United States Patent [19]

Putman

[11] **3,872,286**

[45] **Mar. 18, 1975**

[54] **CONTROL SYSTEM AND METHOD FOR LIMITING POWER DEMAND OF AN INDUSTRIAL PLANT**

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[73] Assignee: **Westinghouse Electric Corporation,** Pittsburgh, Pa.

[22] Filed: **Oct. 12, 1973**

[21] Appl. No.: **406,067**

[52] **U.S. Cl.** **235/151.21,** 444/1, 307/52
[51] **Int. Cl.** **G06f 15/06,** G05b 15/00
[58] **Field of Search** 235/151.21; 324/103; 307/52; 444/1

[56] **References Cited**

UNITED STATES PATENTS

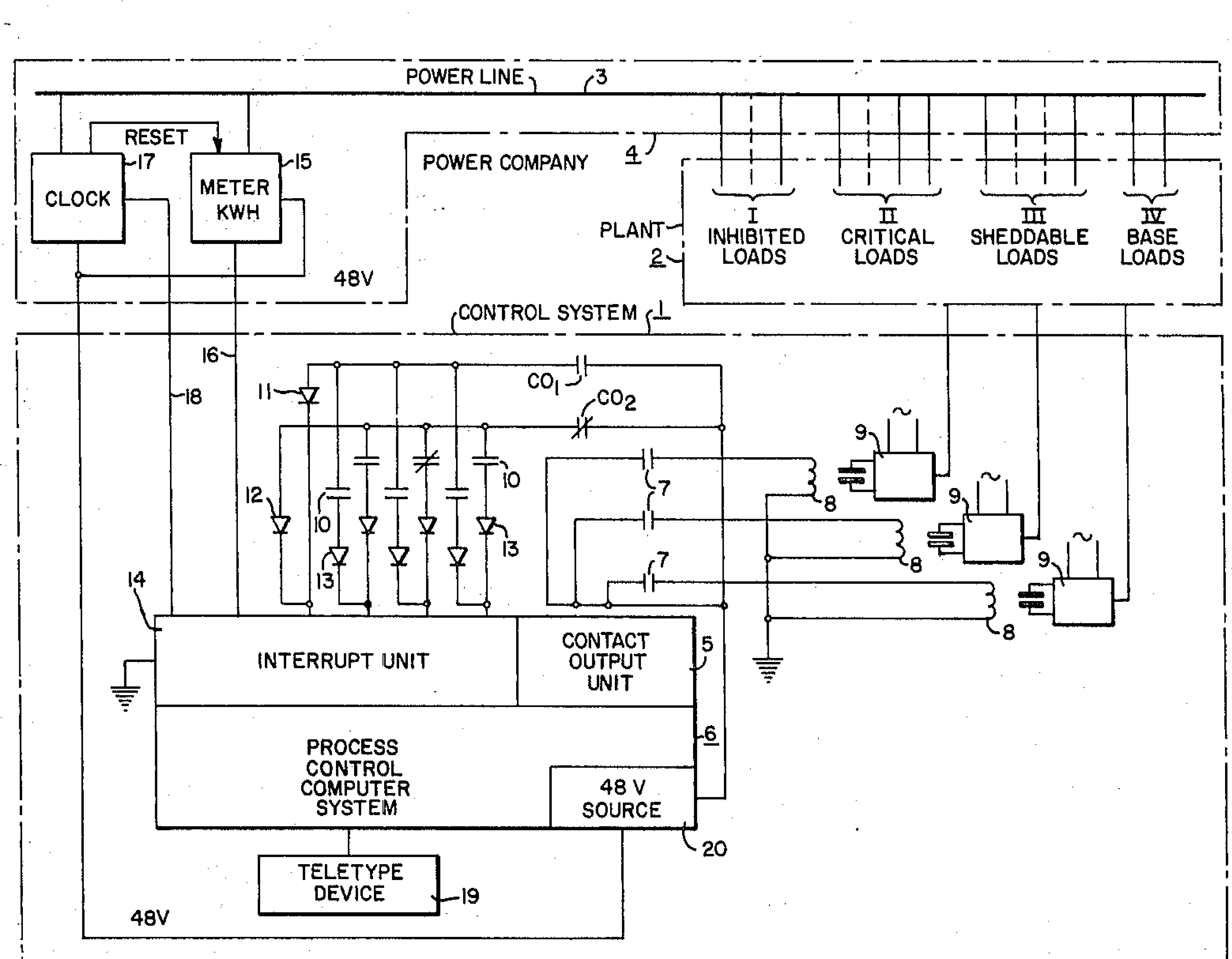
3,296,452	1/1967	Williams	235/151.21 X
3,505,508	4/1970	Leyde	235/151.21 X
3,522,421	8/1970	Miller	235/151.21
3,602,703	8/1971	Polenz	235/151.21
3,659,114	4/1972	Polenz et al.	235/151.21 X
3,719,809	3/1973	Fink	235/151.21

Primary Examiner—Eugene G. Botz
Assistant Examiner—Edward J. Wise
Attorney, Agent, or Firm—C. M. Lorin

[57] **ABSTRACT**

The invention relates in general to control of the consumption of energy derived by an industrial user from a power supply system (electrical, gas or like commodity), and more particularly to a control system for adjusting an industrial load system to limit the demand of power while respecting the constraints of the load system.

