indicates a particular residence, is omitted in the Figures.

From the residential heating system model in Figure 1,

$$P_i = D_i M_i \tag{2}$$

where D_i is the total connected load of a space heating unit and M_i is the energization signal to the heater. D_i is a constant and M_i is a stochastic process. Combining (1) and (2) yields

$$\overline{P}_t = \sum_{i=1}^{n} D_i \eta_i \tag{3}$$

where η_i is the expected value of M_i and is interpreted as the fractional energization

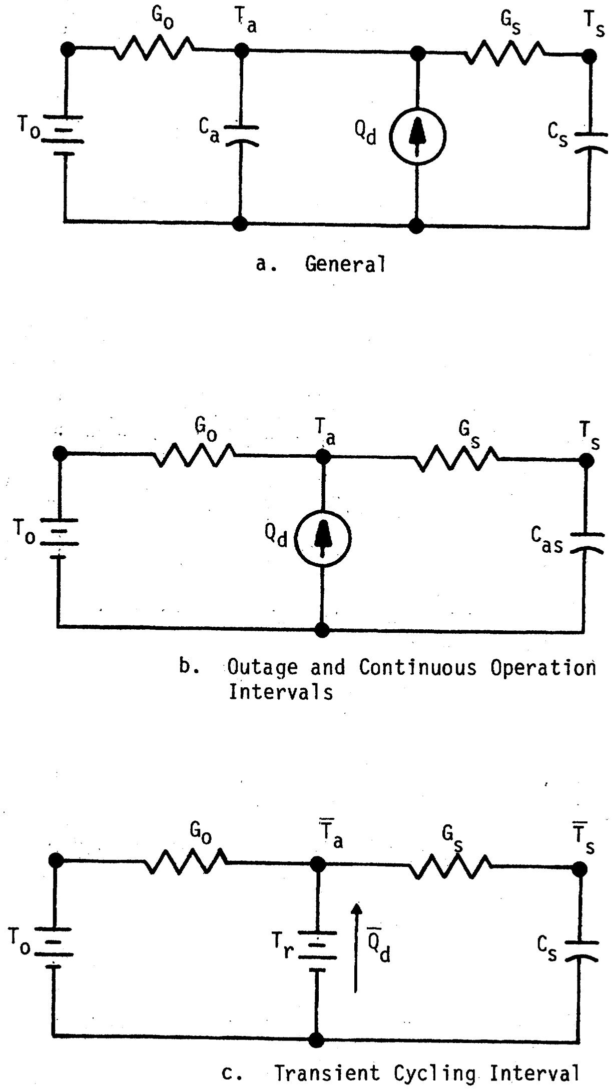

Figure 2. Heated Building Equivalent Models

TABLE I

BASE CASE VALUES FOR RESIDENTIAL

HEATING SYSTEM MODEL PARAMETERS

Space Heating Control System	
T_r=18.33°C	τ_b=.142 h
SD=.440°C	F_s=.260
K_c=1.80°C	F_a=.740
Heat Plant	
D=18.9 kW	τ_p=.0167 h
K_p=18.2 kW	τ_{dp}=.0467 h
K_d=.94	τ_{dz}=.0225 h
Heated Building	
G_o=.318 kW/°C	C_a=.330 kWh/°C
G_s=4.70 kW/°C	C_{as}=3.21 kWh/°C
Non-Fundamental	
τ_a=.0658 h	C_s=2.88 kWh/°C
τ_s=.613 h	K_a=.199°C/kW

time of a space heating unit or the numerical value of its duty cycle.

The behavior of an η_i during a power outage and restoration event is illustrated in Figure 3. Under normal conditions a residential space heater operates with a constant duty cycle, and the living space air temperature oscillates within a controlled range. During an outage the heater is off, η_i is identically zero and all temperatures decay toward the outside ambient. When power is restored, the space heater runs continuously and η_i is identically unity until the air temperature returns to the controlled range. At that time the heater enters a transient cycling period that lasts until the lagging structure temperatures, with their large thermal capacitances, reach normal levels also. The practical significance of Figure 3 is to determine the power flowing through a transformer. It is an intermediate step for calculating the aggregate response of many houses.

