

Demand Limiting Algorithms for Energy Management and Control Systems

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U.S. DEPARTMENT OF COMMERCE National Bureau of Standards Center for Building Technology Building Equipment Division Washington, DC 20234

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ABSTRACT

Demand limiting control is one of popular control strategies for electrical energy management in Energy Management and Control Systems (EMCS) in commercial/office buildings. The purpose of demand limiting is to maintain the peak demand level below a predetermined limit by shedding nonessential loads in a building during the peak demand period. In this present report, description of fixed interval metering and sliding window metering for electrical demands are included. Demand limiting calculation procedures discussed are the ideal rate, the predictive, and the instantaneous rate methods. Demand limiting algorithms, which were developed based on available information, are presented. Computer program listings of demand limiting control algorithms in Fortran 77 and an open-loop computer simulation result are included in the appendices.

Key words: electrical demand; electrical energy management; electric power; energy management and control systems; fixed interval metering; ideal rate method; instantaneous rate method; load control; predictive method; sliding window metering.

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1. INTRODUCTION

Electrical energy management has an important role in energy management and control systems (EMCS) in buildings. The purpose of electrical energy management is to lower the charges imposed by electric utilities. Although popular strategies for electrical energy management include demand limiting, duty cycling, time-of-day control, scheduled start/stop control, and optimum start/stop control, only demand limiting is discussed in this report.

Electric utility charges are typically based on some combination of electric energy consumption, fuel adjustment, electric demand, ratchet adjustment, and power factor [1,2]. Electric energy consumption is defined as the electric energy usage read by a watt-hour meter in kWh, while the fuel adjustment charge is based on the kind and cost of fuel used by the utility. The electric demand charge is the portion of the service charge which is based upon a customer's demand, and will be explained later. A ratchet adjustment is made on the basis of energy use or demand. Finally, the power factor is the relationship between the phase of the current and the phase of the voltage in alternating current distribution systems. (A low power factor can overload generating and distribution networks.) Currently, residential customers are not charged for electric demand and power factor, while industrial and commercial customers may be billed for all or some charges discussed.

Electric demand is defined as the load integrated over a specified time interval [3]. In other words, electric demand is the energy consumption over a specific time interval of 15, 30, or 60 minutes. The time interval is determined by a utility and is called demand interval. The maximum demand is the maximum value of demand measures during a billing period in kW. Charges based on maximum demand allow a utility to recover its capital investment in generating and distributing equipment used to meet the maximum demand for electrical power. When the maximum demand of many customers occurs simultaneously, the peak load of the power system will be high, therefore the utility's capital investment will be large. During the off-peak period, a part of the equipment capacity is idle. Because demand charges are high (as much as 30 percent of some customers' bills [4]) and because a demand charge is usually based upon the highest demand that has occurred during a billing period, controlling demand is very important. A high peak demand for just a few minutes can raise the demand charge for the entire billing period.

An electrical demand limiting strategy is outlined by Shih [5]. The purpose of demand limiting is to maintain the peak demand level below a predetermined limit by shedding (disconnecting) nonessential loads in a building during the peak demand period. In conjunction with demand meter pulse signals, Shih presented two demand limiting methods. These are the predictive method (forecasting method), and the ideal rate method. The ideal rate method was used with analog demand limiting meters many decades ago. The concept of demand control was also explored with comprehensive analyses by Militello [6]. On-peak or off-peak metering, automatic load control, and demand billing control are extensively discussed in his paper in addition to the concepts of demand and demand control. The instantaneous rate principle is mentioned as a load shedding technique by Pannkoke [7]. In this technique, the rate of electric energy use is measured at short time intervals and compared with a limiting value. Good examples of the demand computation can be found in Pannkoke's article. Currently, there exist, as discussed above, three calculation methods; i.e., ideal rate, predictive (forecasting) and

instantaneous methods. These methods are related to the metering technique employed.

Two metering techniques, associated with impulse signals from the demand meter, are known. They are the fixed interval metering and the sliding window metering. The most widely used one is the fixed interval metering in which shedding of loads is generally performed sequentially or rotationally. The loads that have been shed are restored when the demand is lower than a predetermined level. Novak [8] considered on and off times of loads during shedding and restoring activities, keeping the number of on and off actions to a minimum. A new concept for load shedding, called "comfort fairness," was briefly introduced in an article by Spethmann [9]. The comfort fairness concept is not currently involved in the demand limiting algorithm of this report. The use of this concept can be found in the report of time-of-day control and duty cycling algorithms by May [17].

Although many publications relating to demand limiting are available in the public domain, no detailed information that is suitable for implementation utilizing computers has been found. Software on the market, for practical purposes, is proprietary so that general public has limited access to detailed information. The present report is intended to describe the concept of demand limiting, and the possible implementation of the algorithms to digital control hardware. Metering techniques, calculation principles, and load control algorithms are discussed, and computer programs written in Fortran 77 are provided. With presumed data, the open-loop computer simulations were carried out, and the results are appended for illustration purposes. It should be noted that demand limit control is a closed loop control in practice.

2. ELECTRIC DEMAND METERINGS

Electrical energy consumption and maximum demand are measured by meters and serve as the basis of billing for industrial and commercial customers. A utility and a customer make a contract for the electric charge. Discussion of the contents of such contracts is beyond the scope of this report. Some ideas about the rate structure for these charges may be obtained from papers by Teed [10] and Carpenter [11]. In this chapter, demand meters, fixed interval metering, and sliding window metering will be described.

2.1 DEMAND METERS

Ordinarily a utility must provide electric power to any customer in any quantity required. Since alternating-current (AC) power cannot be stored practically, the utility must increase its generating and distributing capacities to meet an increased maximum load condition. This results in larger generators, larger transformers, heavier switches, heavier wires, and so on. Consequently, fixed investment must be increased to meet increased customers' requirements. Such a situation was being investigated as far back as 1892, and as a result, a dual rate of metering was developed [12]. In this scheme, energy use measured by a watt-hour meter and electric power demand measured by a demand meter determine the charge for billing period.

The demand meter is a device to register the integrated energy used for a specific time interval, namely electric power. There are two different sizes of meters available. One is a small demand meter which is housed in the same

case of a watt-hour meter. An internal timer with fixed time interval resets the demand reading at the end of each demand measurement interval. The maximum value of the demand reading is indicated by a sweephand maximum demand pointer during the demand period. The pointer can go upward but not downward until reset is made manually when the meter is read. Thus the maximum demand during a billing period is determined. Internal mechanical connections are made between the demand meter and the watt-hour meter. Figure 1 shows a sketch of a small meter.

Another type of meter is a large demand meter which is a type of recording instrument separate from the integrating watt-hour meter. Recording can be done on a chart or a magnetic tape. Chart recording demand meters have become obsolete and they are being replaced by newer magnetic tape recording device. For large commercial and industrial users who require more than 500 kW peak load, large demand meters are installed [13]. The demand meters are linked to the watt-hour meters electrically. Pulses generated by a signal pickup device in the watt-hour meter are fed into the demand meter in which the pulses are totalized for a short time period, and the totalized value is recorded at each sampling instance for recording. A description of the totalization technique can be found in a report by Hurley, Kelly, and Kopetka [14]. More detailed information on demand meters is described elsewhere [12].

For demand control, sampled data from the pulse counter (totalizer) are required for digital processing by a microprocessor or a computer. The sampling rate, T_s, may depend upon the system of interest. By installing an optical or mechanical device, electric pulses can be generated in small demand meters like those discussed earlier. Figure 2 shows a possible arrangement



Figure 1. A sketch of a small demand meter





for demand metering for a customer using large amounts of electric power. This illustration provides a general view of demand metering. Besides the pulses from the watt-hour meter, it is sometimes possible to obtain (from the utility) a second pulse signal which indicates the end of one demand period and the start of the next period; a demand interval signal.

2.2 FIXED INTERVAL METERING

Fixed interval metering is the most widely used method in the measurement of electric demand. For a fixed time interval (15, 30, or 60 minutes set by the utility), the average power use is computed to be the demand for that period. At the end of each billing period, the peak demand is then taken by the power company, and billing is made based on the peak demand in conjunction with the rate schedule. Since billing methods differ depending on the contract between the utility and its customers, no attempt is made here to discuss a customer's payment to a utility in terms of dollars.

A requirement of the fixed interval metering technique is that a reset signal must be available at the end of every demand interval so that the demand meter can again accumulate the energy use from zero. The reset signal can be originated from an internal clock of the demand meter, or from an external clock. The reset signal may also come directly from the utility to the demand meters. Should the reset signal fail once, measured demand will be doubled if the required electric power remains the same for two consecutive demand periods. Thus, special attention must be paid to detecting the reset signal when fixed interval metering is used to control demand, especially if the reset signal is not continuously synchronized with the power company.

When the demand interval is D, and the sampling period is T_s , the number of samples in the demand interval, n, will be D/T_s . If the total number of pulses during the i-th sampling period is given by N_i , the average power, \overline{P} , which is the demand during the whole demand interval, is expressed by:

$$\overline{P} = \frac{1}{n} \sum_{i=1}^{n} \frac{CN_i}{T_s}$$
(1)

where C is the conversion factor in kWh per pulse. Since C and T_{g} are usually constant, equation (1) yields:

$$\overline{P} = \frac{C}{T_s n} \sum_{i=1}^{n} N_i$$
(2)

The instantaneous power at the i-th sampling instant may be given by:

$$P_{i} = \frac{CN_{i}}{T_{s}}$$
(3)

It should be noted that, since the unit of C is kWh per pulse, both D and T_s must be in hours. The term "instantaneous power" means the average power during a sample period when the pulse counting technique with a watt-hour meter is used for power measurement. However, if continuous direct power measurement is available, for example, by means of using analog devices (voltmeter and ammeter), the sampled data at an instant can be considered the instantaneous value of power at that instant.

As an example, if D is 30 min, T_s is 60 sec, N_i is 10 pulses for i-th period, and C is 0.72 kWh per pulse, the instantaneous power at the i-th period can be computed from equation (3), resulting in:

$$P_{i} = \frac{(.72)(10)}{\frac{60}{3600}} = 432 \text{ kW}$$

If the measured number of pulses for all sampling intervals is the same, the average power in the demand interval is from equation (2):

$$\overline{P} = \frac{0.72}{\left(\frac{60}{3600}\right)(30)} \sum_{i=1}^{30} (10) = (1.44)(300) = 432 \text{ kW}$$

This result coincides with the previous result as expected.

Furthermore, suppose pulse counts of 100 and 200 pulses during the first and second sampling periods, respectively, were obtained during the demand period, then the integrated demand becomes

 \overline{P} = (1.44) (100 + 200) = 432 kW.

We arrive at the same answer as before. This indicates that high peak power for a short time period does not really increase the demand because the demand is an integrated quantity over the demand interval. Figure 3 illustrates fixed interval metering.

2.3 SLIDING WINDOW METERING

A reset signal, preferably synchronized with the utility's metering system, is a requirement for using the fixed interval method. When reset signal is not available or is missing due to equipment failure, fixed interval metering is



Figure 3. Fixed interval metering

not desirable. Sliding window metering is the method that is usually used when there is no synchronized reset pulse. In this technique, the demand interval is still fixed. If the current sampling instant is moved to the next sampling period and it becomes the upper limit of the integration, then the lower limit moves ahead by one sampling period. In this way, the total number of observations remains unchanged as time progresses so the demand during a demand period is calculated at the end of each sampling period and one of those measurements will be the peak demand. Unlike the fixed interval method, this method requires knowledge of the past history of instantaneous power measurements between the lower and the upper time limits. This means that dynamic data storage is needed.

Because dynamic data memory capability is required with sliding window metering, a computer must be incorporated with the demand meter.

If the energy consumption rate (power), P(t), is sampled with a sampling period, T_s , and if a zero-order hold filter [15] is employed to reconstruct the sampled data, the integrated energy consumed, E(t), starting at time t_s and ending the current time, t, can be given by:

$$E(t) = \int_{t_s}^{t} P(t)dt \approx \sum_{k=0}^{n-1} P(kT_s) T_s$$
(4)

where n is the total number of sampled data in the demand period, D. The demand in that period, P(t), is computed by dividing E(t) by D, namely

$$\overline{P}(t) = \frac{E(t)}{D} = \frac{1}{n} \sum_{k=0}^{n-1} P(kT_{g})$$
(5)

At the next time step, $t + T_s$, retaining the same index k for time t, the demand yields:

$$\overline{P}(t+T_{g}) = \frac{E(t+T_{g})}{D} = \frac{1}{n} \sum_{k=1}^{n} P(kT_{g})$$
(6)

At t + 2 T_8 , the computed demand becomes (see figure 4):

$$\overline{P}(t+2T_{g}) = \frac{E(t+2T_{g})}{D} = \frac{1}{n} \sum_{k=2}^{n+2} P(kT_{g})$$
(7)

Clearly, one can see that the sliding window method is a moving integration method. Instead of a zero-order hold filter, use of the linear point connector [15] can be considered to minimize errors when the sampling rate is low.

The integration method employed in this report is the simple trapezoidal method. It would not be surprising if the customer's computation of total energy usage during a billing period disagrees with the utility's meter reading because different integration methods may be used. It is obvious that the accuracy of integration will be increased as the sampling rate increases.



Figure 4. Sliding window metering

3. DEMAND LIMITING CALCULATION METHODS

The highest demand during a billing period is often used as a basis for determining the demand charge for a future billing period. The main purpose of demand limiting is therefore to avoid establishing new higher peaks by maintaining the maximum demand within a preset limit. Non-essential or lower priority loads are usually turned off when load shedding becomes necessary by a demand limiting decision-making process. The load shedding decision is made by a calculation method that is selected as the most appropriate method for a given situation. There exist three well-known calculation methods at the present time [2,5,7,8,9,16]. They are the ideal rate, the predictive (or forecasting), and the instantaneous rate methods.

3.1 IDEAL RATE METHOD

The ideal rate method was first used with analog type demand controllers. In this method, the quantity of energy consumed is measured and accumulated by the demand controller. The integrated value is then compared with a maximum allowable value which varies with respect to time in a predetermined rate. The principle of the ideal rate uses linear prediction to determine the allowable energy at the next sampling instant, and incorporates fixed interval metering. This principle may also be applied on large metering devices that may include computers.

Figure 5 illustrates the ideal rate method. As seen on the figure, an adjustable offset, E_0 , is provided to delay required shedding action to a later stage of time in the demand interval instead of having it in the earlier



TIME, t



time. This offset permits restoring of the shed loads during the previous demand period. If all loads which have been shed are restored at the beginning of the next demand interval, the offset value should be set at a relatively high value.

If the maximum allowable demand power during a demand interval is selected as P_{max} , the integrated energy in that interval will be D times P_{max} . The ideal rate line without the offset, $E_1(t)$, as seen in figure 5, has the slope of P_{max} . When the offset value is other than zero, the integrated energy

expression with respect to time, $E_2(t)$, can be given by:

$$E_2(t) = (P_{max} - \frac{E_0}{D}) t + E_0$$
 (8)

where E is the offset.

Since E_0 and D are positive constants, the rate of change of $E_1(t)$ is always greater than that of $E_2(t)$. The ideal rate of change is thus $(P_{max} - E_0/D)$ instead of P_{max} . Remember that the ideal rate method is used only with fixed interval metering.