3 Claims, 20 Drawing Figures



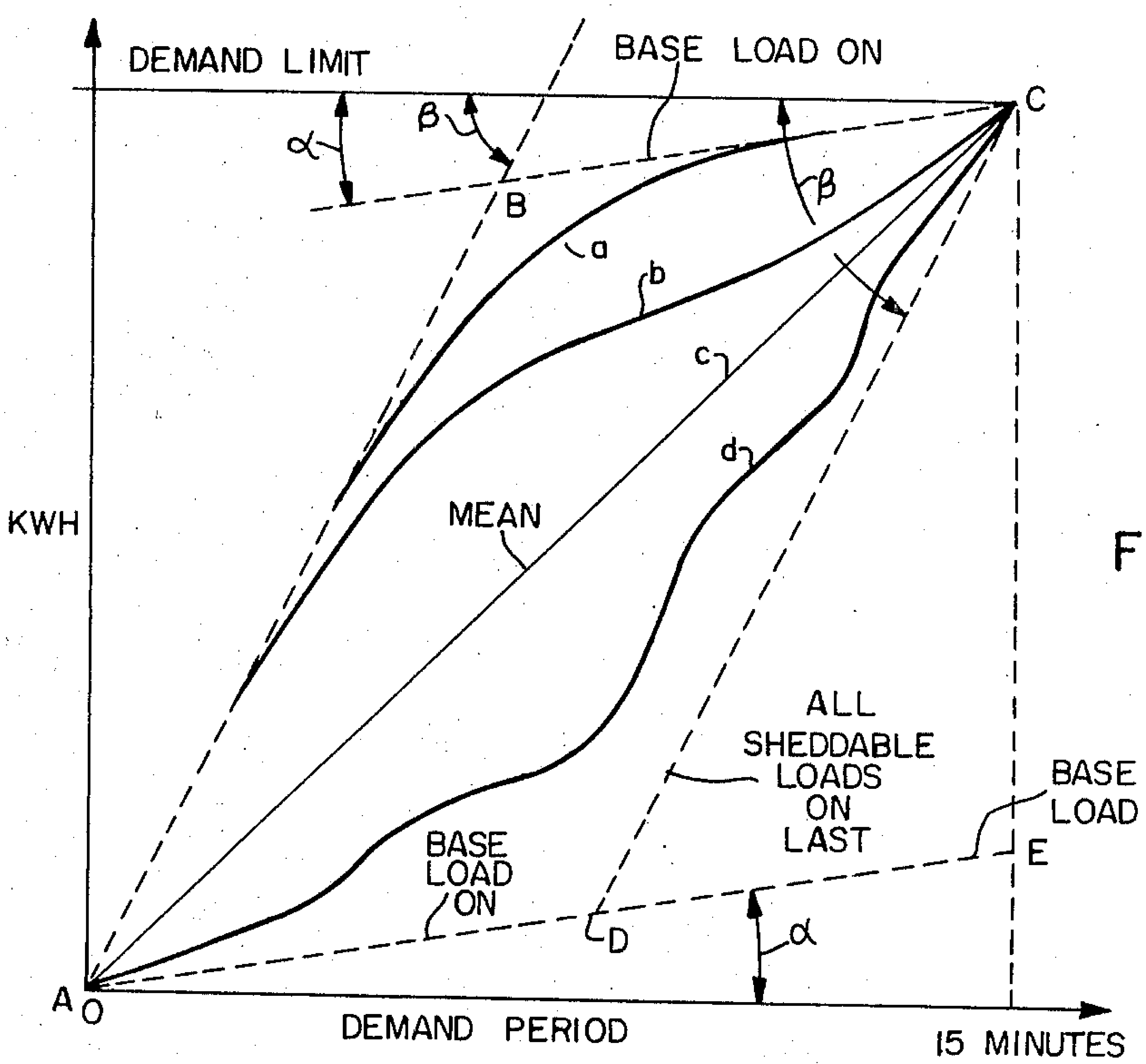

DEMAND LIMIT
BASE LOAD ON
C
B
a
b
c
d
MEAN
KWH
ALL
SHEDDABLE
LOADS
ON
LAST
BASE
LOAD
E
BASE
LOAD
ON
D
A
O
DEMAND PERIOD
15 MINUTES