In Reference (52), it is shown that the thermal response of a heated residence can be modeled by Figure 2.b during the outage and continuously energized intervals and by Figure 2.c during the transient cycling interval. Analytical expressions are derived for the continuously energized duration, t_{fi}, and the exponential decay constant, τ_{si}. Then for simplicity, η_i is aproximated by the rectangular pulse shown in Figure 3. An equivalent CLPU duration for a single residence, t_{eqi}, is defined such that the areas A_1 and A_2 are equal. The result is

$$t_{eqi} = \tau_{1i} \ln \frac{1-\eta_{ssi}\exp(-t_o/\tau_{1i})}{1-\eta_{ssi}} \qquad (4)$$

where

$$\tau_{1i} = (C_{ai}+C_{si})\left(\frac{1}{G_{oi}} + \frac{1}{G_{si}}\right) \qquad (5)$$

$$\eta_{ssi} = \frac{G_{oi}(T_{ri}-T_o)}{K_{pi}K_{di}} \qquad (6)$$

Note that t_o is the length of the outage, T_o is the outside ambient temperature and the rest of the symbols are parameters from the residential heating system model.

According to (3), the η_i are multiplied by their respective D_i and summed to get a staircase pattern which is illustrated in Figure 4. Each rectangle is t_{eqi} long by w_i high where

$$w_i = D_i(1-\eta_{ssi}) \qquad (7)$$

Since w_i is essentially the amount of heating system excess capacity for the specified outside ambient, the shortest t_{eqi} tend to be associated with the largest w_i. In other words, the staircase drops off the fastest at the start which suggests the exponential approximation which is also shown in Figure 4.

Four parameters are necessary to specify the exponential approximation: D_t, the initial value; P_{tss}, the final value; t_r, the