 $E_2(t)$ may be used as an upper limit for the demand limit control, (see figure 6).

$$E_{max}(t) = E_2(t) \tag{9}$$

Whenever the measured, integrated energy usage, E(t), exceeds the limit value, $E_{max}(t)$, load shedding takes place. It is also desirable to restore the loads which were shed if the rate of energy use is much lower than the ideal rate.



TIME, t



A minimum limit value can be assigned so that load restoring may be performed if the energy usage is less than the limit value that is expressed by:

$$E_{\min}(t) = \left(P_{\max} - \frac{E_0}{D}\right)t + E'_0$$
(10)

where E_0' is the intersection that is less than E_0 in the amount of ΔE . In terms of the differential, ΔE , equations (9) and (10) give a relationship as:

$$E_{\min}(t) = E_{\max}(t) - \Delta E \tag{11}$$

Depending upon the value of E at a particular time, the load control actions may be selected. No control action is needed if the E(t) stays in the range as

$$E_{\min}(t) \leq E(t) \leq E_{\max}(t)$$
(12)

3.2 PREDICTIVE METHOD

At each measurement instant in a demand interval, the instantaneous rate of energy consumption is measured and a forecast of the energy consumption at the end of the demand interval is made. This calculation procedure is called the predictive or forecasting method. Either fixed interval or sliding window metering may be used with the predictive method. The predictive principle needs more computational effort than the ideal rate principle. As a result, unlike the ideal rate principle, the predictive method can be employed only with a computer. For simplicity, the predictive method with fixed interval metering will be described in this section. Assume the desired peak demand is P_{max} . When the peak demand occurs, the accumulated energy use will be $P_{max}D$, in which the demand interval is a constant. Knowing that E(t) is the integrated energy consumption from the beginning of the demand interval to a specific time, t, the total energy consumption at the end of the demand interval can be predicted. A simple linear prediction may be made based on the energy use at the current time and at the previous sampling period. The predicted energy consumption without correction (shedding loads) at the end of the demand interval, $E_p(t)$, is given by:

$$E_{p}(t) = \left(\frac{D-t}{T_{g}}\right) \left[E(t) - E(t-T_{g})\right] + E(t)$$
(13)

The value of $E_p(t)$ is compared with $E_{max}(= P_{max}D)$ at a certain time. Loads are then shed when E_p exceeds the preset value E_{max} . Loads may be restored when E_p is less than a limit given by

$$E_{\min} = P_{\min} D \tag{14}$$

where Pmin is the preset value of power selected as the lower limit.

3.3 INSTANTANEOUS RATE METHOD

With the instantaneous rate method, the rate of energy consumption is measured at short time intervals and each measurement is compared with a predetermined limiting value. Whenever this instantaneous rate exceeds the upper limit, P_{max} , load shedding takes place. When the instantaneous rate of energy use is below the limit that is preestablished as the lower limiting value, P_{\min} , loads are restored. The control band, which is the difference between the upper and the lower limits, is needed to minimize rapid cycling of the load control action. As long as the measured power at time t, P(t), stays in the range as given by $P_{\min} \leq P(t) \leq P_{\max}$, loads are neither shed nor restored. The advantage of using this instantaneous rate principle is that synchronization with the utility's demand interval is not necessary. This principle, however, does not involve the demand interval.

4. DEMAND LIMITING ALGORITHMS

In previous sections, the general principles of demand limiting have been reviewed. In this section, the algorithms developed for use with computers will be discussed. The ideal rate and the predictive methods incorporate fixed interval metering. The predictive method may also use sliding window metering, while the instantaneous method does not need specific metering. The load control algorithm is not given with the main algorithms, but is presented in Section 5.

The demand limit algorithms use the trapezoidal integration method in which the average value of the power measured at the current sampling instant and the power measured at the past sampling instant is computed. The average power value is then multiplied by the sampling period to give the instantaneous value of energy consumption at the current time. This approach provides less computational error than the approach using a zero-order holder. Although the accuracy of integration can be improved with a high sampling rate, the system under consideration usually limits the sampling rate.

The algorithms presented here need supporting hardware and software to perform the actual load shedding. With the aid of the supporting software and hardware, the pulse countings can be entered and resulting control action signal can be transmitted to the device of interest. Computer programs are written in FORTRAN 77 and given in the appendices.

4.1 IDEAL RATE METHOD WITH FIXED INTERVAL

The computer algorithm of the ideal rate method is quite simple. Because of using fixed interval metering with this method, a demand interval reset signal must be provided. The important input data is the instantaneous power, P(t), determined by measuring the number of pulses from a watt-hour meter for a sampling period. An expression of the instantaneous power at a sampling instant is given by equation (3). The calculation procedure of power using equation (3) is not included in the algorithm given in this report, because the power can also be determined from direct measurements of the electric current and the voltage at an instant.

For a given demand period, D, and sampling interval, T_s , the average energy consumption rate is calculated, and then is compared with the preset ideal rate as described in the section 3.1. The ideal rate is a function of the maximum allowable power, P_{max} , the offset, E_o , and the demand interval. The actual energy usage, E(t), is compared with the maximum energy use up to the point of time from the beginning of the interval. Load shedding occurs if $E(t) > E_{max}(t)$ and loads are restored if $E(t) < E_{min}(t)$, in which $E_{max}(t)$ and $E_{min}(t)$ are the upper and lower limiting quantities at time t. The amount of load to be shed or restored is calculated by:

$$\Delta P = (P_{max} - E_0/D) - \widetilde{P}(t)$$
(15)

(16)

where $\widetilde{P}(t) = (P(t) + P(t - T_s))/2$

For simplicity, P_{max} is a constant, but if the rate schedule contains different rates for different times-of-day, P_{max} needs to be varied according to a predetermined schedule.

A flow chart of the ideal rate method in conjunction with fixed interval metering is depicted in figure 7. No load shedding or restoring is performed if the reset signal at the end of the demand interval is missed. Load control is resumed when the next reset signal is received.

A computer program (DLRF) for this algorithm appears in Appendix A.

4.2 PREDICTIVE METHOD WITH FIXED INTERVAL

The predictive method using fixed interval metering has been described in Section 3.2. The algorithm for this metering will be explained briefly here. With this algorithm, the ultimate value of energy consumption at the end of the demand period is forecasted. At every sampling time, the forecasting is made and load shedding is performed if the predicted value exceeds the preset value.

To avoid exceeding the preset limit, the amount of power subject to shedding, ΔP , is determined from equation (13) and the demand limit value of P_{max} .

$$\Delta p = \frac{E_{max} - E_{p}(t)}{D - t} = \frac{P_{max}D - E_{p}(t)}{D - t}$$
(17)

By differentiating equation (17) with respect to time, using the assumption that the predicted energy usage at each time during the remaining time in the



Figure 7. Logic flow diagram of the subroutine DLRF for the ideal rate method

demand period remains unchanged, i.e. $E_p(t) = E_p$, the following result is obtained:

$$\frac{d(\Delta P)}{dt} = -(P_{max}D - E_p)/(D-t)^2$$
(18)

As time approaches D, the denominator becomes smaller, resulting in an increment of the rate of change in ΔP , provided $E_p > P_{max}D$. This means that for the same forecasted value of E_p , load shedding is less likely to be needed at the beginning of the demand interval but the need progressively increases as time passes until the end of the interval. Because of this effect, demand limiting control using the predictive method with fixed interval metering allows an electricity customer to use high power at first, then gradually cut down as the end of the demand interval approaches to prevent setting a new peak demand. As a result, utility load curves show a roller-coaster effect with an overload state at the beginning and an underload condition near the end of each demand period [16].

Figure 8 shows a logic flow chart of the predictive method using fixed interval metering. Given P_{max} , P_{min} and D, this method predicts the load shedding required. If the reset pulse is missed, no load control action takes place until the reset pulse is restored. The computer program DLPF is based on this algorithm and is provided in Appendix B.

4.3 PREDICTIVE METHOD WITH SLIDING WINDOW

As mentioned in the previous section, the roller-coaster effect can be observed in the utility's load curves when customers employ demand limit



Figure 8. Logic flow diagram of the subroutine DLPFA for the predictive method with fixed interval metering

controls based on fixed interval metering. Peaks and valleys appear in the load distribution, resulting in short-time overloading and underloading. Although short-time high power places a burden on the utility, the charge for the short-period demand cannot be imposed on the consumers because the integrated energy use for the demand interval is still below the preset value. Various billing methods are devised by some utilities. For instance, one utility company charges its industrial and commercial customers for a maximum demand that is calculated by the addition of any two adjacent 15-minute energy consumptions, while another utility computes the demand charge by adding six adjacent 5-minute energy usages. These cases of sliding window billing methods are illustrated in figure 9.

The predictive method using the sliding window metering is needed for the following cases:

- When the reset signal at the end of each demand period is not provided by the utilities.
- (2) When the reset pulse misses temporarily.
- (3) When the sliding window billing method is used.

For the third case, the sampling period for the instantaneous energy use rate must be less than the period of the sliding billing.

In the algorithm under consideration, the demand at the next sampling instant is predicted on the basis of the demands computed at the current time and at the previous sampling period. The demand period, D, the maximum allowable demand, P_{max} , the minimum demand for restoring loads, P_{min} , and the sampling period, T_{s} , are required input data.




With this algorithm, the demand at the next time step is unknown and thus must be forecasted from known values. Since the present and past energy consumptions are known, the energy consumption for a given demand period at time t + T_s can be expressed using a linear extrapolation as:

$$E(t + T_c) = 2 E(t) - E(t - T_c)$$
 (19)

where E(t) and $E(t+T_s)$ may be obtained from equations (4) and (6) after substituting $\widetilde{P}(t)$ as defined in equation (16) for P(t). The value of $E(t - T_s)$ can be calculated using the equation:

$$E(t - T_s) = \frac{D}{n} \sum_{k=-1}^{n-2} \widetilde{P}(kT_s)$$
(20)

where $n = D/T_s$.

By letting $E(t + T_s)$ be $E_p(t)$, a predicted energy consumption one sampling period ahead, and by letting E_{max} be the the maximum allowable demand times the demand interval (= P_{max} D), the amount of electrical power to be shed when $E_p(t)$ exceeds E_{max} yields:

$$\Delta P = \frac{E_{max} - E_{p}(t)}{T_{s}}$$
(21)

When $E_p(t)$ is lower than E_{min} , which is the product of P_{min} and D, loads can be restored by:

$$\Delta P = \frac{E_{\min} - E_{p}(t)}{T_{s}}$$

Figure 10 shows the logic flow of the predictive method with the sliding window metering. The computer program, DLPS is given in Appendix C.

(22)

4.4 INSTANTANEOUS RATE METHOD

The instantaneous rate method uses a very simple algorithm. The required input data are P(t), P_{max} and P_{min} . The instantaneous energy consumption rate is the average value of the measured power at the present and the past. Load shedding occurs if $\widetilde{P}(t) > P_{max}$, and load restoring takes place if $\widetilde{P}(t) < P_{min}$. The demand interval is not needed and the sampling period is not specifically involved. The sampling period is needed in equation (3) if the measurement of pulses is made in order to determine the power at an instant. Since the algorithm is so simple, the logic diagram is not provided here. However, Appendix D provides the computer program listing, DLIS.

4.5 PREDICTIVE METHOD WITH FLEXIBILITY IN METERING

The algorithm introduced here is a combined version of the predictive methods with the fixed interval metering which appeared in Section 4.2 and the sliding window metering which was discussed in Section 4.3. With this algorithm, one of two metering schemes can be selected depending upon the user's choice. When the fixed interval method is chosen and the demand interval reset signal is missed unexpectedly, the metering method is automatically switched to the sliding window metering. This automatic





changeover helps to prevent the accidental creation of a new peak demand when an unexpected thing happens such as a broken communication link between the reset signal source and the computer. Fixed interval metering is restored as as soon as the reset pulse is detected again. Variable peak demand distributions based on the time-of-day rate schedule may also be incorporated.

The computer program for this algorithm is lengthier than others in this report, because it allows for flexibility in metering. The logic flow of the linking program is shown in figure 11. Because the flow charts of predictive methods used in this algorithm are similar to the ones which appeared in figures 8 and 10, they are not presented here. The computer program listing, DLPFS, can be found in Appendix E.



Figure 11. Logic flow diagram of the subroutine DLP for linking

5. LOAD CONTROL ALGORITHM

Controlling loads is part of the job required by demand limiting control. For clarity, the load control algorithm is separately discussed here. Excellent discussions of load control are given in papers by Zilko [2], Spethmann [9], Novak [8], and Shih [5]. Based upon these previous works, the present load control algorithm was developed. This algorithm sheds or restores loads sequentially or rotationally. Provisions for inhibiting short cycling of equipment are made. However, a "comfort fairness" concept [10] is not included but the application of such a concept can be found elsewhere [17].

As pointed out by Pannkoke [7], resistance and motor loads can be shed. Shedable resistance loads include lighting, electric space heaters, boilers, electric furnaces, electric ovens, electric water heaters, battery chargers, de-icers, etc. Motor loads would be fans, pumps, air compressors, refrigeration compressors, etc. Selective loads to be controlled may be anything that can be turned off without harming equipment, significantly impairing comfort, endangering the safety of personnel, or affecting production capability. Elevators, emergency equipment, essential lighting, and computers must be excluded from a list of candidates for shedding. If such loads are included in the list, they must be assigned the highest priority (i.e., not to be shed).

Sequential load shedding is carried out depending upon priority levels of loads. The lowest priority load is shed first and restored last, while the load with the highest priority is cut off last and turned on first. However,

when a number of loads are classified with the same priority, the order for shedding is determined on a rotational base (round-robin). With the rotational load shedding, a load shed first will be restored first. Each load has a rating and loads are selected and shed until the accumulated loads being shed satisfy the shedding requirement.

It is possible that loads with low priority might experience rapid cycling which might shorten the life of the equipment. To prevent short cycle operations, time parameters are set for minimum off-time and minimum on-times. The minimum off-time ensures that once a load is shed, it will not be turned back on before a predetermined safe period has elapsed. This is particularly needed for the refrigeration system compressors. On the other hand, the minimum on-time is needed so that once a load is turned on, it will remain on for a reasonable time and is essential to prevent motors from being shut off before reaching full rotational speed.

In addition to these two time parameters, Novak [8] described the maximum offtimes of loads. A noticeable change in temperature, humidity, air quality, etc. does not permit a certain type of load to be turned off for more than a specific period. Careful analysis of limiting conditions can determine the length of the maximum off-period of each load. Also, particularly during an initial cycle of load control, delay times for starting loads are necessary to prevent sudden surges of power. Delay times for each load can be set in order to make a smooth start-up during an initial start period of equipment rather than turning on a large number of loads all at once.

The algorithm for controlling loads presented here as the subroutine LDONOF

incorporates all the elements mentioned above. To use this algorithm, a table must be prepared prior to the start of program. Load identification number, priority, average required power, delay time, minimum off-time, minimum ontime, and maximum off-time are tabulated and stored as one of the input files for the demand limiting program. The priority listed in the table is referred to as global priority. In contrast to the global priority, local priority levels are generated internally by the algorithm for loads with the same level of global priority.