FIG. 1

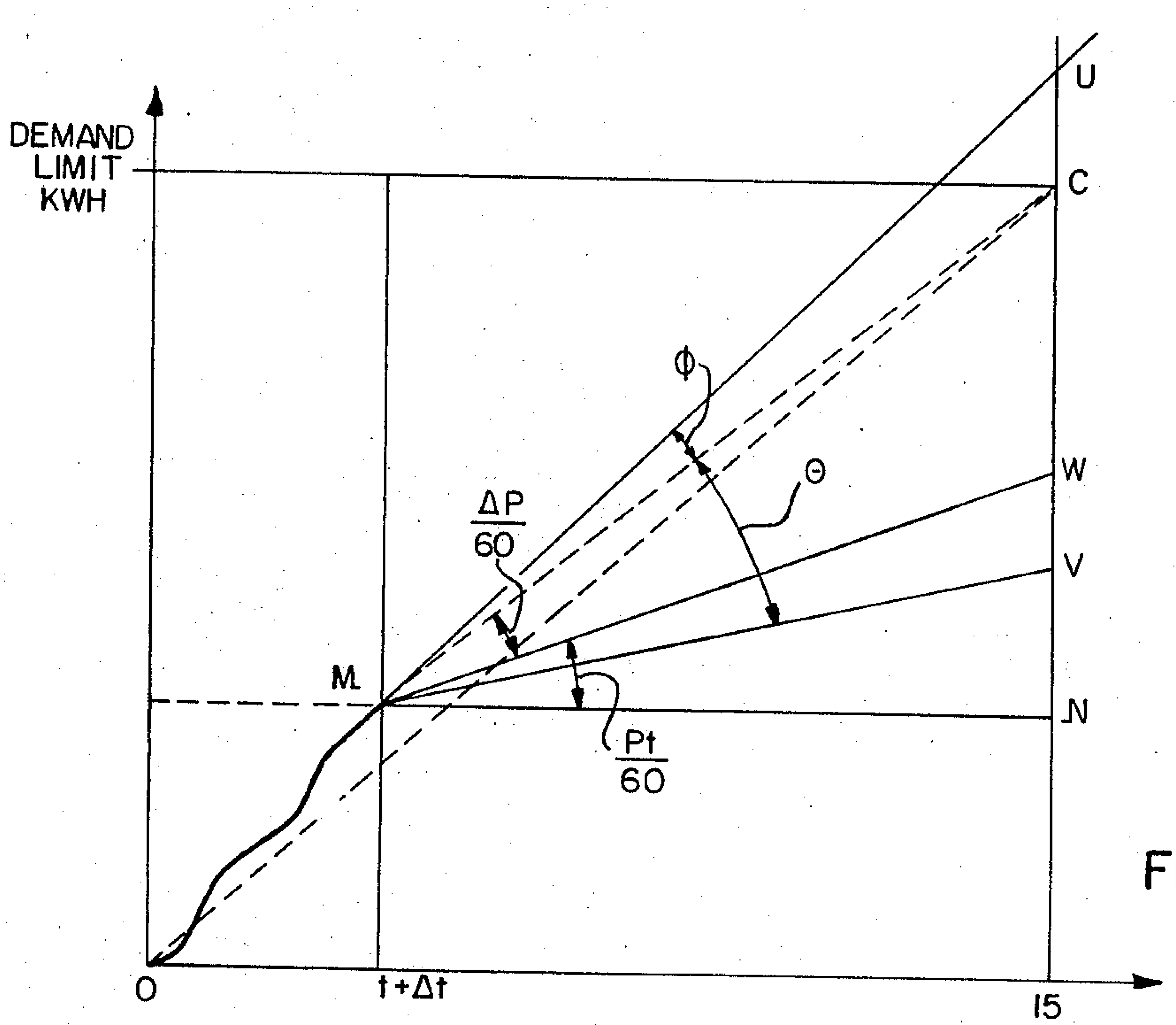

DEMAND
LIMIT
KWH
U
C
W
V
N
M
ΔP
60
Pt
60
O
t+Δt
15