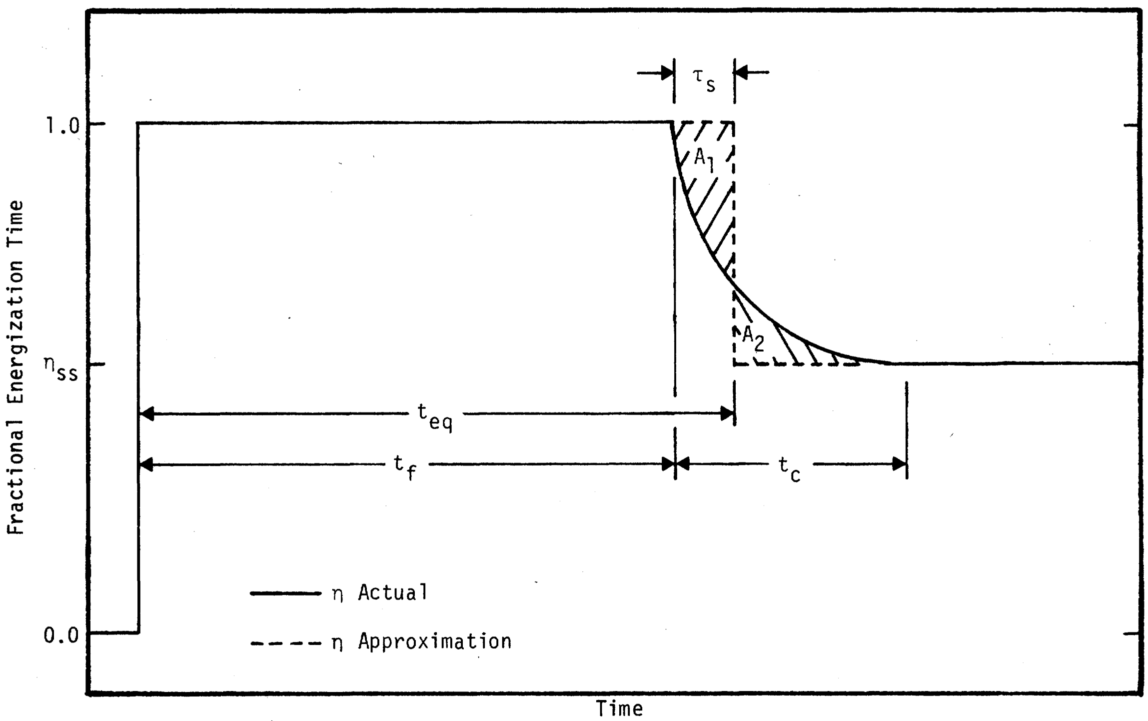

Figure 3. η Response

equivalent continuous operation duration; and τ_r, the exponential decay constant. D_t is the total connected electrical space heating load and P_{tss} is the preoutage average electrical space heating load. It is assumed that the utility has experience in determining these values which specify the magnitude of the ESHC transient. The other two parameters, t_r and τ_r, specify the duration of the transient.

To determine t_r and τ_r, the set of t_{eqi} is assumed to be a discrete random variable, θ, with a weighting of w_i.

$$\theta(i) = t_{eqi}, \quad i=1,2,...,n \tag{8}$$

Then the exponential curve is assumed to be a continuous distribution of the t_{eqi}. Equating the means and variances of the discrete and continuous distributions gives

$$t_r = \bar{\bar{\theta}} \tag{9}$$

$$\tau_r^2 = \sigma_\theta^2 = (\bar{\bar{\theta^2}}) - (\bar{\bar{\theta}})^2 \tag{10}$$

where the weighted mean, $\bar{\bar{\chi}}$, of any discrete random variable, χ, is defined as follows:

$$\chi(i) = x_i, \quad i=1,2,...,n \tag{11}$$

$$\bar{\bar{\chi}} = \frac{\sum_{i=1}^{n} (w_i x_i)}{\sum_{i=1}^{n} w_i} \tag{12}$$

Finally it remains to relate t_r and τ_r through (9) and (10) to a statistical profile of the residences connected to the distribution circuit. Let T_{rd} be the design temperature difference for a given locality as recommended by ASHRAE (27) for heat loss calculations. Then define three random variables that describe the residences.

$$\lambda(i) = \tau_{1i} \tag{13}$$

$$\rho(i) = \frac{K_{pi} K_{di}}{G_{oi} T_{rd}} \tag{14}$$

$$\xi(i) = \frac{T_{ri} - T_o}{T_{rd}} \tag{15}$$

$$i = 1, 2, ..., n$$

By substituting (13) through (15) in (4), the random variable θ can be expressed as a function of the three residential random variables.

$$\theta = F(\lambda,\rho,\xi) = \lambda \ln \frac{1-\xi/\rho \exp(-t_o/\lambda)}{1-\xi/\rho} \tag{16}$$

Since t_r and τ_r^2 are the mean and variance of a function of the three residential random variables, they can be expressed in terms of the means and variances of the three residential random variables by expanding (16) in a second order Taylor Series about the residential random variable means and determining the mean and variance of the truncated series. In the following formulae, partial derivatives are represented by