There are two subroutines, PUSH and POP, that support the main load control routine (LDONOF). One assigns the highest local priority to the load that is most recently shed (PUSH) and the other assigns the lowest local priority to the load most recently restored (POP). Using local priority, the rotational order is created for loads with the same global priority. It is important to point out that even if a load is in the lowest level of priority, it is not shedable if the minimum on-time requirement has not been met. On the other hand, if the minimum off-time for a load has not elapsed, the load cannot be restored. Implementation of these requirements in the algorithm has increased its complexity.

The load controller algorithm is as follows:

- Set up local priority levels for each global priority level. Two local priority levels are assigned in a sequential order, one for turn-off and another for turn-on.
- (2) Turn on loads during the initial cycle after delay times have passed.
- (3) If a power decrease is demanded by a decision-making algorithm as

given in Chapter 4, and only if minimum on-times have passed, start to shed loads with the lowest priority. Then assign the highest local priority to the load which has just shut off.

- (4) Restore loads, if a power increase is allowed, and if minimum offtimes have passed. A load with the highest priority is restored first. Once a load is back on, assign the lowest local priority to the load.
- (5) If the maximum off-time of a load has elapsed, restore the load regardless of its priority.
- (6) Increase on and off times by one sample period for the use in next time step.
- (7) Go to step (3).

The output values of the load control algorithm are logical values (true or false). If the logical value of a load is true, it is expected that the load is turned on, otherwise the load is turned off. A logical value itself cannot be used to directly to control any device. A command given by a high level language must be transformed into signals that are associated with switching devices. Generally machine language subprograms are involved to speed up the process. Therefore, appropriate software and hardware are needed with the load control algorithm.

Figure 12 shows the logic flow diagram for the subroutine LDONOF, and its computer program appears in Appendix F with the PUSH and POP subroutines. To aid hardware implementation, computer simulations using the open-loop assumption are described in Appendix G.



the subrotuine LDONOF for load control Logic flow diagram of Figure 12.

Duty cycle, time-of-day, scheduled start/stop, or optimum start/stop control may be active at the same time that the demand limiting control is in operation. Such a case could cause a conflict between control algorithms. This kind of problem can be resolved by reassigning the level of priority of each control algorithm depending on the conditions to be met. For instance, for shedding, a demand limiting controller should have higher priority than a duty cycling controller. But for restoring activity, the duty cycling controller can ignore a request to turn on by the demand limiting control. As a result, a high level supervisory controller is required to control all control algorithms involved. Since coordination among strategies is discussed by Spethmann [9] and May [17], further discussion will not be made in this report.

6. CONCLUSION

Demand limiting control is an important strategy for energy management and control systems (EMCS). The use of demand limiting control can not only avoid establishment of a new peak demand during a billing period, but it can also reduce energy consumption. Selection of the appropriate demand limit algorithm depends upon the billing method of the utility and the availability of a demand period reset signal. Thus, a demand limiting algorithm should be tailored according to a given situation. In the load control algorithm used with a demand limiting control, the input value determination is the customer's responsibility. The customer must provide sufficient load flexibility to permit adequate shedding capability. Appropriate coordination of the hardware, the computer programs provided in this report, and supporting software are essential for successful controls. When other control strategies are involved simultaneously with demand limiting, a supervisory program must govern the controlling activities to resolve conflicts that may arise between strategies.

It is believed that after necessary modification the algorithms presented here can be implemented on actual hardware.

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2	с ⁻			
34	C C C	DLRFMAIN	I : Demand limiting main program for the ideal ra with fixed interval metering	ite met
5 6 7	000	January	12, 1984 C.P.	
8	с - С			
1ø	č	DELAY	Delay time to start	(min)
11	С	DELP	The amount of power to be shed or restored	(kW)
12	C	DIFF	Difference between maximum and minimum energy le	evels
13	C		No. of the stand	(kWh)
14	C	DMDP	Demand period	(min)
15	C	IU	Identification number of a load	
15	č	INTISI	False when no initial start is moded	
10	č	IDESET	I for operative of the reset signal of demand my	ter ind
19	č	INCOLI	A for off-status of the reset signal	scer mg
28	č	ITIME	Number of samples taken from the beginning of samples	mpling
21	č	LDNAME	Load name	
22	č	LOADON	True if the load is turned on	
23	Ċ		False if the load is turned off	
24 .	С	MAXOFF	Maximum off-time of a load	(min)
25	С	MINOFF	Minimum off-time of a load	(min)
26	С	MINON	Minimum on-time of a load	(min)
27	С	NL	Maximum number of loads (=5Ø)	
28	C	NLD	Total number of loads	
29	C	OFFSET	Offset at the beginning of each demand period	(kWh)
3Ø	C	PDATA	Measured power data	(kW)
31	C	PLUAD	Nominal power of a load	(KW)
32	L C	PMAX	maximum power allowed in a demand limit period	11.5.15
24		PPTLOW	Lowest alobal priority	(KW)
25		PRILOW	Clobal priority of a load	
36	č	FRIOR	The highest priority is 1 and the lowest priorit	
30	č		PPTION	Ly IS
38	č	PRT	True if printing of detailed information of loss	d etatu
39	č	TRI	is desired.	u statu
49	č		False if short print-out is desired.	
41	č	RESET	True when a reset signal is on.	
42	č		False when the reset signal is off.	
43	č	TSAMPL	Sampling period	(min)
44	č			
45	Č *	********	***************************************	*****
46	С			
47		LOGICAL	RESET, LOADON, INITST, PRT	
48		REAL	MAXOFF, MINOFF, MINON	
49		INTEGER	PRIOR, PRILOW	
5 <i>ø</i>		CHARACT	ER LDNAME*15	
51		PARAMET	$ER (NL=5\emptyset)$	
52		COMMON	/BK1/ DMDP, TSAMPL, PMAX, DIFF, OFFSET, PDATA	
53		&	/BK2/ RESET, IRESET, ENCAL	
54		å	/BK3/ MAXOFF(NL), MINOFF(NL), MINON(NL), PRIOR(NL),	
			IDNAME (NE) PIOAD (NE) DELAV(NE) INITET	
55		Ox .		

APPENDIX A. Computer Program Listing of the Ideal Rate Method with Fixed Interval-DLRF

58 59		NAMELIST /INPUT/ DMDP, TSAMPL, PMAX, DIFF, OFFSET, PRILOW, PRT, INITST /OUTPUT/ ITIME, PDATA, IRESET, DELP
68	С	
61	č	Read input data files and print them.
62	č	
63	Ŭ	OPEN(7 FILE='INPUTRE')
64		
64		
65		OPEN(9, FILE= INPOIPWR')
66		KEWIND /
6/		KEWIND 8
68		KEWIND 9
69	C	
7.0		READ(7, INPUT)
71		PRINT INPUT
72		PRINT 4888
73		I=1
74	18	READ(8,1888,END=28) ID(I),LDNAME(I)
75		READ(8,*) ID(I), PRIOR(I), PLOAD(I), DELAY(I), MINOFF(I).
76		& MINON(I), MAXOFF(I)
77		PRINT 2888. ID(I), LDNAME(I), PRIOR(I), PLOAD(I), DELAY(I), MINOFE(I),
78		A MINON(I) MAXOFF(I)
79		
89		
0.0	24	
01	20	
82	L L	
83	L L	Kead power and reset signals from a meter in real control
84	C	
85		ITIME=8
86	3ø	READ(9, *, END=999) PDATA, IRESET
87		IF(ITIME.EQ.Ø.AND.IRESET.NE.1) GOTO 3Ø
88		IF(ITIME.EQ.1441) ITIME=1
89		PRINT 3000
9ø	С	
91	С	Ideal rate method using fixed interval metering
92	С	
93		CALL DLRF(DELP)
94	С	
95	Ċ	Control loads based on priorities, minimum on/off-times
96	C	and maximum on-times of loads.
97	č	
98		CALL LDONOF(DELP)
99		PRINT OUTPUT
188		IF(.NOT.PRT) THEN
โตโ		PRINT 5999.(ID(I), I=1, NLD)
192		PRINT $6\pi\pi\pi$ (LOADON(I), I=1, NLD)
193		
194		ITIME ITIME +1
195		$\Delta F = a$
196		
107	C	
100	1000	FORMAT/12 1V A15)
100	1000	FORMAT/15,14,8157
1105	2000	FORMAT(10,14,A10,10,0710.67
1 1 10	3000	FORMATION TA THE TO TTEM TO TO TOTAL TO TOTAL
111	4101010	TURMATUTTA, TD, TS, TIEM, TZT, TRIURITT, TSB, FLUAD,
112	F. 0.0.7	a 140, UELAY, 150, MINULL, 160, MINUN, 1/0, MAXULL'I
113	5000	
114	6888	FUKMAI(20L4)
115	С	

999 STOP 116 117 END 118 С 119 С c c DLRF : Demand limiting using ideal rate method with fixed interval metering 120 121 122 С С С January 12, 1984 C.P. 123 124 125 C C C C 126 DELP The amount of power to be shed or restored (kW)DIFF Difference between maximum and minimum energy 127 levels 128 (kWh) 129 DMDP Demand period (min) 13Ø F The amount of energy used from the beginning of a demand limit period to the current time Maximum energy level allowed at sampling instant 131 (kWh) 132 EMAX (kWh) 133 134 EMIN Minimum energy level allowed at sampling instant 135 (kWh) ENCAL 136 Energy used from the beginning of demand period to the sampling instant(i.e., the latest value of E) (kWh)
1 for on-status of the reset signal of demand metering 137 138 IRESET 139 140 N 141 NINT 142 OFFSET 143 PDATA Measured power data (kW) 144 PMAX Maximum power allowed in a demand limit period 145 (kW)PWR 146 Average value of power at current and past sampling 147 (**k**W) instants 148 RESET True when a reset signal is on. 149 False when the reset signal is off. TSAMPL Sampling period 15Ø (min) Ċ 151 ** 152 C 153 SUBROUTINE DLRF(DELP) LOGICAL RESET PARAMETER (NINT=6Ø) DIMENSION P(Ø:NINT),E(Ø:NINT) COMMON /BK1/ DMDP,TSAMPL,PMAX,DIFF,OFFSET,PDATA /BK2/ RESET,IRESET,ENCAL NAMELIST /OUTRFI/ I,PWR,ENCAL,EMAX,EMIN DATA ICYCLE,IFLAG/Ø,1/,E(Ø)/Ø.Ø/ 154 RESET 155 156 157 158 & 159 16Ø 161 0000 Bypass when the reset signal is missed and resume the normal operation when the reset signal appears 162 163 164 IF(IFLAG.EQ.2) THEN IF(IRESET.EQ.1) THEN 165 166 167 IFLAG=1 ICYCLE=Ø 168 169 ELSE PRINT 3000 17Ø 171 172 RETURN ENDIF 173 FNDIF

```
174
            C
C
175
                    Reset the counting of samples
            č
                    IF(IRESET.EQ.1 .AND. IFLAG.EQ.1) THEN
177
178
                      N=DMDP/TSAMPL+Ø.Ø1
                      RESET=.TRUE.
                      NN = \emptyset
18Ø
181
                    ENDIF
182
            0000
                    Set all energy stock values zero at the end of demand period except the initial cycle
183
184
185
                    IF(RESET) THEN
IF(ICYCLE.EQ.8) THEN
186
187
                         P(Ø)=PDATA
188
189
                         ENCAL=Ø.Ø
190
                         ICYCLE=1
191
                      ELSE
                         P(I)=PDATA
192
193
                         ENCAL=ENCAL+(P(1)+P(1-1))/2.*TSAMPL/68.
194
195
                         P(\emptyset) = P(I)
                       ENDIF
196
                       I =Ø
197
198
                      DO 18 K=8,N
E(K)=8.8
            10
199
                      RESET=.FALSE.
200
            С
            Č
C
2Ø1
                    Calculate average power and determine the power to be shed
2.02
                    or restored.
2Ø3
            С
284
                    ELSE
                      P(I)=PDATA
E(I)=(P(I)+P(I-1))/2.*TSAMPL/60.+E(I-1)
2.05
206
2Ø7
                       ENCAL=E(I)
208
                       EMAX=(PMAX-68.8*OFFSET/DMDP)*(I*TSAMPL/68.)+OFFSET
                       EMIN=EMAX-DIFF
2Ø9
                       IF(I.LT.N) THEN

P(I)=60.*(E(I)-E(I-1))/TSAMPL

PWR=P(I)
210
211
212
213
                         IF(E(I).GT.EMAX) THEN
DELP=PMAX-60.*OFFSET/DMDP-P(I)
214
215
216
                         PRINT 1888,-DELP
ELSEIF(E(I).LT.EMIN) THEN
DELP=PMAX-68.*OFFSET/DMDP-P(I)
217
218
219
228
221
222
                            PRINT 2000, DELP
                         ENDIF
                       ENDIF
                    ENDIF
            С
223
224
                    PRINT OUTRFI
                    I = I + 1
                    NN=NN+1
225
226 227
            000
                    Set a flag to bypass the calculation when the reset signal misses
228
229
                     IF(NN.GT.N) THEN
23Ø
                       NN=NN-1
231
                       IFLAG=2
```

232		ENDIF
233	C	
234	1999	FORMAT(/5X,' POWER TO BE SHED', F10.2,'')
235	2000	FORMAT(/5X, '+++++ POWER TO BE RESTORED', F18.2, '+++++')
236	3000	FORMAT('1111111 MISSING RESET SIGNAL 11111'/)
237	С	
238		RETURN
239		END



APPENDIX B.	Computer Program	Listing of	the	Predictive	Method	with
	Fixed Interval -	DLPF				

Q\$Q\$Q\$*DL(1)	.DLPF	(Ø)						
1	C ***	********	***************************************	*******				
2	C	DIREMAIN, Depend limiting main program for predictive wethod						
3	C	ULPEMAIN	It Demand limiting main program for predictive met	noa				
4			using fixed interval metering					
5		1	12 1004 C D					
5		January	12, 1904 C.F.					
0	с с							
0	<u> </u>			_				
19	č		Delay time to start	(min)				
11	ř	DELP	The amount of nower to be shed or restored	(FM)				
12	č	DMDP	Demand period	(min)				
13	č	ID	Identification number of a load					
14	č	INITST	True for initial start					
15	Ċ		False when no initial start is needed					
16	Č	IRESET	1 for on-status of the reset signal of demand met	ering				
17	С		Ø for off-status of the reset signal	-				
18	С	IT1ME	Number of samples taken from the beginning of sam	pling				
19	C	LDNAME	Load name					
200 .	C	LOADON	True if the load is turned on					
21	C		False if the load is turned off					
22	C	MAXOFF	Maximum off-time of a load	(min)				
23	5	MINUFF	Minimum off-time of a load	(min)				
24			Maximum on-time of a loade (250)	(min)				
25	č		Total number of loads					
27	č	PDATA	Measured power data	(12)				
28	č	PLOAD	Nominal power of a load	(kW)				
29	č	PMAX	Maximum power allowed in a demand limit period					
3Ø	C			(kW)				
31	С	PMIN	Minimum power allowed in a demand limit period					
32	С			(kW)				
33	С	PRILOW	Lowest global priority					
34	C	PRIOR	Global priority of a load					
35	C		The highest priority is 1 and the lowest priority	/ 15				
36		00T	True (6 pointing of detailed information of land					
37	č	PKI	is desired	status				
39	č		False if short print-out is desired					
4.97	č	RESET	True when a reset signal is on.					
41	č		False when the reset signal is off.					
42	č							
43	C ***	********	***************************************	********				
4.4	С							
45		LOGICAL	RESET, LOADON, INITST, PRT					
46		REAL	MAXOFF, MINOFF, MINON					
47		INTEGER	PRIOR, PRILOW					
48		CHARACTE	ER LUNAME*15					
49		COMMON	LK (NL=50) (DV1/ DMDD TSAMDI DMAY DMIN DDATA					
50		COMMON A	/DRI/ UMUF,ISAMFL,FMAX,FMIN,FUAIA /RF2/ DESET IDESET DODED ENCAL					
52		t i	/RK3/ MAXOFF(NI) MINOFF(NI) MINON/NI) PRIOR/NI)					
53		1	IDNAME(NI) PLOAD(NI) DELAV(NI) INITST					
54		Ł	/BK4/ NLD. TD(NL), LOADON(NL), PRILOW, IPPIOF(NL NL)					
55		&	LPRLOW(NL), LPRION(NL,NL), PRT					
56		NAMEL IS	T /INPUT/ DMDP, TSAMPL, PMAX, PMIN, PRILOW, PRT, INITST					
57		&	/OUTPUT/ ITIME, PDATA, IRESET, DELP					