FIG. 5

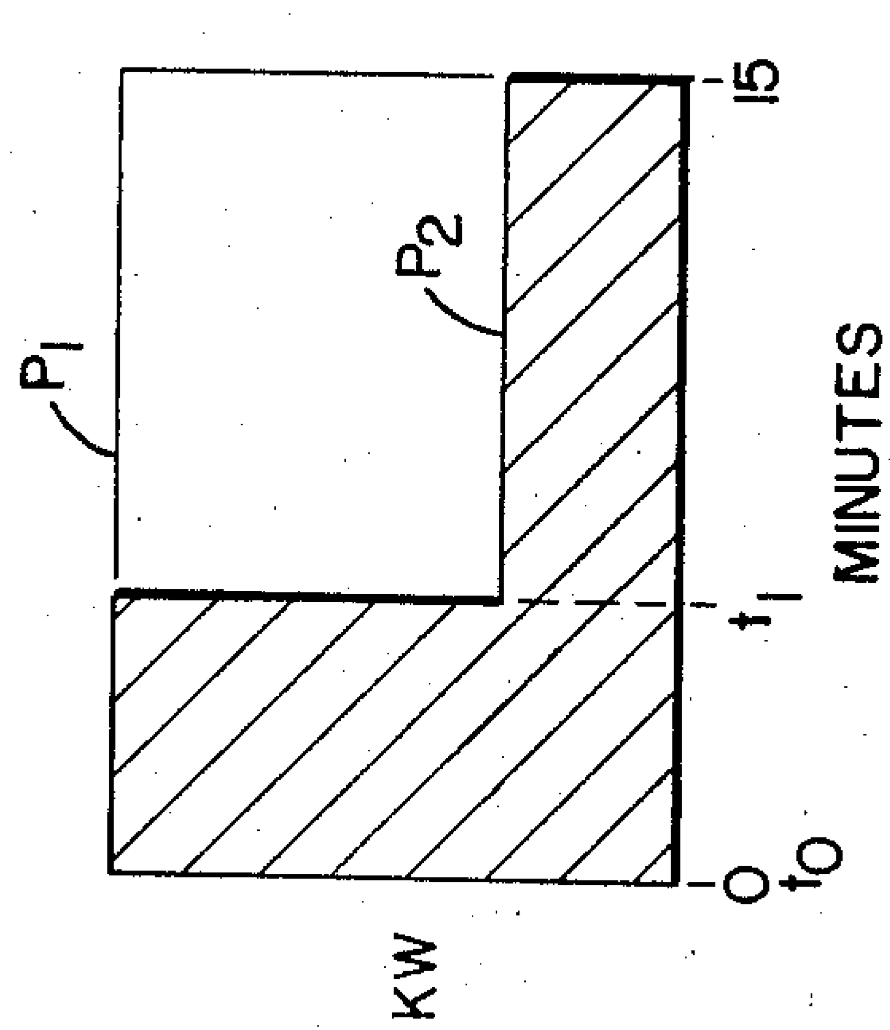


FIG.2A

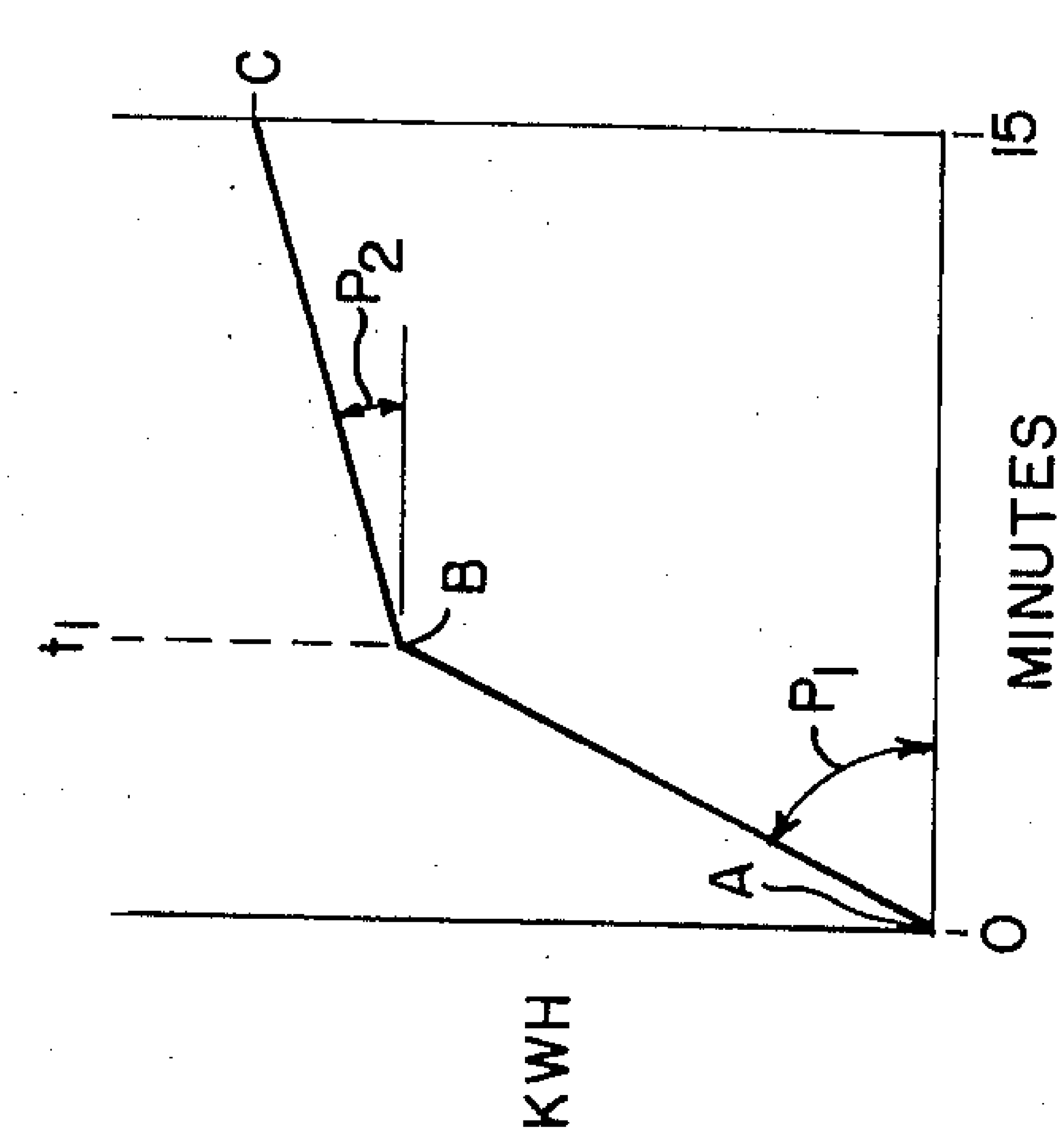