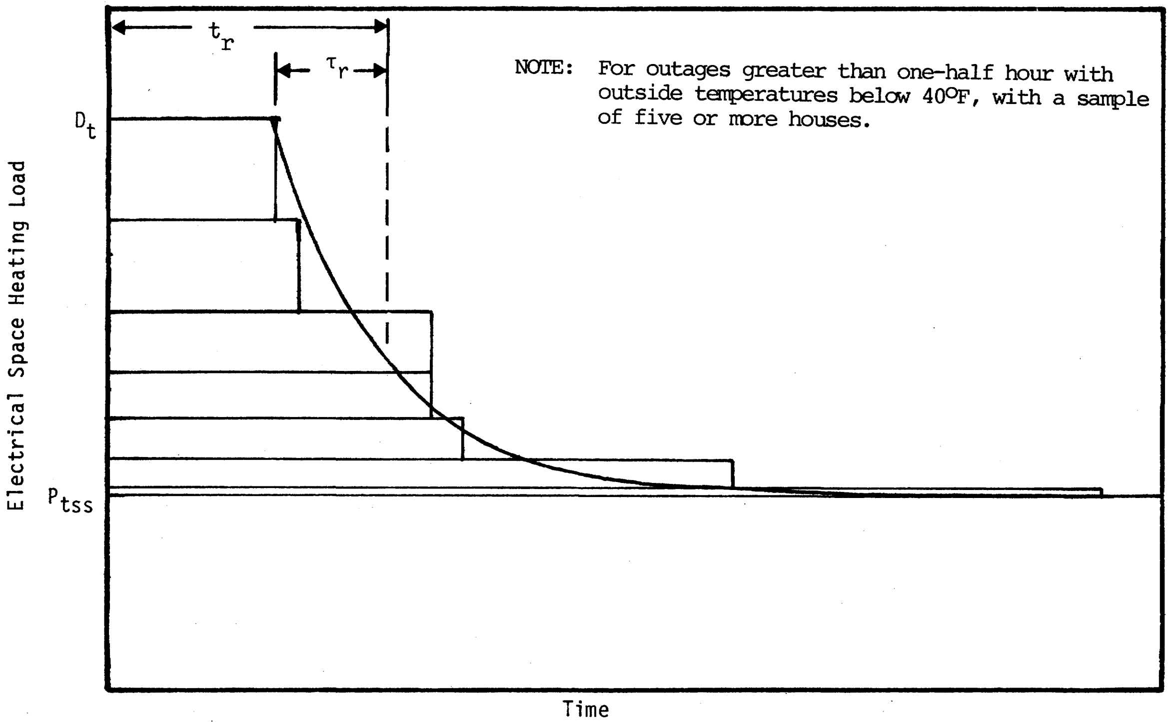

Figure 4. $\overline{P}_t$ Derivation

$$F_\chi = \frac{\partial F}{\partial \chi} \quad (17)$$

and central moments by

$$\mu_{jkl} = \overline{\overline{\left[(\lambda-\bar{\bar{\lambda}})^j(\rho-\bar{\bar{\rho}})^k(\xi-\bar{\bar{\xi}})^l\right]}} \quad (18)$$

Then

$$\bar{\bar{\theta}} \simeq F(\bar{\bar{\lambda}},\bar{\bar{\rho}},\bar{\bar{\xi}}) + 1/2(\mu_{200}F_{\lambda\lambda}+\mu_{020}F_{\rho\rho} +\mu_{022}F_{\xi\xi}+2\mu_{110}F_{\lambda\rho}+2\mu_{011}F_{\rho\xi}+2\mu_{101}F_{\lambda\xi}) \quad (19)$$

$$\sigma_\theta^2 \simeq F_\lambda^2\mu_{200}+F_\rho^2\mu_{020}+F_\xi^2\mu_{002} +2F_\lambda F_\rho\mu_{110}+2F_\rho F_\xi\mu_{011}+2F_\lambda F_\xi\mu_{101} \quad (20)$$

where all the partial derivatives are evaluated at the residential variable means. As defined, λ, ρ and ξ are logically uncorrelated; therefore, assume

$$\mu_{110} = \mu_{011} = \mu_{101} = 0 \quad (21)$$

Additionally, the range of thermostat settings is relatively narrow so further assume

$$\mu_{002} = 0 \quad (22)$$

Substituting (17), (18), (21), and (22) into (19) and (20) results in

$$t_r = \bar{\bar{\theta}} \simeq F(\bar{\bar{\lambda}},\bar{\bar{\rho}},\bar{\bar{\xi}})+1/2(\mu_{200}F_{\lambda\lambda}+\mu_{020}F_{\rho\rho}) \quad (23)$$

$$\tau_r^2 = \sigma_\theta^2 \simeq F_\lambda^2\mu_{200}+F_\rho^2\mu_{020} \quad (24)$$

VERIFICATION

The results of the analytical method were compared to those from a computer simulation for a seven-house sample located in Rolla, Missouri (52). Figure 5 shows the comparison. In the simulation, P_t was smoothed by a low-pass filtering.

DISCUSSION

The analytical method presented here has several useful features that are worth emphasizing:

1. Given the proper data base, the calculation is relatively simple. Determination of the residential random variable statistics and numerical evaluation of the partial derivatives to use in (23) and (24) can be done without a large computer.