B-1

```
CCC
 58
 59
                        Read input data files and print them.
 6Ø
                       OPEN(7,FILE='INPUTPF')
OPEN(8,FILE='LOADTABL')
OPEN(9,FILE='INPUTPWR')
 61
 62
 63
                        REWIND 7
 64
                        REWIND 8
 65
 66
                        REWIND 9
 67
              С
                        READ(7, INPUT)
PRINT INPUT
PRINT 4000
 68
 69
 7Ø
 71
72
                        I = 1
              1.
                        READ(8,1000,END=20) ID(I),LDNAME(I)
                      READ(8,*) ID(I), PRIOR(I), PLOAD(I), DELAY(I), MINOFF(I),

& MINON(I), MAXOFF(I)

PRINT 2000, ID(I), LDNAME(I), PRIOR(I), PLOAD(I), DELAY(I), MINOFF(I),

& MINON(I), MAXOFF(I)
 73
 74
75
76
 77
                        I = I + 1
 78
                        GOTO IN
              2Ø
                        NLD = I - 1
 79
 8Ø
              С
              CC
 81
                        Read power and reset signals from a meter in real control
 82
 83
                         ITIME=Ø
                        READ(9,*,END=999) PDATA,IRESET
IF(ITIME.EQ.Ø.AND.IRESET.NE.I) GOTO 3Ø
IF(ITIME.EQ.144I) ITIME=I
 84
              30
 85
 86
 87
                        PRINT 3000
 88
              С
                        Predictive method using fixed interval metering
 89
               С
 9Ø
              С
 91
92
                        CALL DLPFA(DELP)
              0000
                        Control loads based on priorities, minimum on/off-times
and maximum on-times of loads.
 93
 94
 95
 96
                        CALL LDONOF(DELP)
PRINT OUTPUT
 97
 98
                         IF(.NOT.PRT) THEN
 99
                           PRINT 5888, (ID(I), I=I, NLD)
PRINT 6888, (LOADON(I), I=I, NLD)
100
101
                         ENDIF
182
                         ITIME=ITIME+I
                         DELP=Ø.Ø
1Ø3
                         GOTO 3Ø
104
1Ø5
              С
186
               1888
                         FORMAT(13,1X,A15)
                       FORMAT(13,17,415,
FORMAT(15,11,415,13,5F1Ø.2)
FORMAT(8Ø('-')/)
FORMAT(//T4,'ID',T9,'ITEM',T21,'PRIORITY',T3Ø,'PLOAD',
& T4Ø,'DELAY',T5Ø,'MINOFF',T6Ø,'MINON',T7Ø,'MAXOFF'/)
FORMAT(2Ø14)
               2888
107
1Ø8
               3000
189
               4888
110
111
               5000
112
               6888
                         FORMAT(28L4)
113
               C
               999
114
                         STOP
115
                         END
```

-----116 С 117 С DLPFA: Demand limiting using predictive method with fixed interval metering 118 č 119 С С С 120 121 January 12, 1984 C.P. CC 122 123 C C The amount of power to be shed or restored 124 DELP (kW) 125 DMDP Demand period (min) 126 127 The amount of energy used from the beginning of a demand limit period to the current time F (kWh) 128 EMAX Maximum energy level allowed in a demand limit period 129 13Ø (kWh) Minimum energy level allowed in a demand limit period EM1N 131 (kWh) Energy used during a sampling period (kWr Predicted value of energy use during a demand period 132 ENCAL (kWh) 133 EPRED 134 (kWh) 1 for on-status of the reset signal of demand metering 135 **1RESET** 136 137 N N1NT 138 139 Power at a sampling instant (kW) Measured power data 14Ø 141 PDATA (kW) PLOAD Nominal power of a load (kW) Maximum power allowed in a demand limit period 142 PMAX 143 144 (kW) Minimum power allowed in a demand limit period PM1N 145 (kW) 146 147 PPRED Predicted value of average power for a demand limit period (kW) 148 RESET True when a reset signal is on. 149 С С С С False when the reset signal is off. Sampling period 15Ø TSAMPL (min) ************************************ 151 С 152 SUBROUTINE DLPFA(DELP) 153 LOGICAL RESET PARAMETER (NINT=6Ø) 154 155 DIMENSION P(S:NINT), E(S:NINT) 156 COMMON /BK1/ DMDP.TSAMPL,PMAX.PMIN.PDATA /BK2/ RESET.IRESET.PPRED.ENCAL NAMEL1ST /OUTPF1/ 1.PPRED.EPRED.EMAX.EMIN.ENCAL 157 158 Ł 159 16Ø DATA 1CYCLE, 1FLAG/Ø, 1/ 161 C C C C C C C Bypass when the reset signal is missing and resume the normal operation when the reset signal appears. 162 163 164 165 1F(1FLAG.EQ.2) THEN 166 IF(IRESET.EQ.1) THEN 1CYCLE=Ø 167 168 1FLAG=1 ELSE 169 17Ø 171 PRINT 3000 RETURN 172 END1F 173 END1F

174	~	
1/4	6	
175	С	Reset the counting of samples
176	С	
177		IF(IRESET.EQ.1 .AND. IFLAG.EQ.1) THEN
178		N=DMDP/TSAMPI+Ø Ø1
170		
1/9		RESET=.IRVE.
180		N=8
181		ENDIF
182	С	
183	С	Set all energy stock values zero at the end of demand period
184	Ċ	except the initial cycle.
185	č	
196	Ŭ	IE/DESET) THEN
107		
187		IF (ICFCLE.EG.D/ INEN
188		P(B)=PDATA
189		ENCAL=8.8
19Ø		ICYCLE=1
191		ELSE
192		P(I)=PDATA
193		FNCAL = FNCAL + (P(I) + P(I-1))/2 + TSAMPL / 6R
194		$P(\alpha) = P(1)$
195	•	
195		
196		
197		DO IB K=B, N
198	1.5	E(K)=10.10
199		RESET=.FALSE.
200	С	
201	С	Predict energy use at the end of demand period and
282	Ċ	determine the power to be shed or restored.
293	č	
294	v	FISE
204		
2.05		
206		E(1)=(P(1)+P(1-1))/2.*TSAMPL/60.+E(1-1)
2.07		ENCAL=E(I)
208		EMAX=PMAX*DMDP/6Ø.
2Ø9		EMIN=PMIN*DMDP/6Ø.
210		IF(I.LT.N) THEN
211		$FPRFD = (N-T)^{*}(F(T)-F(T-1)) + F(T)$
212		
212		
213		
214		DELF=00(EMAX-EFRED)/(DMDF-I-ISAMPL)
215		rkini 1000,-DELP
216		ELSEIF(EPRED.LT.EMIN) THEN
217		DELP=6Ø.*(EMIN-EPRED)/(DMDP-I*TSAMPL)
218		PRINT 2000, DELP
219		ENDIF
220		ENDIF
221		ENDIF
222		PRINT OUTPEL
222		
224		
224	~	
225	C	
226	C	Set a flag to bypass the prediction when the reset signal misses.
227	C	
228		IF(NN.GT.N) THEN
229		NN=NN-1
230		IFLAG=2
231		PRINT 3888

232		PRINT 3000
233		ENDIF
234	С	
235	1000	FORMAT(/5X,' POWER TO BE SHED', F18.2,'')
236	2888	FORMAT(/5X, '+++++ POWER TO BE RESTORED'.F10.2, '+++++')
237	3888	FORMAT('IIIIII MISSING RESET SIGNAL IIII'/)
238	С	
239		RETURN
248		END



APPENDIX C.	Computer Program Listing of the Predictive Method
	with Sliding Window - DLPS

SOSOS*DL	(1).DL	PS(Ø)		
1	C *	*********		
3	č	DIPSMAIN	I: Demand limiting main program for predictive met	hod
Ă	č	DEFORMU	using sliding window metering	inou
5	č			
6	č	Januarv	12. 1984 C.P.	
7	Ċ	•		
8	Č -			
9	Ċ			
1.9	С	DELAY	Delay time to start	(min)
11	С	DELP	The amount of power to be shed or restored	(kW)
12	С	DMDP	Demand period	(min)
13	С	ID	Identification number of a load	
14	С	INITST	True for initial start	
15	С		False when no initial start is needed	
16	С	ITIME	Number of samples taken from the beginning of sam	pling
17	С	LDNAME	Load name	
18	С	LOADON	True if the load is turned on	
19	C		False if the load is turned off	
2.9	C	MAXOFF	Maximum off-time of a load	(min)
21	C	MINOFF	Minimum off-time of a load	(min)
22	C	MINON	Minimum on-time of a load	(min)
23	C	NL	Maximum number of loads (=58)	
24	L	NLU	lotal number of loads	(1.5.15
25	L C	PUATA	Measured power data	
20	L C	PLOAD	Nominal power of a load	(KW)
29		PMAA	maximum power allowed in a demand limit period	(144)
29	č	PMTN	Minimum newer allowed in a demand limit period	(KW)
30	č	1 114 11	Annihum power arrowed in a demand rimite period	(KW)
31	č	PRILOW	Lowest global priority	
32	č	PRIOR	Global priority of a load	
33	č		The highest priority is 1 and the lowest priority	/ 15
34	Č		PRILOW.	
35	Ċ	PRT	True if printing of detailed information of load	status
36	С		is desired.	
37	С		False if short print-out is desired.	
38	С	TSAMPL	Sampling period	(min)
39	С			
4Ø	C *	******	***************************************	*******
41	C			
42		LOGICAL	LOADON, INITST, PRT	
43		REAL	MAXOFF, MINOFF, MINON	
44		INTEGER	PRIOR, PRILOW	
45		CHARACTI	ER LDNAME*15	
46		PARAMETE	LK (NL=50)	
47		COMMON	/BKI/ DMDP, ISAMPL, PMAX, PMIN, PDATA	
48		Če i	BK2/ PPKED, ENCAL	
49		Čr i	DK3/ MAXUFF(NL), MINUFF(NL), MINUN(NL), PKIOK(NL),	
510		Čr.	(PV4/ NLD TD(NL) LOADON(NL) PRIOU LEDTOCINU	
51		dr i	DR47 NLD, ID(NL), LOADON(NL), PRILOW, LPRIOF(NL, NL),	
52		CC NAMEL TO	T ANDIT A DADD TRANDI DWAY DATA DOTION DOT THITET	
53		NAMELIS	AUTDUT / ITIME DOATA DELO	
54	c	Čr.	JOUIFUIJ IIIME, FDAIA, DELF	
55	L C	Pond in	out data files and print them	
50	C C	Read In	put uata i i los anu print them.	
	6			

OPEN(7,FILE='INPUTPS') OPEN(8,FILE='LOADTABL') 58 . 59 OPEN(9, FILE='INPUTPWR') 6Ø 61 62 **REWIND** 7 **REWIND 8 REWIND 9** 63 64 С READ(7, INPUT) PRINT INPUT PRINT 4000 65 66 67 68 READ(8,1000,END=20) ID(1),LDNAME(1)
READ(8,*) ID(1),PRIOR(1),PLOAD(1),DELAY(1),MINOFF(1),
& MINON(1),MAXOFF(1)
PRINT 2000, ID(1),LDNAME(1),PRIOR(1),PLOAD(1),DELAY(1),MINOFF(1),
& MINON(1),MAXOFF(1) I = 169 10 7Ø 71 72 73 74 I = I + 1GOTO 1Ø 75 76 2Ø NLD = I - 177 C C C C 78 Read power signal from a meter in real control 79 8Ø ITIME=Ø READ(9,*,END=999) PDATA IF(ITIME.EQ.1441) ITIME=1 81 38 82 83 PRINT 3000 84 000 85 Predictive method using sliding window metering 86 87 CALL DLPSA(DELP) 88 0000 89 Control loads based on priorities, minimum on/off-times 90 and maximum on-times of loads. 91 92 93 CALL LDONOF(DELP) PRINT OUTPUT IF(.NOT.PRT) THEN PRINT 5000,(ID(I),I=1,NLD) PRINT 6000,(IOADON(I),I=1,NLD) 94 95 96 97 ENDIF 98 ITIME=ITIME+1 99 DELP=Ø.Ø 100 GOTO 3Ø 1Ø1 С FORMAT(I3,1X,A15) FORMAT(I5,1X,A15,I3,5F1Ø.2) FORMAT(8Ø('-')/) 1.02 1888 1Ø3 2000 FORMAT(88('-')/) FORMAT(//T4,'ID',T9,'ITEM',T21,'PRIORITY',T38,'PLOAD', & T48,'DELAY',T58,'MINOFF',T68,'MINON',T78,'MAXOFF'/) FORMAT(2814) 1Ø4 3000 1Ø5 4000 106 Ł 5000 1Ø7 108 6000 FORMAT(20L4) 109 C 999 STOP 110 111 END 112 С ***** 113 C C C C 114 DLPSA : Demand limiting using predictive method with 115 sliding window metering

1

C-2

110	C C			
.17	С	January	12, 1984 C.P.	
18	С			
19	C			
28	č	DELP	The amount of power to be shed or restored	(KV)
21	č	DMDD	Demand and to power to be shed of restored	(=1=)
21	č	CHUR	The second	VIRTEE
22	L L	L	ine amount of energy used from the beginning of	
23	С		a demand limit period to the current time	(kWh)
24	С	EMAX	Maximum energy level allowed in a demand limit p	eriod
25	C			(kWh)
26	č	EMIN	Minimum energy level allowed in a demand limit of	boing
27	č	E11110	The second state of the se	
20	č	ENCAL	France word doubter a second term and terd	(KWN)
28	L L	ENCAL	Energy used during a sampling period	(KWN)
29	C	EPRED	Predicted value of energy use during a demand pe	riod
3Ø	С			(kWh)
31	С	N	Number of samples in a demand limit period	
32	Ċ	NINT	Maximum number of samples in a demand limit peri	d(=6%)
22	č	PDATA	Massured power date	
33	č	PLAC	Transmission and a star	(KW)
34	L L	PLAG	lime-lagged power	(KW)
35	С	PMAX	Maximum power allowed in a demand limit period	
36	С			(kW)
37	С	PMIN	Minimum power allowed in a demand limit period	
38	č			(KN)
20	č	DDDED	Predicted uplus of success source for a depend lit	- * +
33	Č.	FFRED	riedicted value of average power for a demand in	n 1 C
410	U U		period	(KW)
41	С	START	True at the beginning of program run	
42	С		False otherwise	
43	С	TSAMPL	Sampling period	(min)
44	Č **	********	******	*******
45	č			
40	L.	CURROUT		
40		SUBRUUT	THE DEFSALDELF/	
4/		LOGICAL	START	
.48		PARAMET	ER (NINT=6.07)	
.49		DIMENSI	ON PLAG(Ø:NINT),E(Ø:2)	
5Ø		COMMON	/BK1/ DMDP.TSAMPL.PMAX.PMIN.PDATA	
51		L	/BK2/ PPRED.FNCAL	
52		NAMELIS	T CONTEST I PERED EPRED EMAY EMIN ENCAL	
52		DATA CT	ADT / TOUE /	
53	•	DATA ST	ARTZ.IRUE.Z	
54	L.			
55	С	Determi	ne the number of samples per sample period.	
56	C			
57		N=DMDP/	TSAMPL+Ø.Ø1	
58	C			
59	č	Initial	ize the regressor vector of nower	
ca	5	Interat	The the regressor vector of power.	
00	L	TE COTO	TA TUEN	
61		IFISTAR	17 THEN	
62		ICYCL	E=Ø	
63		I = Ø		
64		DO 10	′K≖Ø.Ν	
65	10	PLACE	$(\mathbf{K}) = \mathbf{A}, \mathbf{A}$	
60	1.0	CTADT		
00		START	FALSE.	
67	С			
68	С	Determi	ne the regressor vector of power in the learning	period.
	С			
69		ELSELE(ICYCLE.EQ.Ø) THEN	
69 7Ø			**····································	
69 7Ø		PLACE	Ø) = PDATA	
69 7Ø 71		PLAG($(\theta) = PDATA$	
169 17Ø 171 172		PLAG(DO 2Ø	Ø)=PDATA K=N-1,Ø,-1	

. .