FIG.2B

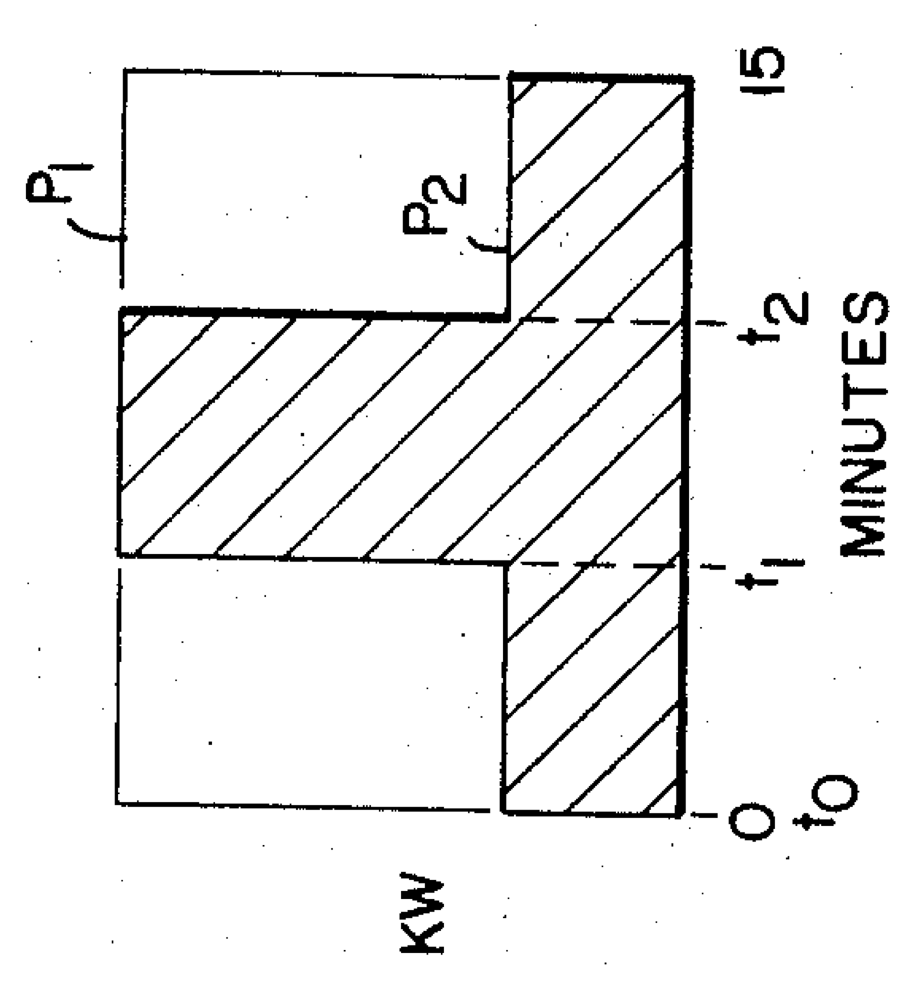


FIG.3A

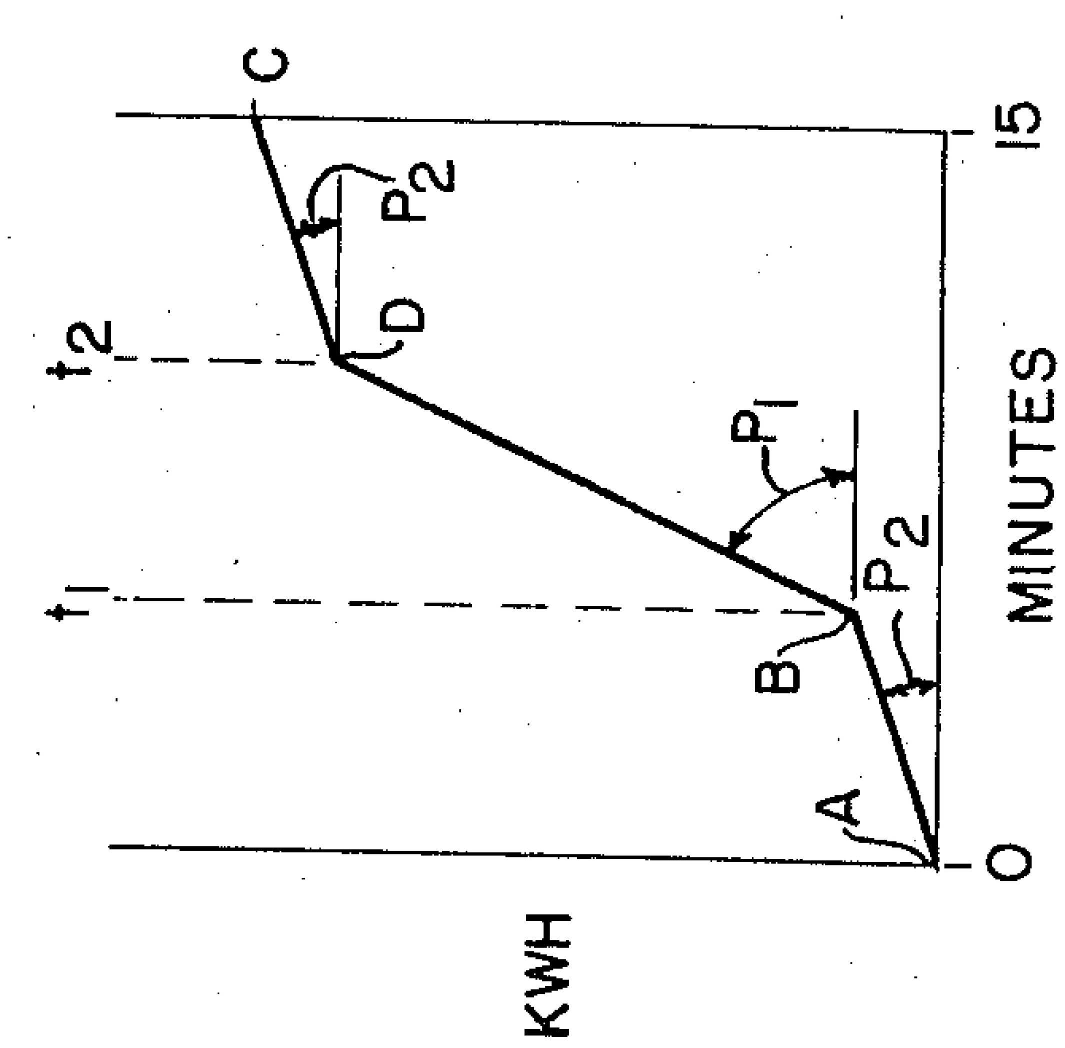