2. Because the parameters t_r and τ_r are defined in terms of the statistics of the residential random variables, it is only necessary to collect data from a representative sample of the residences.

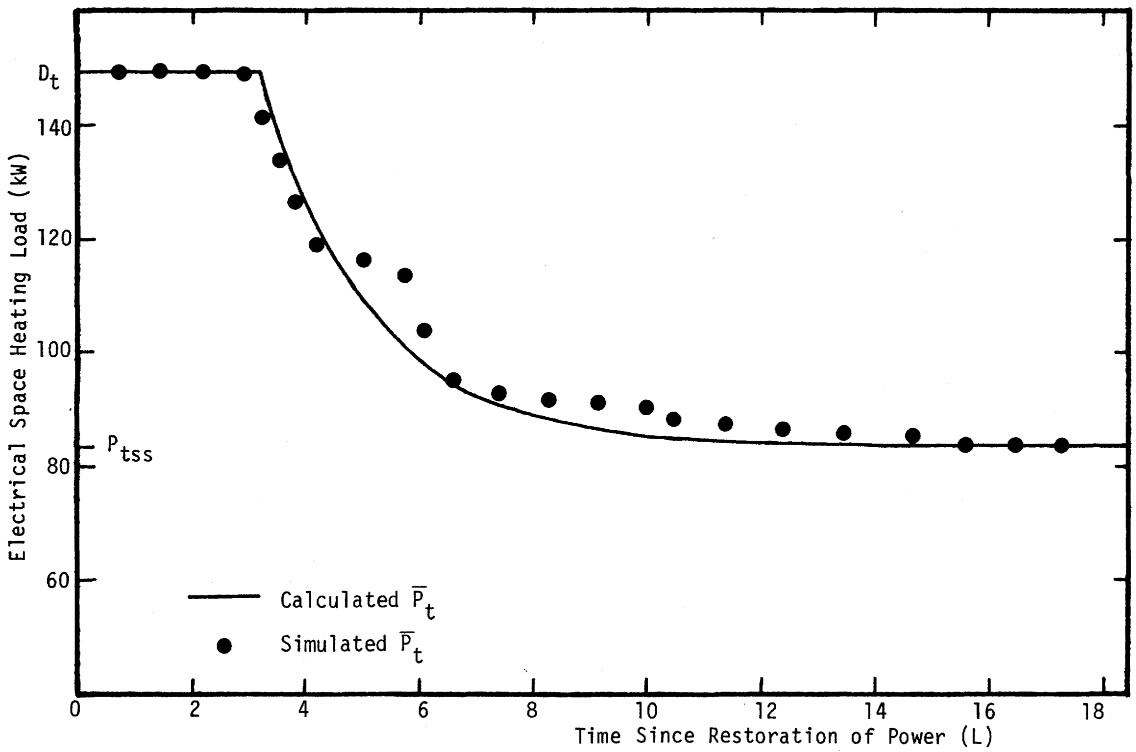

Figure 5. Seven-House Sample $\overline{P}_t$ Response

3. If an estimation of t_r is sufficient, the variances of the residential random variables are unnecessary. For example, the first term in (23) accounts for about 90% of t_r.

4. For most applications, sufficient accuracy is obtained if judicious estimates of the residential random variable statistics are used rather than making a direct calculation. Toward this end, the variables have been defined to have a definite physical significance. Note, however, that the means and variances of these variables are weighted. Fortunately the weighting function is only slightly correlated with two of the variables, ξ and λ, so the weighting can be neglected in their cases.

ξ is called the outage severity ratio. It is simply the ratio of actual temperature differential between the thermostat setting and the outside ambient to the ASHRAE recommended differential for heat loss calculations. Since thermostat settings fall into a narrow range and the outside ambient is specified, the mean of ξ can be estimated easily.

λ is the residential, first order, heat transfer long time constant. The dependence on residential size tends to cancel in λ (52). In other words λ for the same type of construction is approximately independent of size; and λ is a function of the type of construction for the purpose of estimating λ's mean and variance. λ is easily determined experimentally by observing the thermal decay of a residence over a several hour period. Note also that, of the three residential random variables, λ has the least influence on t_r and τ_r.