174		IF(I.EQ.N-1) ICYCLE=I
176	C	* - * * *
177	č	Predict energy use at the next sampling instance
178	č	and determine the power to be shed or restored.
179	č	
189	•	FISE
181		PLAC(g)=PDATA
182		SUM=#.#
183		DO 38 K=1.N-1
184	38	SUM=SUM+TSAMPL/68.*(PLAG(K)+PLAG(K+I))/2.
185		E(Ø)=SUM
186		$E(1) = TSAMPL/6\vartheta$. *(PLAG(ϑ) +PLAG(1))/2.+E(ϑ)
187		ENCAL=E(1)
188		E(2)=2*E(I)-E(Ø)
189		EPRED=E(2)
19ø		PPRED=60.*EPRED/DMDP
191		EMAX=PMAX*DMDP/60.
192		EM1N=PMIN*DMDP/6Ø.
193		IF(EPRED.GT.EMAX) THEN
194		DELP=68.*(EMAX-EPRED)/TSAMPL
195		PRINT 1888,-DELP
196		ELSEIF(EPRED.LT.EMIN) THEN
197		DELP=68.*(EMIN-EPRED)/TSAMPL
198		PRINT 2888, DELP
199		ENDIF
200	C	
281		PRINT OUTPSW
282	C	
2.03	C	Shift back the regressor vector by one sample period
204	C	
285		
200	4.07	FLAG(K+1)=FLAG(K)
201	~	ENDIF
200	1000	FORMATIVEN ISSUED TO BE SUEDI ELG 2 ISSUEDI
207	2000	FORMATI / SV TAAAAA POUED TO BE DESTORED FIR 2 TAAAAAT
211	2000	FURMALLIDA, TYTT FUWER TO BE RESTORED , FID. 2, "TTTT)
212	L	DETIIDN
212		
213		END

APPENDIX D.	Computer	Program	Listing	of	the	Instantaneous	Rate
· · ·	Method -	DLIS					

Q\$Q\$Q\$*DL(1).DLI	S(Ø)	*************	********
234		DLISMAIN	: Demand limiting main program for instantaneou rate method	5
5 6 7		Januar y	12, 1984 C.P.	
8	C			
18	c	DELAY	Delay time to start	(min)
11	č	DELP	The amount of power to be shed or restored	(kW)
12	Č	ID	Identification number of a load	
13	С	INITST	True for initial start	
14	С		False when no initial start is needed	
15	C	ITIME	Number of samples taken from the beginning of sa	mpling
16	C	LDNAME	Load name	
17	C	LOADON	Irue if the load is turned on	
18	L C	MAYOFE	Havinum offetime of a load	1-1-1
28	č	MINOFF	Minimum off-time of a load	(min)
21	č	MINON	Minimum on-time of a load	(min)
22	č	NL	Maximum number of loads (=50)	CHITT
23	č	NLD	Total number of loads	
24	Ċ	PDATA	Measured power data	(kW)
25	С	PLOAD	Nominal power of a load	(kW)
26	C	PMAX	Maximum power allowed in a demand limit period	
27	C			(kW)
28	C	PMIN	Minimum power allowed in a demand limit period	(1.1.)
29	L C	BB TLOV	Lounat alabal antenttu	(KW)
30	č	PRILOW	Clobal priority of a load	
32	č	r RIOR	The highest priority is 1 and the lowest priorit	u fe
33	č		PRILOW.	y 13
34	č	PRT	True if printing of detailed information of load	i status
35	С		is desired.	
36	С		False if short print-out is desired.	
37	C			
38	C *1	*********	***************************************	*********
39	C	LOCICAL	LOADON INITET DET	
4.0		DEAL	LUADUN, INIISI, FRI MAVOEE MINOEE MINON	
42		INTEGER	PRIOR PRIIOU	
43		CHARACT	ER LDNAME*15	
44		PARAMET	ER (NL=5%)	
45		COMMON	/BK1/ PMAX, PMIN, PDATA	
46		& · .	/BK3/ MAXOFF(NL), MINOFF(NL), MINON(NL), PRIOR(NL),	
47		&	LDNAME(NL), PLOAD(NL), DELAY(NL), INITST	
48		& .	/BK4/ NLD, ID(NL), LOADON(NL), PRILOW, LPRIOF(NL, NL),	,
49		& 	LPRLOW(NL), LPRION(NL, NL), PRT	
50		NAMELIS	I /INFUI/ PMAX, PMIN, PKILOW, PKI, INIISI	
51	C	œ	/OUTFOI/ ITIME, FDATA, DELF	
53	č	Read in	put data files and print them.	
54	č	iteau ini		
55		OPEN(7.	FILE='INPUTIS')	
56		OPEN(8,	FILE='LOADTABL')	
57		OPEN(9,	FILE='INPUTPWR')	

```
58
                       REWIND 7
 59
                       REWIND 8
                       REWIND 9
 6Ø
             C
 61
                      READ(7,INPUT)
PRINT INPUT
PRINT 4000
 62
63
 64
 65
                       I=1
                     READ(8,1000,END=20) ID(I),LDNAME(I)
READ(8,*) ID(I),PRIOR(I),PLOAD(I),DELAY(I),MINOFF(I),
& MINON(I),MAXOFF(I)
 66
             18
 67
 68
                     PRINT 2000, ID(I),LDNAME(I),PRIOR(I),PLOAD(I),DELAY(I),MINOFF(I),
& MINON(I),MAXOFF(I)
 69
7Ø
71
                       I = I + 1
 72
73
74
                       GOTO IØ
NLD=I-1
             2Ø
             000
 75
76
77
78
79
                       Read power from a meter in real control
                       ITIME=Ø
                       READ(9,*,END=999) PDATA
IF(ITIME.EQ.I441) ITIME=I
             3Ø
 8Ø
                       PRINT 3000
 81
             000
 82
                       Instantaneous rate method
 83
 84
                       CALL DLIS(DELP)
             0000
 85
                       Control loads based on priorities, minimum on/off-times
and maximum on-times of loads.
 86
 87
 88
                       CALL LDONOF(DELP)
PRINT OUTPUT
 89
 90
 91
92
93
                       IF(.NOT.PRT) THEN
PRINT 5888,(ID(I),I=I,NLD)
PRINT 6888,(LOADON(I),I=1,NLD)
 94
95
                       ENDIF
                       ITIME=ITIME+I
 96
97
                       DELP=Ø.Ø
                       GOTO 3Ø
 98
             С
                       FORMAT(13,1X,A15)
FORMAT(15,1X,A15,13,5F1Ø.2)
FORMAT(8Ø('-')/)
 99
              1000
100
              2000
                     FORMAT(//T4,'ID', T9,'ITEM', T21,'PRIORITY', T3Ø, 'PLOAD',
& T4Ø,'DELAY', T5Ø,'MINOFF', T6Ø,'MINON', T7Ø,'MAXOFF'/)
FORMAT(2ØI4)
1Ø1
              3000
1Ø2
              4888
1Ø3
184
              5000
                       FORMAT(20L4)
1Ø5
              6888
1Ø6
              C
                       STOP
1Ø7
              999
108
              С
1Ø9
                 ***
                       ....
I1Ø
             CCCC
111
                       DLIS : Demand limiting using instantaneous rate method
112
113
                       January 12, 1984 C.P.
114
              Ĉ
115
              Ċ
```

116 117 118 129 121 122 123 124 125 126 127 128 129 130 137 134 135 136 137	0000000000	DELP PAVG PDATA PLAG PMAX PMIN RESET	The amount of power to be shed or restored Average value of current and past powers Measured power data Time-lagged power Maximum power allowed in a demand limit period Minimum power allowed in a demand limit period True when a reset signal is on. False when the reset signal is off.	(kW) (kW) (kW) (kW)
	c ***	SUBROUT LOGICAL DIMENSIC COMMON NAMELIS DATA RES IF(RESE PLAG() PLAG()	INE DLIS(DELP) RESET ON PLAG(Ø:1) /BK1/ PMAX,PMIN,PDATA T /OUTISW/ PAVG,PMAX,PMIN SET/.TRUE./ T) THEN Ø)=Ø.Ø 1)=Ø.Ø = EALSE	*****
138 139 140 141 142 143 144 145 145 146 147 148 149 149	c	ELSE PLAG() PAVG= IF(PA DEL PRI ELSEI DEL PRI ENDIF	#.FALSE. Ø)=PDATA (PLAG(Ø)+PLAG(1))/2. VG.GT.PMAX) THEN P=PMAX-PAVG NT 1000,-DELP F(PAVG.LT.PMIN) THEN P=PMIN-PAVG NT 2000,DELP	
150	C	PRINT	OUTISW	
152 153 154	C	PLAG(ENDIF	1)=PLAG(Ø)	
155 156 157	1000	FORMAT FORMAT	(/5X,' POWER TO BE SHED', F1Ø.2,'') (/5X,'+++++ POWER TO BE RESTORED', F1Ø.2,'+++++')	
159 16Ø	C	RETURN		

D-3


APPENDIX E. Computer Program Listing of the Predictive Method with Flexibility in Metering - DLPFS

2 3	C C	DLPFSM	AIN: Demand limiting main program for predictive m	nethod
4	C	Janus	ary 12, 1984 C.P.	
6	č	• and	ury 12, 1904 offi	
8	с - С			
9	C	DELAY	Delay time to start	(min)
1Ø	C	DELP	The amount of power to be shed or restored	(kW)
11	C	DMDP	Demand period	(min)
12	C C	FIXINI	False if aliding window metering is used	
14	č	tn	Identification number of a load	
15	č	INITST	True for initial start	
16	č		False when no initial start is needed	
17	č	IRESET	1 for on-status of the reset signal of demand me	tering
18	C		Ø for off-status of the reset signal	
19	С	ITIME	Number of samples taken from the beginning of sa	mpling
2Ø	С	LDNAME	Load name	
21	C	LOADON	True if the load is turned on	
22	C		False if the load is turned off	
23	C	MAXOFF	Maximum off-time of a load	(mfn)
24	C	MINUFF	Minimum off-time of a load	(min)
25		MODE	minimum on-time of a load	(min)
20	č	MODE	= 1 for fixed interval metering	
28	č	MI	Maximum number of loads (=50)	
29	č	NED	Total number of loads	
3Ø	č	PDATA	Measured power data	(kW)
31	Č	PLOAD	Nominal power of a load	(kW)
32	С	PMAX	Maximum power allowed in a demand limit period	
33	С			(kW)
34	C	PMIN	Minimum power allowed in a demand limit period	(4.1)
35	č	PRILOW	Lowest global priority	VKW7
37	č	PRIOR	Global priority of a load	
38	č	T K I OK	The highest priority is 1 and the lowest priorit	tv is
39	Č		PRILOW.	
4.Ø	С	PRT	True if printing of detailed information of load	d status
41	С		is desired.	
42	C		False if short print-out is desired.	
43	C	TSAMPL	Sampling period	(mîn)
44	C a	********	***************************************	
45	C .			
47	C	LOGICA	RESET. FIXINT. LOADON, INITST. PRT	
48		REAL	MAXOFF, MINOFF, MINON	
49		INTEGE	R PRIOR, PRILOW	
5Ø		CHARAC	TER LDNAME*15	
51		PARAME	TER (NL=5Ø)	
52		COMMON	/BK1/ DMDP,TSAMPL,PMAX,PMIN,PDATA	
53		å	/BK2/ FIXINT, RESET, IRESET, PPRED, ENCAL	
54		ě.	/BK3/ MAXUFF(NL), MINOFF(NL), MINON(NL), PRIOR(NL),	
55		č.	ARAY NED TO (NE) LOADON (NE) BETLOW LED TO F (NE NE)	
30		CK CK	JURAJ NED, IDINEJ, EORDONINEJ, FRIEDW, EFRIDFINE, NEJ	•

.

--

. .

58 59		NAMELIST /INPUT/ DMDP,TSAMPL,PMAX,PMIN,PRILOW,PRT,MODE,INITST & /OUTPUT/ ITIME,PDATA,IRESET,DELP,FIXINT
6Ø 6 I	С	DATA FIXINT/.FALSE./
62 63	Ċ	Read input data files and print them.
64	•	OPEN(7,FILE='INPUTPFS')
65 66		OPEN(8,FILE='LOADTABL') OPEN(9,FILE='INPUTPWR')
67		REWIND 7
68		REWIND B REVIND 9
7.0	С	
7I		READ(7, INPUT)
72		PRINT 4888
74		1=1
75 76	1.0	READ(8,1888,END=28) ID(1),LDNAME(1) READ(8,*) ID(1),PRIOR(1),PLOAD(1),DELAY(1),MINOFF(1),
78		PRINT 2888, ID(I), LDNAME(I), PRIOR(I), PLOAD(I), DELAY(I), MINOFF(I),
79		& MINON(I), MAXOFF(I)
8 <i>0</i> 81		
82	2.0	NLD=I-1
83	C	Dead around and march along la fram a maker to youl sectors)
85	C C	when fixed interval metering is used(MODF=I).
86	č	Read power data only from a meter when sliding window
87	C	metering is used(MODE=2).
89	C	ITIME#Ø
9ø	3Ø	READ(9,*,END=999) PDATA, IRESET
91		IF (MODE.EQ.I.AND.ITIME.EQ.Ø.AND.IRESET.NE.I) GOTO 3Ø IF (ITIME.EQ.1441) ITIME=1
93		PRINT 3888
94	Ç	Deadletter mathed to a 71-d union aliding of day on filled
96	Č.	interval metering
97	Ċ	
98	r	CALL DLP(MODE, DELP)
ØØ	č	Control loads based on priorities, minimum on/off-times
Ø1	C	and maximum on-times of loads.
102	C	CALL DONOF (DELP)
84		PRINT OUTPUT
1 <i>8</i> 5		IF(.NOT.PRT) THEN
1.007		PRINT 6888, (LOADON(I), I=1, NLD)
88		ENDIF
1.09		111ME=111ME+1 DF1P=Ø.Ø
ĨĨ		GOTO 3Ø
112	C	
13	2888	FORMAT(15,1X,A15) FORMAT(15,1X,A15,13,5F1#,2)
115	3888	FORMAT(BØ('-')/)

.