FIG.3B

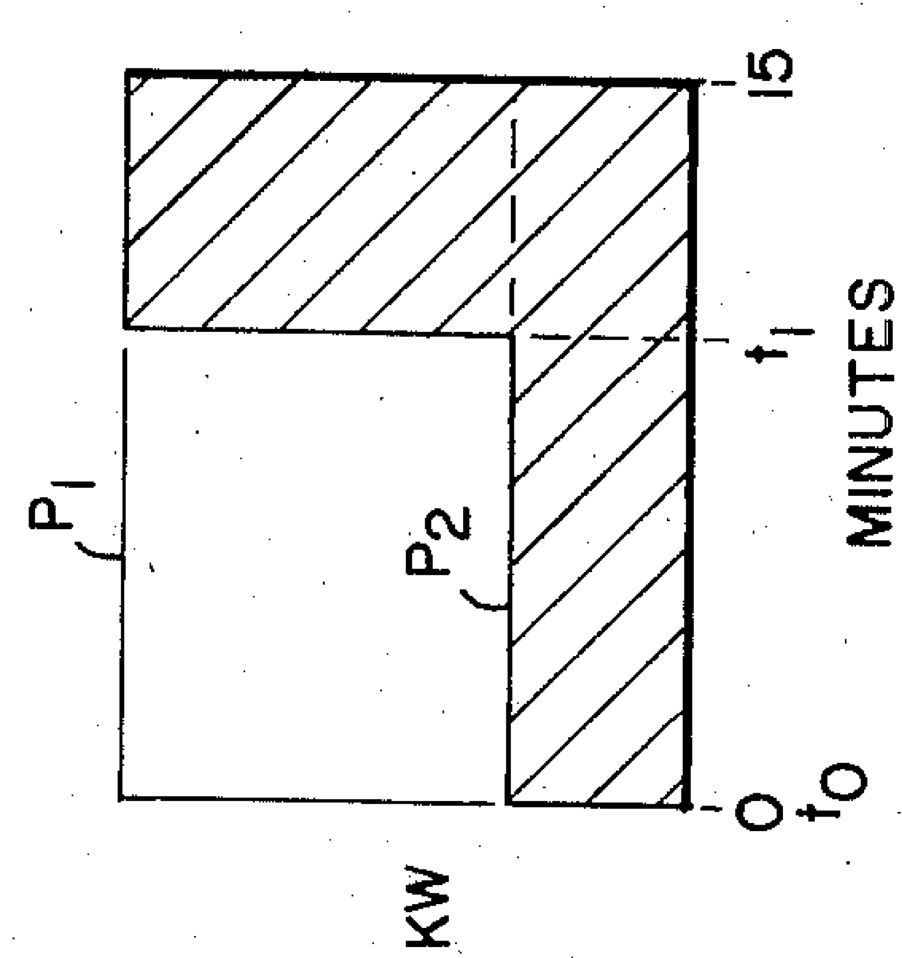


FIG.4A

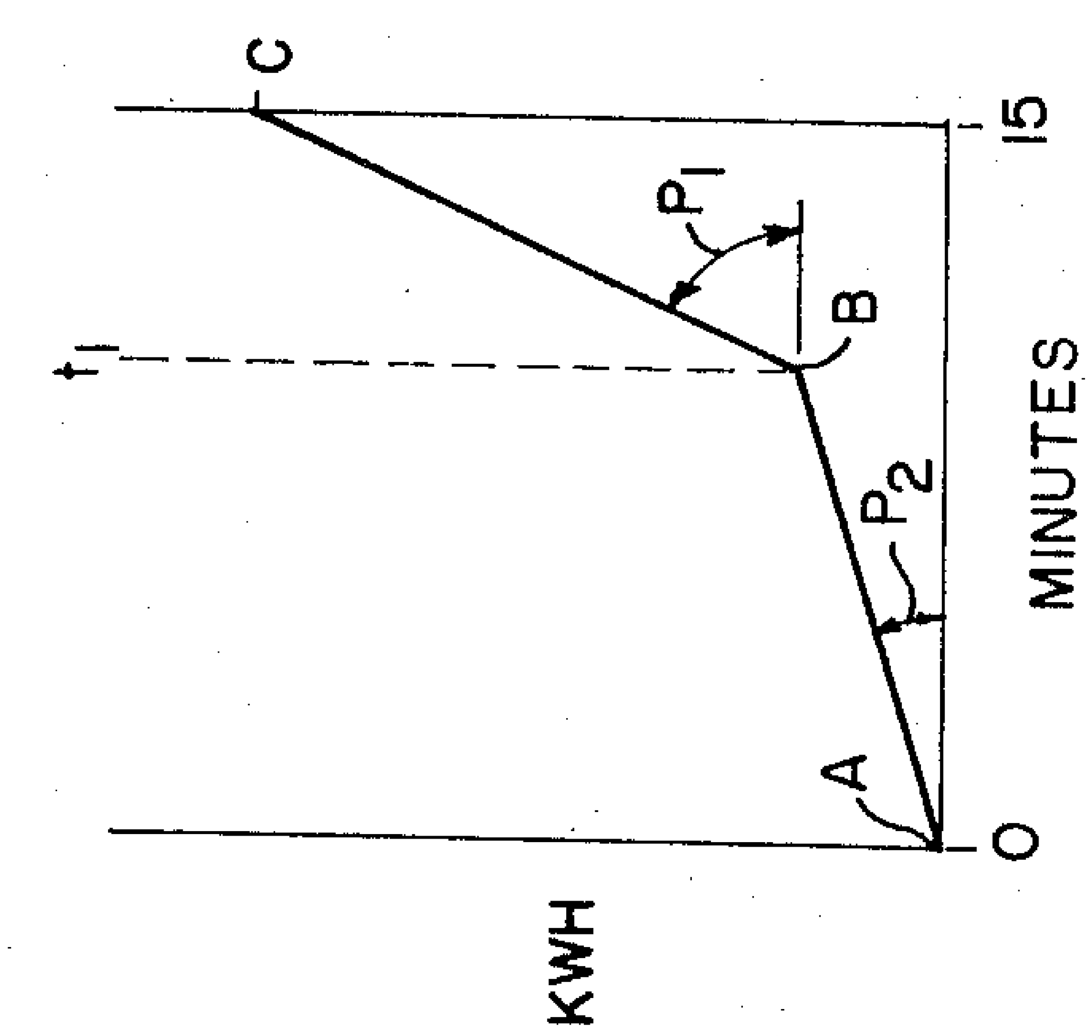