ρ is the heating system oversize ratio and is found by dividing the maximum heat input to the living space when the heater is running continuously by the heat loss at the ASHRAE recommended temperature differential. In general, the weighted mean of ρ will be about 10 to 15% higher than a simple average.

To summarize, the residential random variables are defined as described to facilitate the estimation of their means and variances. The best method of establishing the proper data base needed for a direct calculation of the statistics will vary with each user. In general, the data from an energy audit form combined with the calculation methods found in Reference (52) could be used. It is estimated that the parameter values could be determined experimentally with an initial investment of $1000 for recorders and about 3 to 4 hours of effort per residence (48).

To evaluate the results, a sensitivity analysis was made in which the effect on a single residence's t_{eqi} due to each model parameter by itself was determined by simulation. The percent change in t_{eqi} divided by the percent change in each parameter is tabulated in Table II. Two conclusions are drawn:

1. The parameters of the residential heating system model that strongly affect t_{eqi} are represented in a proven manner. All of the significant parameters can be related to the heated building model shown in Figure 2.a. Sonderegger (39) has demonstrated that this model will follow freely floating living space temperatures. Furthermore, it is essentially the same model which McDonald (4)

TABLE II

t_{eq} SENSITIVITY TO OTHER PARAMETERS

Parameter	$\frac{\Delta t_{eq}}{\Delta \text{Parameter}}$	Estimated % parameter Uncertainity	Approximate % t_{eq} Uncertainity
T_r	1.08	5	5
SD	†		
K_c	-0.06	50	3
τ_b	†		
F_a	†		
D	-1.25	10	13
K_p	-1.25	10	13
K_d††	-2.29	5	11
τ_p	†		
τ_{dp}	†		
τ_{dz}	†		
G_o	1.16	20	23
G_s	†		
C_a	0.05	100	5
C_{as}	0.45	25	11
t_o	0.41	0	0
T_o	-0.57	0	0

Base Case Parameters $T_o=-10^oC$ $t_o=10$ h

† Less than .02

†† Decreased since upper range is limited

fitted to the residential thermal response to staged outages.

2. The methods used to derive the parameter values for the simulation verification did not introduce significant errors. Also tabulated in Table II are the estimated uncertainties in the parameter values which, when multiplied by the respective sensitivity of t_{eqi} to the parameters, yields a rough estimate of the uncertainty in t_{eqi} attributable to each parameter value.

CONCLUSIONS

Previous studies have quantified the ESHC of CLPU demand as a function of outside temperature and outage duration only. A method is presented in this paper that accounts for prevailing construction features as well, still without the need for large data bases or extensive computer effort. The method is generally accurate for outages longer than one-half hour (52).

Several possibilities for future work are suggested:

1. Multiple heating zones and changing ambient temperatures were not included in this analysis. They could be investigated using a more sophisticated residential heating system model. It is expected that the results will be applicable.

2. Because of the social impact of a severe cold weather outage on a large distribution circuit, it was not feasible to stage an actual field test. An interested utility could record CLPU power flow and outage conditions when an inadvertant outage does occur for future comparison.

3. A study of the residential variable statistics would be useful as a basis for estimating means and variances. Tables for t_r and τ_r could be generated for various construction features and outage conditions.

APPENDIX: NOTATION

NOTE: Symbols applying to a particular residence are subscripted with an i in the text.

OPERATORS:

$\overline{Y}$ expected value of any stochastic process Y; removes randomness caused by space heater cycling

$\overline{\overline{\chi}}$ weighted mean of any discrete random variable χ

Z_χ $\partial Z/\partial\chi$ for any differentiable $Z(\chi)$

SYMBOLS:

B low-pass filter

C_a responsive thermal mass associated with a living space air temperature; kWh/°C

C_{as} (C_a+C_s); equivalent thermal mass of a building; kWh/°C

C_s equivalent thermal mass of a building's structure; kWh/°C

D connected load of a space heating plant; kW

D_t total connected load of all the space heating plants; kW

E error signal sent to a thermostat relay; °C

F $\theta=F(\lambda,\rho,\xi)$

F_a fraction of air temperature seen by a thermostat sensor

F_s fraction of wall temperature seen by a thermostat sensor

G_o lumped thermal conductance between a living space and the exterior ambient; kW/°C