16	4000	FORMAT(//T4, 'ID', T9, 'ITEM', T21, 'PRIORITY', T30, 'PLOAD',
17	Faaa	E TAB, DELAY, 150, MINOFF', 160, MINON', T70, MAXOFF')
18	5000	FORMAI(2014)
29	0000	FORMAT(2024)
21	aaa	STOP .
22	222	
23	C ***	
24	č	
25	č	DIP : Demand limiting link program for predictive method
26	č	ber o bemane thistoring think program for productive method
27	č	January 12, 1984 C.P.
28	Č	
29	C ***	**********************
30	С	
31		SUBROUTINE DLP(MODE, DELP)
32		LOGICAL RESET,FIXINT
33		COMMON /BK1/ DMDP,TSAMPL,PMAX,PM1N,PDATA
34		BK2/ F1X1NT, RESET, 1RESET, PPRED, ENCAL
35	C	
36	C	Sliding window metering
37	C	TECHORE FOR AN THEN
38		IF (MODE.EU.2) THEN
39	~	CALL DEPSB(DELP)
410	č	Etvad Interval metering
42	č	rixed interval metering If the rest class is missing at the next sampling
43	č	instance, sliding window metering is activated When
44	č	the reset signal is restored. Fixed interval metering
45	č	is also restored.
46	č	
47		ELSE1F(MODE.EQ.1) THEN
48		1F(1RESET.EQ.1) THEN
149		FIXINT=.TRUE.
15 <i>Ø</i>		ENDIF
151		1F(F1XINT) THEN
152		CALL DLPFB(DELP)
153		ELSE
154		CALL DLPSB(DELP)
155		
155	~	ENDIF
150	C	DETIIDN
159		
160	C ***	
161	č	
162	Č	DLPFB: Demand limiting using predictive method with
163	Ċ	fixed interval metering
164	С	
165	С	January 12, 1984 C.P.
166	С	
167	C	
168	C	DELP The amount of power to be shed or restored (kW)
169	C	umur vemand period (min)
1710		e amount or energy used from the beginning of
172	c	MAY May mum energy layed allowed the adverted limit period
173	č	

174	C	EMIN	Minimum energy level allowed in a demand limit pe	rfod
175	С			(kWh)
176	С	ENCAL	Energy used during a sampling period	(kWh)
177	С	EPRED	Predicted value of energy use during a demand per	fod
178	č			(kWh)
179	ř	FPS	A small positive number (sf. fl)	
100	č	ETVINT	Thus if fived interval material to used	
100		L TVTUT	The it fixed incerval mechanics used	
181	L A		raise it sliding window metering is used	
182	C	IRESET	I for on-status of the reset signal of demand met	ering
183	С		Ø for off-status of the reset signal	
184	С	N	Number of samples in a demand limit period	
185	С	NINT	Maximum number of samples in a demand limit perio	d(=6Ø)
186	С	P	Power at a sampling instant	(kW)
187	Ċ	PDATA	Measured power data	(kW)
188	ř	PMAX	Maximum power allowed in a demand limit period	
100	č	1 1000	having power arrowed in a demand thate period	1241
107	2	DMTN	Minimum neuron allound in a domand limit nonied	
190		LUTU	minimum power allowed in a demand limit period	****
191	C .			(KW)
192	C	PPRED	Predicted value of average power for a demand lim	It
193	С		period	(kW)
194	С	RESET	True when a reset signal is on.	
195	С		False when the reset signal is off.	
196	C	TSAMPL	Sampling period	(min)
197	C **	******	********	*******
198	č			
100	U	SUPPORT		
200		LOCICAL		
200		LUGICAL		
2.01		PARAMETI		
2102		DIMENSIO	ON P(B:NINI), E(B:NINI)	
2Ø3		COMMON	/BK1/ DMDP,TSAMPL,PMAX,PMIN,PDATA	
2.04		& .	/BK2/ FIXINT,RÉSET,IRESET,PPRED,ENCAL	
2ø5		NAMEL IS	T /OUTPFI/ I.PPRED.EPRED.EMAX.EMIN.ENCAL	
2.06		DATA IC'	YCLE/Ø/	
2.87	C			
208	ř	Reset ti	he counting of samples	
200	č	Nebee e	is countring of samples	
210	C	TE / TRES	ET EO 11 THEN	
210		IFVIKES	LI-EG.I/ INEN	
211		N=UMU	T/ISAMPLTD.DI	
212		RESET	=.IKUE.	
213		NN=107		
214		ENDIF		
215	С			
216	С	Set all	energy stock values zero at the end of demand per	lod
217	Ċ	except	the initial cycle	
218	ć			
219	•	TE (RESE	T) THEN	
220		TELIC		
2210		ITTIC		
221		PUB	J=FUATA	
222		ENC		
223		ICY	CLE=1	
224		ELSE		
225		P(I)=PDATA	
226		ENC	AL=ENCAL+(P(I)+P(I-1))/2.*TSAMPL/60.	
227		Pla)=P(T)	
228		ENDIE		
229		t-a		
220			K-a N	
230	10	00 10		
231	1.0	E(K)=	19 · 19	

232		RESET=	·FALSE.
233	С		
234	С	Predict	energy use at the end of demand period and
235	С	determin	e the power to be shed or restored.
236	С		
237		FLSE	
238		P(I)=P	DATA
220			POID P/1320/1-133/20 #TEAMD1/20 20/1 13
235		E(1/=(r(1)+r(1-1)//2.*(SAMPL/60.+E(1-1)
240		ENCAL	
241		EMAX=P	MAX*DMDP768.
242		EMIN=P	MIN*DMDP/68.
243		IF(I.L	T.N) THEN
244		EPRE	D=(N-I)*(E(I)-E(I-1))+E(I)
245		PPRE	D=68.*EPRED/DMDP
246		IF (E	PRED.GT.EMAX) THEN
247		DE	1P = 6R + (FMAX - FPRED) / (DMDP - T + TSAMPL)
248		PR	INT 1000 -DELP
249		FISE	TE (EPPED IT EMIN) THEN
250			
251			TAT 2000 DELD
252		ENDI	
252		ENDI	, r
253		ENDIF	
254		ENDIF	
255		PRINT OU	JIPF I
256		I=I+1	
257		NN=NN+1	
258	C		
259	С	Switch c	over to sliding window metering when
26Ø	С	the rese	et signal is not detected.
261	С		
262		IF(NN.GT	T.N) THEN
263		ICYCLE	
264		FIXINT	T=.FALSE.
265		RESET=	•.TRUE.
266		PRINT	3000
267		ENDIE	
268	c	211021	
269	1000	FORMAT	(SY PARATE POWER TO BE SHED! E10 2 PARATE)
270	2000	FORMATI	(5) 'AAAAA POWER TO BE RESTORED' E10 2 'AAAAA')
271	2000	FORMATI	SA, THE SUITCHED TO SERVISIONED FILLERAL
272	5000	FURMATY	TITTE SWITCHED TO SEIDING WINDOW TITTE //
272	C	OFTHON	
273		CND	
275			***************************************
275	C		
276	C C		Description of the second
2//	C .	DLPSB :	Demand limiting using predictive method with
278	C		sliging window metering
279	C		10 1004 0.0
280	C	January	12, 1984 C.P.
281	C		
282	C		
283	C	DELP	The amount of power to be shed or restored (kW)
284	С	DMDP	Demand period (min)
285	С	E	The amount of energy used from the beginning of
286	С		a demand limit period to the current time (kWh)
287	С	EMAX	Maximum energy level allowed in a demand limit period
288	C		(kWb)
200	U		

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29Ø (kWh) C C C Energy used during a sampling period (kW Predicted value of energy use during a demand period (kWh) 291 ENCAL 292 EPRED 293 С (kWh) Number of samples in a demand limit period Maximum number of samples in a demand limit period(=68) 294 0000 N N1NT 295 296 PDATA Measured power data (kW) 297 PLAG 0000000 Time-lagged power (kW) 298 Maximum power allowed in a demand limit period PMAX 299 (kW) 300 PMIN Minimum power allowed in a demand limit period 3Ø1 (kW) PPRED Predicted value of average power for a demand limit 302 3Ø3 period (kW) C C 3Ø4 RESET True when a reset signal is on. 3Ø5 False when the reset signal is off. С Sampling period 3Ø6 TSAMPL (min) C ********** 3Ø7 ** ***** C 3Ø8 SUBROUTINE DLPSB(DELP) 309 31Ø LOGICAL RESET PARAMETER (NINT=6Ø) 311 DIMENSION PLAG(S:N1NT), E(S:2) 312 COMMON /BK1/ DMDP,TSAMPL,PMAX,PMIN,PDATA /BK2/ FIXINT,RESET,IRESET,PPRED,ENCAL NAMELIST /OUTPSW/ I,PPRED,EPRED,EMAX,EMIN,ENCAL 313 314 2 315 316 C C 317 Determine the number of samples per demand period č 318 N=DMDP/TSAMPL+Ø.Ø1 319 32Ø С C C 321 Initialize the regressor vector of power. 322 IF(RESET) THEN 323 324 ICYCLE=Ø 325 1=Ø 326 DO 10 K=0, N 327 10 PLAG(K)=Ø.Ø 328 RESET=.FALSE. C C 329 33Ø Determine the regressor vector of power in the learning period. 331 C 332 ELSE1F(1CYCLE.EQ.Ø) THEN PLAG(Ø)=PDATA 333 DO $2\emptyset$ K=N-1, \emptyset ,-1 PLAG(K+1)=PLAG(K) 334 335 2Ø 336 IF(I.EQ.N-1) ICYCLE=1 337 I = I + 1338 С С С Predict energy use at the next sampling instance and determine the power to be shed or restored. 339 340 341 С 342 ELSE 343 PLAG(Ø)=PDATA SUM=Ø.Ø 344 345 DO 3Ø K=1,N-1 346 3Ø SUM=SUM+TSAMPL/60.*(PLAG(K)+PLAG(K+1))/2. 347 $E(\emptyset) = SUM$

348		E(1)=TSAMPL/6Ø.*(PLAG(Ø)+PLAG(1))/2.+E(Ø)
349		ENCAL=E(1)
35Ø		E(2)=2*E(1)-E(0)
351		EPRED=E(2)
352		PPRED=60.*EPRED/DMDP
353		EMAX=PMAX*DMDP/60.
354		EMIN=PMIN*DMDP/50.
355		IF (FPRED.GT.FMAX) THEN
356		DELP=60.*(EMAX-EPRED)/TSAMPI
357		PRINT 1999DELP
358		FLSEIF(FPRED.IT.EMIN) THEN
359		DELP=60.*(EMIN-EPRED)/TSAMPI
368		PRINT 2000, DELP
361		ENDIE
362	С	
363	•	PRINT OUTPSW
364	С	
365	č	Shift back the regressor vector by one sample period
366	č	entre back end regresser obeect by end campic period
367	· ·	DO 49 K=N-1.91
368	4.11	PLAG(K+1)=PLAG(K)
369		ENDIF
378	С	
371	1888	FORMAT(/5X,' POWER TO BE SHED', F18, 2, '')
372	2999	FORMAT(/5X, '+++++ POWER TO BE RESTORED', E18.2, '+++++')
373	č	
374	•	RETURN
375		END

.



APPENDIX F.	Computer Pr	rogram	Listing	of	the	Load	Control
	Algorithm -	- LDONC)F				

	^			
3	C	LDONOF	: Turn on or off loads	
5	C	April 2	9, 1983 C.P.	
67	с –			
9	C C	DELAY	Delay time to start	(min)
1 <i>ø</i> 11 12	C C C	DELP EPS INITST	The amount of power to be shed or restored Small positive number for tolerance(=Ø.Ø1) True for initial start	(KW)
13 14	C C	ISTAT	False when no initial start is needed Number of loads which are turned on at an init	ial stage
15	C C C	ISUM Loadon	Number of loads turned on during initial cycle True if the load is turned on	
18			Local priority of a load	
28	000		Local priority of a load for restoring	
22	0	MAXOFF	Maximum off-time of a load	(min)
24	C C	MINON	Minimum on-time of a load Maximum number of loads (=5%)	(min)
26	Č C	NLD PLOAD	Total number of loads Nominal power of a load	(kV)
28 29	C C	PRI PRILOW	Global priority of a load Lowest global priority	
3Ø 31 32	C C C	PRIOR	Global priority of a load The highest priority is 1 and the lowest prior PRIION	ity is
33 34	C C	PRT	True if printing of detailed information of lo. is desired.	ad status
35 36 37	C C C	SUMP INT SUMP	False if short print-out is desired. Summed nominal power turned on during initial Summed nominal power actually shed or restored	cycle at an instant
38 39	C C	TOFF	Off-time of a load	(kW) (min)
4.Ø 41	C C	TON TSAMPL	On-time of a load Sampling period	(min) (min)
42 43	С С*	******	****************	******
44	c	SUBROUT	INE LDONOF(DELP)	
40	Ľ	REAL	MAXOFF, MINOFF, MINON PRIOR, PRI, PRILOW	
49 5Ø		LOGICAL CHARACT	LOADON, INITST, PRT ER LDNAME*15	
51 52			EK (NL=50) ON TON(NL),TOFF(NL),ISTAT(NL) /RKI/ DMDP TSAMPI PMAX PMIN PDATA	
54 55		COMMON &	/BK3/ MAXOFF(NL), MINOFF(NL), MINON(NL), PRIOR(NL) LDNAME(NL), PLOAD(NL), DELAY(NL), INITST /BK4/ NLD LD(NL), LOADON(NL), PRILOY LPRIOF(NL)	•