FIG.4B

FIG.6

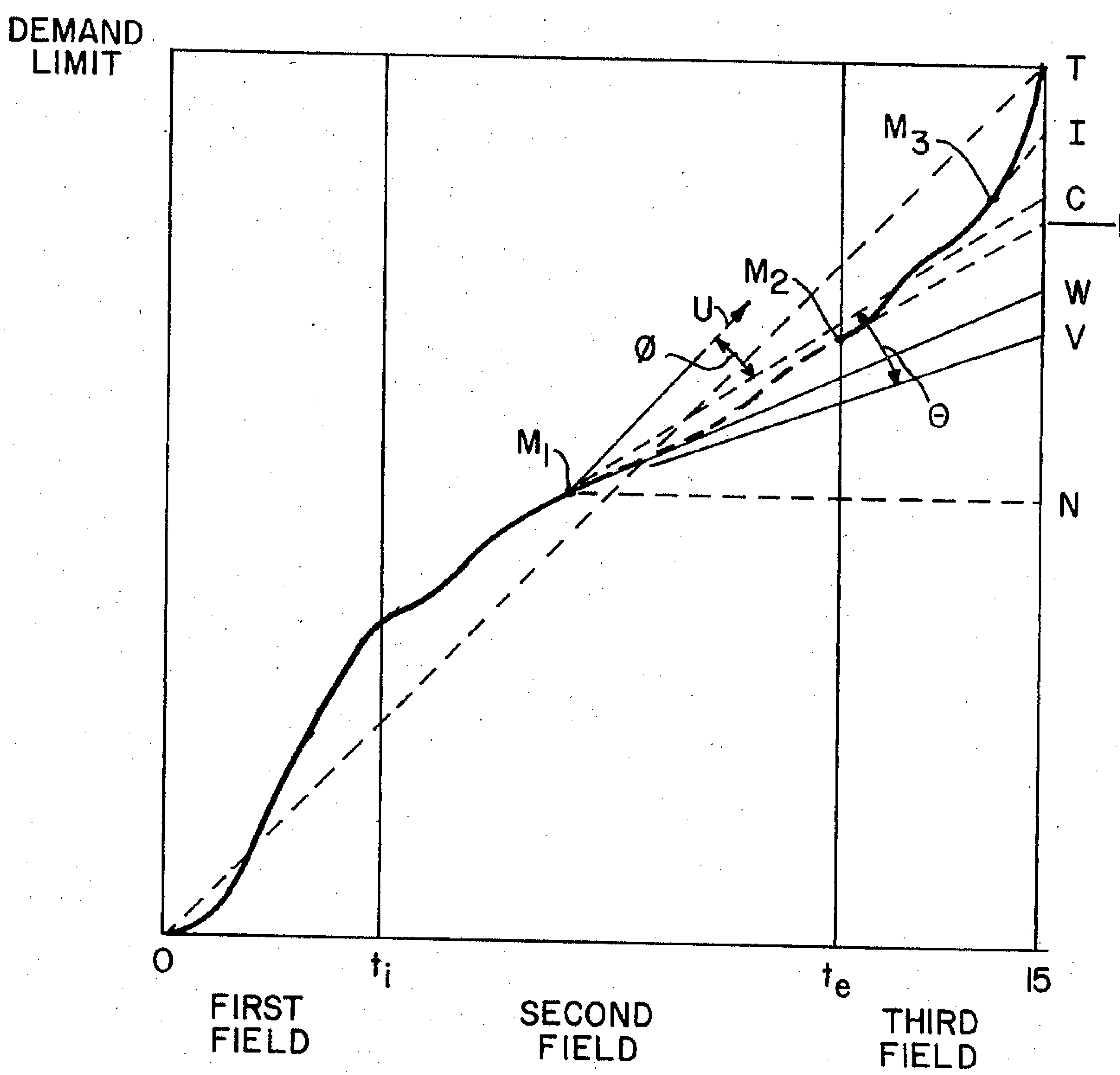
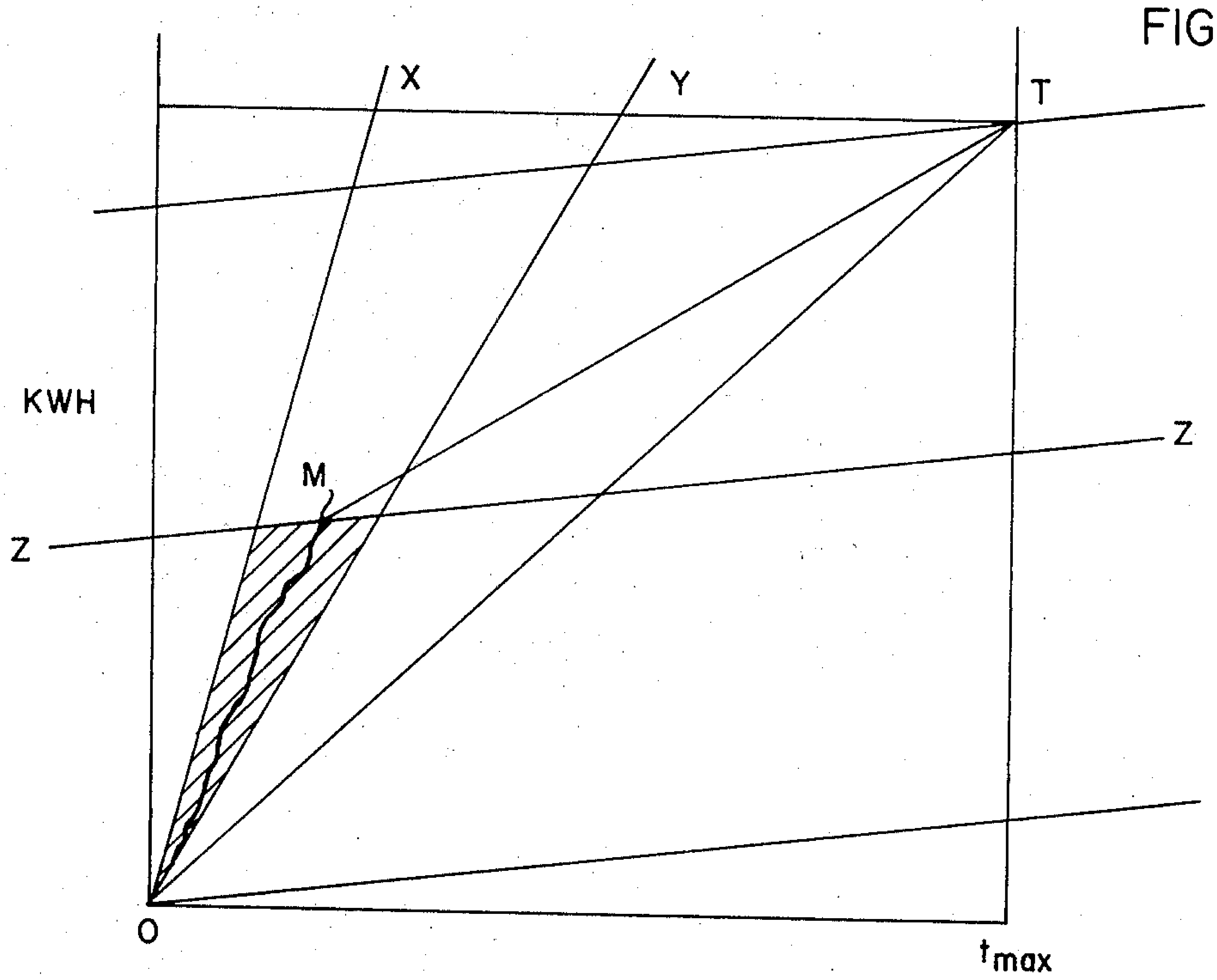