G_s lumped thermal conductance between a living space and its building structure thermal mass; kW/°C

i residential index

K_a $(G_o+G_s)^{-1}$; °C/kW

K_c gain of a thermostat anticipator; °C

K_d gain of a heat distribution system

K_p gain of a space heating unit with respect to its heat output; kW

L line power availability signal; off-on

M input control signal to a heat plant; off-on

n the number of residences with electrical space heaters

NL nonlinear relay in thermostat

P instantaneous electrical power demand of a space heater; kW

P_t instantaneous electrical power demand of all the space heaters; kW

P_{tss} average value of the preoutage electrical power demand of all the space heaters; kW

Q_d total heat injected into a living space; kW

s	Laplace transform variable; h^{-1}
S	output signal of a thermostat; off-on
t_c	duration of a residence's transient cycling interval; h
t_{eq}	equivalent continuous operation CLPU duration for a single residence; h
t_f	duration of a residence's actual continuous operation interval; h
t_o	duration of the outage; h
t_r	equivalent continuous operation CLPU duration for all the residences; h
T_a	temperature of a living space air thermal mass; °C
T_e	effective temperature seen by a thermostat sensor; °C
T_m	temperature measured by a thermostat; °C
T_o	exterior ambient temperature; °C
T_s	temperature of a building structure equivalent thermal mass; °C
T_r	a thermostat reference temperature setting; °C
T_{rd}	recommended ASHRAE design temperature differential for heat loss calculations; °C
w	weighting function used in calculating the expected values of the residential random variables; kW
η	expected value of M; fractional energization time of a space heater
η_{ss}	preoutage value of η
θ	discrete random variable whose outcomes is the set of t_{eqi}; h
λ	discrete random variable whose outcomes are the residential long time constants; h
μ	weighted moments of the residential random variables
ξ	discrete random variable whose outcomes are the residential outage severity ratios
ρ	discrete random variable whose outcomes are the residential space heating oversize ratios
σ_X^2	variance of any discrete random variable X
τ_a	$C_a/(G_o+G_s)$; h
τ_b	time constant of a thermostat heat sensor; h
τ_{dp}	time constant of a heat distribution system lag; h
τ_{dz}	time constant of a heat distribution system lead; h
τ_1	long time constant of a heated building; h
τ_p	time constant of a space heating unit; h
τ_r	exponential decay constant of the average electrical space heating load during a CLPU; h
τ_s	exponential decay constant of a residence's during the transient cycling time; h
χ	any discrete random variable

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BIOGRAPHY

Walter William Lang was born on January 14, 1945, in Greensburg, Pennsylvania. He received a B.S. degree in electrical engineering in 1970 and a M.S. degree in electrical power engineering in 1976 from Carnegie-Mellon University. He received a PhD in electrical power system engineering from the University of Missouri-Rolla in 1980.

During ten years at the Low Voltage Breaker Division of Westinghouse Electric Corporation, Mr. Lang held a number of positions including Design Engineer. He was a Project Engineer and Consultant for A. B. Chance Company. At the University of Missouri-Rolla he taught electrical circuits, machines and power systems. Mr. Lang is currently employed as a Senior Engineer in Research and Development at the Square D Company. His primary experience is in circuit interruption, overload timing, and distribution circuit coordination.

Mr. Lang has six U.S. patents pertaining to low voltage circuit breaker designs and is a member of the IEEE.

Max Darwin Anderson received his BSEE (1958) and MSEE (1959) from Oklahoma State University, attended Northwestern University, and received his PhD (1967) from Arizona State University. Since 1975 he has been Associate Professor of Electrical Engineering at the University of Missouri-Rolla. His area of research is power system monitoring, control, and operations.

Dr. Anderson served as a consultant to Stagg Systems, Inc. (1980) to determine operator training requirements for the EPRI Human Factors Review of Dispatch Center Contract.