EO		NAMELIST /NAMI/ SUMINT ISUM INITST
20		NAMELISI /NAMI/ SUMINI,ISUM,INIISI
23		
610	-	DATA EPS/B.BI/, IFLAG/B/
6 I	C	
62	С	Initialization
63	С	
64	Ť	TE(TELAG, EQ. Ø) THEN
66		
05		
66		
67		TOFF(I)=0.0
68		LOADON(I)=.FALSE.
69		ISTAT(I)=Ø
79	1.01	CONTINUE
71	÷~	0000000
71	5	Colore leads and a lead to be and a lead a standay
12	C	Set up local priority levels for each global priority
73	С	level, PRIOR(I). Two local priority levels are assigned
74	С	in a sequential order, one for turn-off and another for
75	С	turn-on.
76	č	
77	Ŭ	DO 40 PRI-I PRI/OU
11		bo ab FRI-I, FRILOW
78		K=0
79		DO 28 I=I,NLD
8Ø		IF(PRIOR(I).EQ.PRI) THEN
81		K=K+1
82		IPRIOF(PRI I)=K
02		
03		
84	210	CONTINUE
85		LPRLOW(PRI)=K
86		KK=LPRLOW(PRI)+I
87		DO 38 I I.NLD
88		IF (PRIOR(I), FO, PRI) THEN
89		
00		
70		
91		ENDIF
92	3Ø	CONTINUE
93	4.8	CONTINUE
94		IFLAG=I
95		ENDIE
96	c	
50	č	The second design at a second se
97	C	furn on loads during the initial cycle after delay times
98	C	are over.
99	с	
100	С	
1Ø1		IF(INITST) THEN
1 0 2		I SIIM=R
102		
103		
104		DO 58 I=I,NLD
105		IF(TOFF(I),GE.DELAY(I)) THEN
1ø6		LOADON(I)=.TRUE.
1Ø7		SUMINT=SUMINT+PLOAD(1)
108		ISTAT(I)=I
1 99		
1.1.0		
110		150m=150m+151A1(1)
111		IF(ISUM.EQ.NLD) INITST=.FALSE.
112	50	CONTINUE
113		PRINT NAMI
114		ENDIF
115	C	

116	С	Shed loads if power decrease is demanded by the
117	С	amount of DELP, and if minimum on-times are passed.
118	С	Start to shed loads with low priority first.
119	С	Assign the highest local priority to the load most
120	С	recently shed.
121	С	
122		IF(DELP.LTEPS) THEN
123		SUMP = Ø . Ø
124		DO 90 PRI=PR1LOW, 1, -1
125	6.0	DO 80 LPR=LPRLOW(PR1),1,-1
126		DO 78 1=1.NLD
127		IF(PRIOR(I).GE.PR1.AND.TON(1).GE.MINON(1).AND.MAXOFF(I).GT.
128		& Ø.Ø.AND.LOADON(I).AND.LPRIOF(PRI.1).EQ.LPR) THEN
129		LOADON(I)=.FALSE.
130		$TOFF(1) = \emptyset, \emptyset$
131		KEY=LPRIOF(PR1.1)
132		CALL PUSH(KEY, PR1)
133		
134		PRINT 1999, 1
135		
136		
137		15 (SIMP CE -DELP) COTO 100
130	79	
130	20	
140	00	
140	100	
141	100	
142	~	ENDIF
143	C C	Destant lands if source increase is allound by the
144	L L	Restore loads it power increase is allowed by the
145	C	amount of DELF, and it minimum off-times are passed.
146	C	Start to restore loads with high priority first.
14/	C	Assign the lowest local priority to the load most
148	C C	recently restored.
149	C	
150		IF (DELF.GI.EFS) THEN
151		
152		DU 140 PRIEI, PRILOW
153	110	DU 130 LPR=1, LPRLOW(PRI)
154		
155		IF (PRIOR(I).EQ.PRI.AND.IOFF(I).GE.MINOFF(I).AND.
156		G (.NUT.LUADUN(I)).AND.LFKIUN(FKI,I).EU.LFK) THEN
15/		
158		
159		
160		KEY=LPRION(PRI,I)
161		
162		SUMP = SUMP + PLUAD(I)
163		PRINT 2000, 1
164		
165		
166		IF (SUMP.GE.UELP) GOTO 150
167	120	CONTINUE
168	130	CONTINUE
169	14.0	CONTINUE
17.0	15Ø	PRINT NAM2
171		ENDIF
172	С	
173	С	Restore loads regardless of priority level, if maximum

F-3

174	С	off-times are passed.
175	С	
176		IF(.NOT.1N1TST) THEN
177		DO 168 PRI=1, PR1LOW
178		DO 168 1=1,NLD
179		IF (PRIOR (I), EQ, PR1, AND, TOFF (I), GE, MAXOFF (I)
180		A AND. (.NOT. LOADON(I))) THEN
181		$I \cap A \cap O(I) = . TRUE$
192		
192		
103		
104		CALL FOR (KET, FRI)
185		FRINT 5200,1
185		
187	160	CONTINUE
188		ENDIF
189	Ç	
19Ø	С	Print details
191	С	
192		IF(PRT) THEN
193		PRINT 3000
194		DO 178 I=1,NLD
195	178	PRINT 4000, 1, PLOAD(I), TOFF(I), MINOFF(I), TON(I), MINON(I).
196		A LOADON(T), PRIOR(T), PRIOF(PRIOR(T), T), PRION(PRIOR(T), T)
197		FND1F
198	C	
199	ř	Increase one and offertimes by one sample period for
200	č	the use on- and on- threes by one sample period for
200	ž	the use in the next time step
201	C	DO 107 1-1 NUD
202		
2.03		IF (LOADON(I)) THEN
2.04		ION(I)=ION(I)+ISAMPL
2.65		1F(TON(I).GE.2*M1NON(I)+24*6Ø) TON(I)=2*MINON(I)
2.06		ELSE
2Ø7		TOFF(I)=TOFF(I)+TSAMPL
2.078		1F(TOFF(I).GE.2*MAXOFF(I)+24*6Ø) TOFF(I)=2*MAXOFF(I)
2Ø9		ENDIF
21Ø	18Ø	CONTINUE
211	C	
212	1000	FORMAT(5X,' LOAD #',15,2X,'SHED')
213	2000	FORMAT(5X,'+++++ LOAD #',15,2X,'RESTORED++++++')
214	3000	FORMAT(/T5,'1',T1Ø,'PLOAD',T21,'TOFF',T29,'M1NOFF',T41,'TON',
215		&T50, 'MINON', T56, 'STATUS', T63, 'PRI', T67, 'LPRIOF', T74, 'LPRION'/)
216	4888	FORMAT(15.5(F9.2.1X).3X.L1.2X.14.2(3X.13.1X))
217	5000	FORMAT(5X,'++++++ LOAD #'. 15.2X, 'RESTORED SINCE '.
218		& 'THE MAXIMUM OFF-TIME IS PASSED')
219	С	
229	•	PETIIRN
221		END
222	C ***	
223	č	
224	č	BUSH . Determine level reterity levels for each stur-
225	č	alebal patentity levels for each given
225	5	global priority .
220	č	And the Aber bishers from the transfer the second
22/	C	Assign the highest local priority to the load
228	C	which is most recently shed.
229	C	
230	C	April 27, 1983 C.P.
231	С	

1

```
232
           C
C
233
234
                   SUBROUTINE PUSH(KEY, PRI)
235
                                LOADON, PRT
                   LOGICAL
236
                   INTEGER
                                PRI, PRÍLOW
237
                   PARAMETER (NL=5Ø)
238
239
                   COMMON /BK4/ NLD, ID(NL), LOADON(NL), PRILOW, LPRIOF(NL, NL),
LPRLOW(NL), LPRION(NL, NL), PRT
                  å
240
                   DIMENSION ITEMP(NL,NL)
241
242
           С
                   DO 1Ø I=1, NLD
                      IF (LPRIOF(PRI,I).LT.KEY) THEN
ITEMP(PRI,I)=LPRIOF(PRI,I)+1
ELSEIF(LPRIOF(PRI,I).GT.KEY) THEN
243
244
245
                         ITEMP(PRI,I)=LPRIOF(PRI,I)
246
247
                      ELSE
248
249
25Ø
                        ITEMP(PRI,I)=1
                      ENDIF
            1.0
                   CONTINUE
251
            С
                   DO 2Ø I=1,NLD
LPRIOF(PRI,I)=ITEMP(PRI,I)
252
253
           2Ø
C
254
255
                   RETURN
256
                   END
257
            С
258
           Determine local priority levels for each given global priority .
259
                   POP :
26Ø
261
262
                             Assign the lowest local priority to the load
                             which is most recently restored.
263
264
265
266
                   April 27, 1983 C.P.
267
                      *************
268
              **
269
            С
27Ø
271
                    SUBROUTINE POP(KEY, PRI)
                    LOGICAL
                                 LOADON, PRT
                    INTEGER PRI, PRILOW
PARAMETER (NL=5Ø)
272
273
                    COMMON /BK4/ NLD, ID(NL), LOADON(NL), PRILOW, LPRIOF(NL, NL),
LPRLOW(NL), LPRION(NL, NL), PRT
274
275
                  &
276
277
278
                    DIMENSION ITEMP(NL,NL)
            С
                    DO 10 I=1,NLD
                      IF (LPRION(PRI,I).GT.KEY) THEN
ITEMP(PRI,I)=LPRION(PRI,I)-1
ELSEIF(LPRION(PRI,I).LT.KEY) THEN
ITEMP(PRI,I)=LPRION(PRI,I)
279
28Ø
281
282
283
                      ELSE
284
                         ITEMP(PRI,I)=LPRLOW(PRI)
                      ENDIF
285
                    CONTINUE
286
            10
287
            С
                    DO 2Ø I=1,NLD
LPRION(PRI,I)=ITEMP(PRI,I)
288
            2Ø
289
29Ø
            C
                    RETURN
291
292
                    END
```



APPENDIX G. Open-Loop Computer Simulation

For illustration purposes, a computer simulation was performed under an openloop condition and is presented in this appendix. The open-loop assumption cannot be applied in actual load control condition, employing demand limiting control algorithms. Without feedback, the effects of load shedding or restoring are not realized in the control action. The selected algorithm for the simulation was the predictive method with flexibility in metering (either fixed interval or sliding window metering) as described in section 4.5. Accordingly, the computer programs given in Appendix E and Appendix F were used. Most numerical values of input data were arbitrarily selected but some of the values for average power requirement were extracted from the work by May.* Some extremely large and small numerical values were specified as input data in order to check the capability of the computer program.

The main program, DLPFSMAIN, in Appendix E calls three input files as follows:

Logical Unit	File Name
7	INPUTPFS
8	LOADTABL
9	INPUTPWR

The format used by the file, INPUTPFS, is an input format for the NAMELIST statement of Fortran 77 in a Sperry 1100/82 computer. Since this format is machine-dependent, a Fortran user's manual should be consulted if other

^{*}W. B. May, "Analysis of Data from the Energy Monitoring and Control System at the Norris Cotton Federal Office Building," Natl. Bur. of Standards, NBSIR 81-2358, 1981.

computers are employed. If desired, the main program, DLPFSMAIN, may be modified to read the information in the INPUTPFS file interactively. The INPUTPFS file contains the following:

: demand period
: sampling period
: maximum power allowed in a demand period
above which shedding loads takes place
: minimum power allowed in a demand period
below which restoring loads takes place
: integer variable, lowest global priority.
The highest priority is 1 and the lowest
priority is PRILOW
: logical variable, set true (=T) if printing
of detailed information of load status is
desired, set false (=F) otherwise.
: integer variable, choice of metering.
When fixed interval used, MODE = 1 and
when sliding window is used, MODE = 2.
: logical variable, true (=T) if initial
start; otherwise set false (=F).

The file, LOADTABL, is needed for the load control routine, LDONOF, that is listed in Appendix F. The file comprises the following items for each load: ID = 001 : integer variable, load identification number LDNAME = NORMAL LIGHT #1 : description of a load, up to 15 characters

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PRIOR = 2: integer variable indicating the global priority of a load. The lower the number the higher the priority, and vice versa. nominal average power of a load PLOAD = 5.974 kW: $DELAY = 0.0 \min$: delay time for starting at the initial period $MINOFF = 0.0 \min$: minimum off-time of a load. Only after this off-time, the load may be restored. MINON = 0.0 min: minimum on-time of a load. Only after the on-time passes the minimum on-time, the load may be shed. $MAXOFF = 1440.0 \min$: maximum off-time of a load. If the load is maintained off more than the time period specified by MAXOFF, restoring the load occurs automatically. Assignment of highest number (=1440) prevents automatic restoring.

The values given above are the values for the first load in the file, LOADTABL, in this appendix. For each load, two lines of data are needed such as shown below:

1st line:ID, LDNAME(I3, 1X, A15)2nd line:ID, PRIOR, PLOAD, DELAY, MINOFF, MINON, MAXOFF (free format)

The instantaneous power, PDATA, is actually measured at each sampling instant in a real control environment. In this open-loop simulation, the instantaneous power is not measured, but specified arbitrarily. The file,

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INPUTPWR, contains the instantaneous power, PDATA, and a reset signal, IRESET. PDATA has a unit of kW, and IRESET is an integer, either 0 or 1. Presence of the reset signal from the utility's meter is indicated by IRESET = 1. PDATA and IRESET have a free format in the INPUTPWR file.

Important simulation output data are:

- DELP: the amount of power to be shed or restored LOADON: logical variable. True (=T) if the load is turned on and false
- (=F) if off. Using a supporting program, this logical value may be translated into a binary code and used as input to actual hardware controls.

Printout of I/O operation for the simulation is included in the following pages.

INPUT DATA FOR SIMULATION

Q\$Q\$Q\$*INPUTPFS(1) 1 \$1NPUT DMDP=5.0,TSAMPL=1.0,PMAX=75.0,PMIN=70.0,PR1LOW=3,PRT=F, 2 MODE=1,1N1TST=T,\$END

Q\$Q\$Q\$*LOAD	TABL	(1)				
1	ØØ1	NORMAL L10	GHT#1			
2	001	2 5.974	0.0	0.0	0.0	1440.0
3	882	NORMAL L10	GHT#2			
4	882	3 3.625	2.0	0.0	0.0	1448.8
5	003	ESSENTIAL	L1GH	r		
6	883	1 8.516	0.0	0.0	0.0	Ø.Ø
7	884	HEAT PUMP	#1			
8	884	3 13.753	3.0	5.0	90.0	20.0
9	005	HEAT PUMP	#2			
1Ø	005	3 5.597	4.0	3.0	3.0	15.0
11	006	FAN COIL				
12	006	2 0.546	3.0	2.0	2.0	10.0
13	887	FAN				
14	887	3 9.554	4.0	3.0	3.0	10.0
15	008	COOLER				
16	008	3 Ø.Ø37	5.0	5.0	5.0	20.0
17	889	PUMP				
18	009	2 0.748	4.0	3.0	3.0	20.0
19	Ø1Ø	ELEVATOR				
20	Ø1Ø	1 8.876	0.0	0.0	0.0	8.8
21	Ø11	EMERG. SY	STEM			
22	Ø11	1 8.395	0.0	0.0	0.0	8.8
23	Ø12	OTHER				
24	Ø12	3 2.091	2.0		90.0	1448.8

Q\$Q\$Q\$*1NPUTPWR(1)

1	31.76	ø
2	31.76	ø
3	31.76	Ø
4	31.76	ø
5	31.76	Ø
6	31.76	1
7	31.76	Ø
8	37.48	Ø
9	51.78	Ø
1.0	67.68	ø
11	67.72	1
12	67.72	Ø
13	67.72	Ø
14	67.75	ø
15	67.00	Ø
16	75.ØØ	1
17	60.00	ø
18	78.88	ø
19	75.00	Ø
2ø	60.00	ø
21	78.88	1
22	75.00	ø
23	80.00	Ø
24	85.00	ø
25	60.00	ø
26	50.00	1
27	80.00	ø
28	48.88	ø
29	50.00	Ø
3Ø	67.00	Ø
31	80.00	1
32	40.00	Ø

SOUTPFI 1 - 8,PPRED - .8888888 SERD SNAN1 SUMINT - .31761888+882.15UM -SERD SOUTPUT 1TIME - 8,PDATA - .31 SERD SEND 2 A S C 7 .EMAX ,ENCAL 4.1HIT5T = T #.PDATA = .3176########2.IRESET = 1.DELP - FIXINT + T SEND 1 2 3 4 5 6 7 8 9 18 11 12 T F T F F F F F F T T F T F T F F F F F F T T F POWER TO BE RESTORED SOUTPF1 47.88..... SOUTPF1 1 = I.PPRED = .31759999*##2.EP SEND SWAH1 SUMINT = .31761###-##2.ISUM = SEND SUMINT = .0AD # 12 RESTORED+..... SNAM2 SUMP = .5716####9*##1 SEND SOUTPUT ITIME = 1.PDATA = .3176####+#1 SEND 1 2 3 4 5 6 7 8 9 11 I.PPRED + .31759999+##2.EPRED + .26466666+##1.EMAX + .625#####1.EMIN + .5033333+##1.EMCAL - .5293333+### 4,1H1T5T + T 1,PDATA = .31768888+882,IRESET = SEND 1 2 3 4 5 6 7 8 9 18 11 12 T T F F F F F F T T T T SOUTPF1 59.92**** 2,PPRED + .34847999+882.EPRED + .20373333+881.EMAX + .62588888+881.EM1N + .50333333+881.EMCAL + .11863333+881 END SEND SNAM1 SUM1NT = .31761888+882.15UM = SEND SUM1 = .54688888+882.15UM = SUMP = .5468888+888 SEND SOUTPUT ITIME = 2.PDATA = .374888888+884 SEND 1 2 3 4 5 6 7 8 9 14 6.1HITST + T 2.PDATA + .374888888+882.1RE5ET + #.DELF = .5992###1+##2.FIXINT = T SEMD 1 2 3 4 5 6 7 0 9 10 11 12 T T T F F T F F F T T T SOUTPF1 74.87**** 1 + SEND SHAH1 3.PPRED + .48853999+882.EPRED + .33378333+881.EMAX + .62588888+881.EMIN + .58333333+881.EMCAL + .18581666+881

10	1TEH	PR	IORITY	PLOAD	DELAY	MINDEE	HINON	HAXOFF
1 .	NORMAL LI	GHT#1	2	5.97				1448.88
2 >	NORMAL LI	GHT#2	3	3.63	2.88			1448.88
3 8	ESSENTIAL.	LIGHT	1	8.52	. 28			
4 3	HEAT PUMP	#1	3	13.75	3.11	5.88	98.88	28.88
5 1	HEAT PUMP	42	3	5.68	4.88	3.11	3.88	15.88
6 1	FAN COLL	-	2	.55	3.88	2.88	2.11	18.88
7 1	FAN		3	9.55	4.88	3.88	3.88	18.88
5 (COOLER		3		5.88	5.88	5.82	28.88
9.1	PLMP		2	.75	4.88	3.11	3.88	28.88
1.0	FLEVATOR		ī	8.88				
11	EMERG. SY	STEM	i	8.79				
12	OTHER		3	2.89	2.88		98.88	1448.88

SOUTPFI

3.PRT = F.

SUMINT - .45514888+882.15UM -\$END LOAD # 9 RESTORED..... LOAD # 7 RESTORED..... 8,IHIT5T + T ****** LOAD # 5 RESTOPED***** SMAM2 5UMP = .15899888*882 SEND SOUTPUT ITIME = 3,PDATA = .51788888*882.1RESET SEND 1 2 3 4 5 6 7 8 9 18 11 12 T T T T T T T T T T T T T 3.PDATA = .51788888+882.IRESET + #.DELP = .74865##1+##2.FIXINT = T SOUTPFI
 SUDIPP1

 I =

 4.PPRED =

 SHAMI

 SUMINT =

 SERD

 SUMP =

 <td 4.PPRED + .468939999*882.EPRED + .38411666*881.EMAX + .62588888*881.EMIN + .58333333-881.EMCAL + .28456666*881 11.INIT5T = T #.DELP = .11953###+##3.F1XINT = T 4,PDATA = .676888888*882.1RE5ET = 1 2 3 4 5 6 7 8 9 18 11 12 T T T T T T T T T T T T T T T SOUTPFI SOUTPLI SEND SNAA1 SUMINT - .45551888+882.15UM -SEND SOUTPUT ITIME - .65 12.1H1T5T + F 1.DELP - .BBBBBBBB .FIXINT - T 5.PDATA + .67728888+882.IRESET + SEND 1 T 2 3 4 8 9 18 11 12 T T T T T 5 6 T T SOUTPFI 2.85**** I,PPRED = .67719999+#82.EPRED = .56433333+881.EMAX = .625##888+881.EMIN = .58333333+881.EMCAL = .11286667+881 I + SEND SEND SNAM2 SUMP = .88888888 SEND SOUTPUT ITIME = 6.PDATA - .67728888+882.1RE5ET -8,DELP - .28588888.881,F1XINT - T SEND 2 3 4 5 6 7 8 9 18 11 12 SOUTPFI 3.88+++++ SOUTPFI 1 - 2.PI SEND SNAM2 SUMP - .B8888888 SEND SOUTPUT ITIME -SEND 1 2 3 4 2.PPRED = .67719999+882.EPRED = .56433333+881.EMAX = .62588888+881.EMIN = .5833333+881.EMCAL = .22573333+881 7, PDATA = .67728888+882, IRESET = #.DELP + .3888888888881.FIXINT + T 1 2 3 4 5 6 7 8 9 18 11 12 T T T T T T T T T T T T T SOUTPEN TO BE RESTORED - 5.68..... SUDIFII 1 = 3.P SEND SNAM2 SUMP = .88888888 SEND SOUTPUT ITIME = SEND 1 2 3 4 3.PPRED + .67728998+882.EPRED + .56448833+881.EMAX + .62588888+881.EMIN = .58333333+881.EMCAL + .33862588+881 8.PDATA = .67758888+882.IRESET = #,DELP + .56775#16+##1.F1X1HT + T 1 2 3 4 5 6 7 8 9 18 11 12 T T T T T T T T T T T T T SOUTPF1 12.#8**** 4,PPRED + .67584998+##2.EPRED + .5632#832+##1.EMAX + .625########1.EMIN + .58333333+##1.EMCAL + .45#91666+##1 9.PDATA - .67888888-882.IRESET -#.DELP = .12#75##5+##2,F1XINT = T 1 2 3 4 5 6 7 8 9 18 11 12 T T T T T T T T T T T T T SOUTPFI I + SEND SOUTPUT ITIME + SEND #.PPRED + .67584998+##2.EPRED + .5632#032+##1.EMAX + .625#####+##1.EMIN + .58333333+##1.EMCAL + .56924999+##1 18.PDATA . .75888888.882.IRESET . I.DELP -FIXINT + T 3 4 5 6 7 0 9 1# 11 12 T T T T T T T T T T T 2 1 T

1 = SEND SNAH2 SUMP = .8 SEND SOUTPUT ITIME = #,DELP = .31249997+##1,F1X1NT = T 11.PDATA = .688888888888.882.1RESET = SEND $\frac{1}{T}$ $\frac{2}{T}$ 6 7 8 9 18 11 12 T T T T T T T SOUTPFI 7.58**** 1 = 2.PF \$END \$NAM2 SUMP = .88888888 \$END \$OUTPUT 2.PPRED = .65499998+882.EPRED = .54583333+881.EMAX = .62588888+881.EMIN = .58333333+881.EMCAL = .22883333+881 #,DELP = .75####12+##1,F1X1NT = T ITIME -12.PDATA = .788888888888.1RESET = SEND 1 2 T T 4 5 6 7 8 9 18 11 12 T T T T T T T T T T SOUTPF1 3.PPRED - .699999998-882.EPRED - .58333333-881.EMAX - .62588888-881.EMIN - .58333333-881.EMCAL - .34166666-881 1 = SEND SOUTPUT ITIME = SEND 13.PDATA = .758888888+882,1RESET = #.DELP = .17881393-##5,F1X1NT = T 2 3 4 5 T T T $\frac{1}{T}$ SOUTPF1 18.88**** 4,PPRED = .67999999+882,EPRED = .56666666+881,EMAX = .62588888+881.EMIN = .58333333+881,ENCAL = .45416666+881 14, PDATA - .688888888+882, 1RESET -8.DELP = .18888881+882.F1X1NT = T SEND 9 18 11 12 T T T T 4 5 6 7 8 T T T T T SOUTPF1 1 = SEND SOUTPUT 1T1ME = SEND 8.PPRED = .67999999+882.EPRED = .56666666+881.EMAX = .62588888+881.EMIN = .58333333+881.ENCAL = .56249999+881 15, PDATA = .7888888888882, IRESET = 1.DELP - "FIXINT = T 1 2 T T 7 8 9 18 11 12 T T T T T T -------SOUTPFI 1,PPRED = .72499999+882.EPRED = .6841E666+881.EMAX = .62588888+881.EMIN = .50333333+881.ENCAL = .12803333+881 SEND SOUTPUT ITIME SEND 16,PDATA - .75888888+882,IRESET -.FIXINT = T S.DELP - Ž 6 7 8 9 18 11 12 T T T T T T T T 1 T SOUTPEL POWER TO BE SHED 2.58-----2,PPRED = .76499999+882,EPRED = .63749999+881,EMAX = .62588888+881,EM1N = .58333333+881,ENCAL = .25888888+881 SEND ----- LOAD # 8 SHED-----7 SHED-----17,PDATA = .888888888888.1RESET = #,DELP =-.24999988+##1,FIXINT = T ----- POWER TO BE SHED 11.25-----soutpf1 1 = 3,PPRED = .79499999+882,EPRED = .66249999+881,EMAX = .62588888+881,EMIN = .50333333+881,ENCAL = .38758888+881 SEND D ----- LOAD • ----- LOAD • ----- LOAD • ----- LOAD • 5 SHED-----2 SHED-----9 SHED-----6 SHED-----1 SHED-----SNAM2 SUMP = .16498888+882 SEND SOUTPUT 1TIME = SEND 18,PDATA - .85888888+882,1RESET -#.DELP +-.11249998+##2.FIXINT = T D 2 F 3 4 5 6 7 8 9 1# 11 12 T T F F F F F T T T -1 F ---- POWER TO BE SHED 2.58-----

1,PPRED = .67588888+882,EPRED = .56258888+881,EMAX = .62588888+881,EMIN = .56333333+881,EMCAL = .11258888+881

***** POWER TO BE RESTORED

3.12****

SOUTPF1 4.PPRED = .75499998+882.EPRED = .62916666+881.EMAX = .62588888+881.EM1N = .58333333+881.ENCAL = .58833333+881 I = SEND SNAM2 SUMP = SEND SOUTPUT #.DELP =-.2499994#+##1.F1X1NT = T 19.PDATA - .688888888+882,1RESET -ITIME -SEND 1 2 F F 3 4 5 6 7 8 9 18 11 12 T F F F F F T T T SOUTPF1 8,PPRED - .75499998+882,EPRED - .62916666+881,EMAX - .62588888+881,EMIN - .58333333+881.EMCAL - .59999999+881 I = SEND SOUTPUT ITIME = SEND 28, PDATA - .588888888+882, 1RESET -.FIXINT = T 2 6 7 8 F F F 9 18 11 12 F T T T 1 F 3 T 5 ***** POWER TO BE RESTORED 6.25++++ 1,PPRED = .649999999+882,EPRED = .541666666+881,EMAX = .62588888+881,EMIN = .58333333+881.ENCAL = .18833333+881 1 -SEND ····· LOAD / 1 RESTORED+++++ 6 RESTORED+++++ \$NAM2 SUMP = .65199999+881 \$END \$OUTPUT 8.DELP = .62588883+881.F1X1NT = T ITIME -21,PDATA = .88888888884882.1RESET = SEND 1 2 T F 3 4 5 6 7 8 9 18 11 12 T T F T F F F T T T +++++ POWER TO BE RESTORED 15.00+++++ 2,PPRED = .68999999998882.EPRED = .58833333+881.EMAX = .62588888+881.EMIN = .58333333+881.ENCAL = .28833333+881 1 = SEND ······ LOAD · SNAM2 SUMP = .19561888+882 SUMP SOUTPUT ITIME -SEND 22,PDATA = .4888888888882,1RESET = 8.DELP = .158888888+882.F1XINT = T 2 3 4 5 6 7 8 9 1*8* 11 12 T T T T T T T T T T T T 1 T -----*** POWER TO BE RESTORED 45.00+++++ SOUTPF1 3.PPRED = .51999999998882.EPRED = .43333333*881.EMAX = .625888888+881.EMIN = .58333333+881.ENCAL = .28333333+881 1 = SEND SNAM2 SIMP - .88888888 SUMP = .4 SEND SOUTPUT ITIME = 23.PDATA = .508888888+882.1RESET = #,DELP = .458888888+882,F1X1NT = T SEND 2 3 4 5 T T T T 1 T 6 T 7 8 9 1*8* 11 12 T T T T T T -------++++ POWER TO BE RESTORED 63.00+++++ SOUTPET SUMP = .B SEND SUMP = .B SEND SOUTPUT 4, PPRED = .57399999+882, EPRED = .47833333+881, EMAX = .62588888+881, EMIN = .58333333+881, ENCAL = .38883333+881 ITIME -24.PDATA = .67888888+882.1RESET = 8.DELP = .63888888888882.E1XINT = T 234 TTT 5 6 7 8 9 1*8* 11 12 T T T T T T T T 1 T SOUTPF1 1 = SEND SOUTPUT 1T1ME = SEND 8.PPRED = .57399999+882.EPRED = .47833333+881.EMAX = .62588888+881.EMIN = .58333333+881.ENCAL = .58333333+881 25.PDATA - .888888888888.1RESET -"FIXINT = T D 2 T 3 T 4 5 6 7 8 9 18 11 12 T T T T T T T T T T 1 T ------+++++ POWER TO BE RESTORED SOUTPF1 12.58++++ 1 - 1,PI SEND SNAM2 SUMP - .888888888 SEND SOUTPUT ITIME -1.PPRED = .680888888+882.EPRED = .588888888+881.EMAX = .625888888+881.EM1N = .58333333+881.EMCAL = .188888884+881 26.PDATA - .488888888+882,1RESET -#,DELP = .12588888.882.F1X1NT = T SEND Z 4 5 6 7 8 9 1*8* 11 12 T T T T T T T T T T 1 T 3 T

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bibliography or literature	survey, mention it here)							
Demand limiting co	ontrol is one of popu	lar control strategie	s for electrical					
energy management	in Energy Management	and Control Systems	(EMCS) in					
commercial/office	buildings. The purp	ose of demand limitin	g is to maintain					
the peak demand le	evel below a predeter	mined limit by sheddi	ng nonessential					
loads in a buildin	ng during the peak de	emand period. In this	present report,					
description of fit	xed interval metering	, and sliding window m	etering for					
discussed are the	ideal rate the prod	ind limiting calculati	on procedures					
methods Demand	limiting algorithms	which were developed	hased on available					
information, are i	presented. Computer	program listings of d	emand limiting					
control algorithms	s in Fortran 77 and a	in open-loop computer	simulation result					
are included in th	are included in the appendices.							
12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)								
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and control systems; fixed interval metering; ideal rate method; instantaneous rate								
method; load cont:	rol; predictive metho	d; sliding window met	ering.					
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