As a consultant to Emerson Electric Company, St. Louis, Missouri in 1979 he has been involved with interfacing their TWACS Distribution Automation System with a SCADA/Control Center and billing computer systems.

He has been a consultant to the Union Electric Company, St. Louis, Missouri from 1976 to 1978 on the requirements analysis and specification for a new Load Dispatch Control Center.

Prior utility experience includes software requirements, design and testing for the Ontario Hydro DACS Control Center project and engineering studies for Bonneville Power Administration's Dittmer Control Center.

He is a member of IEEE and Chairman of the Working Group on Operator Training (WG 78-4). For EPRI, he served as Editor of the Proceeding of the Workshop on Operator Training Simulators held in New York City, September 1978. He is a registered professional engineer and a member of Tau Beta Pi and Eta Kappa Nu.

David Ronald Fannin was born in Houston, Texas on June 5, 1943. He received the B.S. degree in engineering physics from Texas Tech University in 1965 and the M.S. degree in engineering science from Florida State University in 1966. In 1970 he received the PhD in electrical engineering from Texas Tech University.

In 1970 he joined the faculty of the electrical engineering department at the University of Missouri-Rolla as assistant professor. He is presently associate professor of electrical engineering and assistant dean of undergraduate affairs at the University of Missouri-Rolla. His research interests are in the areas of system modeling, stability theory, and applications of modern control theory.

Dr. Fannin is a member of Eta Kappa Nu and Tau Beta Pi.

Discussion

J. B. Bunch, J. T. Tengdin, and **S. S. Zelingher** (General Electric Co., King of Prussia, PA): The authors are to be commended for their method for quantifying this component of cold load pick-up. The paper provides an interesting approach, and further efforts in this area are encouraged.

Modeling, either mathematical or simulation, is a first step in better understanding a problem that is being faced by the industry. This paper is an important contribution in that direction.

The authors' comments on the following points would be helpful.

- Many utilities are considering selective load shedding/restoration as a load management tool. The expectation is that the end result of this concept would be the reduction of peak demand per feeder, transformer and substation, by employing sequential interruptions and energizations of loads. It is generally believed that a better understanding of the cold load pick-up concept would be very useful in achieving this goal.
- Similarly, expansion of the cold load pick-up concept to situations that involve return-to-normal of feeders following forced outages (due to maintenance, repair, etc.) and space cooling component may also be required.
- Based on the above, there seems to be a need to develop a unified cold load pick-up strategy. The mathematical modeling of the electrical space heating component could provide an investigative tool toward developing this strategy.

We would also like to hear the authors' opinions about the impact their present and possibly future work would have upon the cold load pick-up strategy in view of the points mentioned above. Along these lines, we feel that, for a successful resolution of the problem, there may be a need to revisit some of this paper's concepts, such as:

- Model dependence with temperature
- Data collection at the feeder level rather than at the end-user
- Relatively short interruption time intervals which would result in expected values, η, smaller than unity immediately following cold load pick-up.

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W. Lang, M. Anderson, and **D. Fannin:** The authors would like to thank Messrs Bunch, Tengdin and Zelingher for an interesting and enlightening discussion. In general, we agree with your comments and appreciate your observations. The following comments are in response to your request.

- A better understanding of the cold load pick-up concept would be useful. Selective load shedding could help shave a generating peak; however, the return transient effect may be alright for generation but damaging to the distribution system hardware.
- We agree that expansion of the cold load pick-up concepts to situations involving return-to-normal of feeders, etc. is importnat.
- A unified cold load pick-up strategy is important. The method developed can handle electric heating, water heating, and cooling with some modifications. These would be calculated separately and added algebraically as appropriate. The method cannot handle the magnetization transient; i.e., the first 15 seconds.
- Outside temperature is modelled explicitly. The inherent uncertainly of unmodelled parameters such as human behavior would mask out any accuracy grained by making the model parameters dependent on temperature.
- Data collection at the feeder level would require a staged outage, because normal weather changes are too slow to observe the dynamic response of the home heating system to those changes.
- For a short outage, η would be small. The present method cannot handle short interruption time intervals now, but it is an interesting suggestion which should be investigated.

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