DEMAND LIMIT
T
I
C
R
W
V
N
M3
M2
U
Ø
Θ
M1
O
ti
te
15
FIRST FIELD
SECOND FIELD
THIRD FIELD

FIG.7


X
Y
T
KWH
Z
Z
M
O
tmax

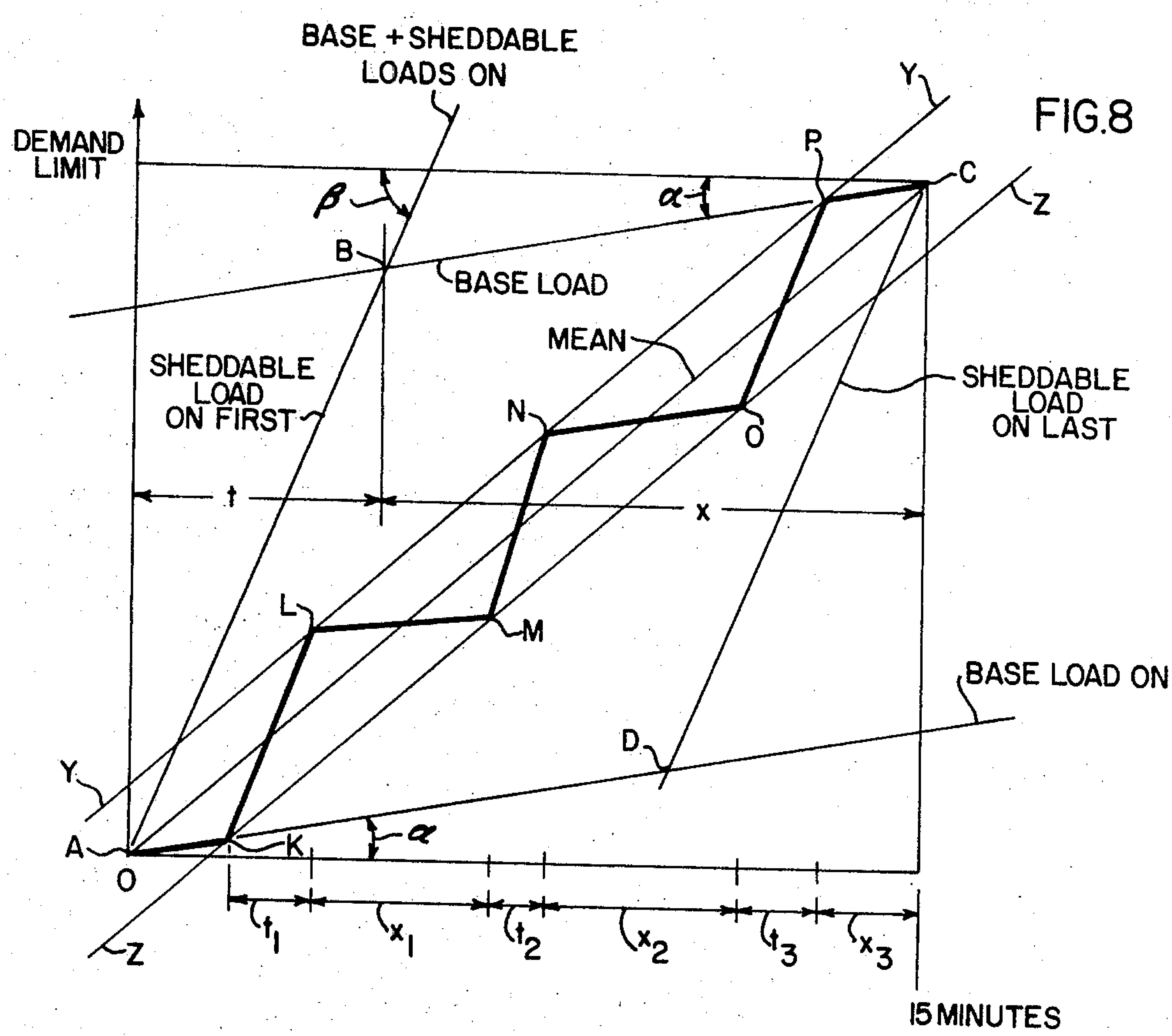

BASE + SHEDDABLE LOADS ON
DEMAND LIMIT
β
α
P
C
Y
Z
B
BASE LOAD
MEAN
SHEDDABLE LOAD ON FIRST
N
O
SHEDDABLE LOAD ON LAST
t
x
L
M
BASE LOAD ON
D
Y
A
K
α
O
Z
t1
x1
t2
x2
t3
x3
15 MINUTES

FIG.8

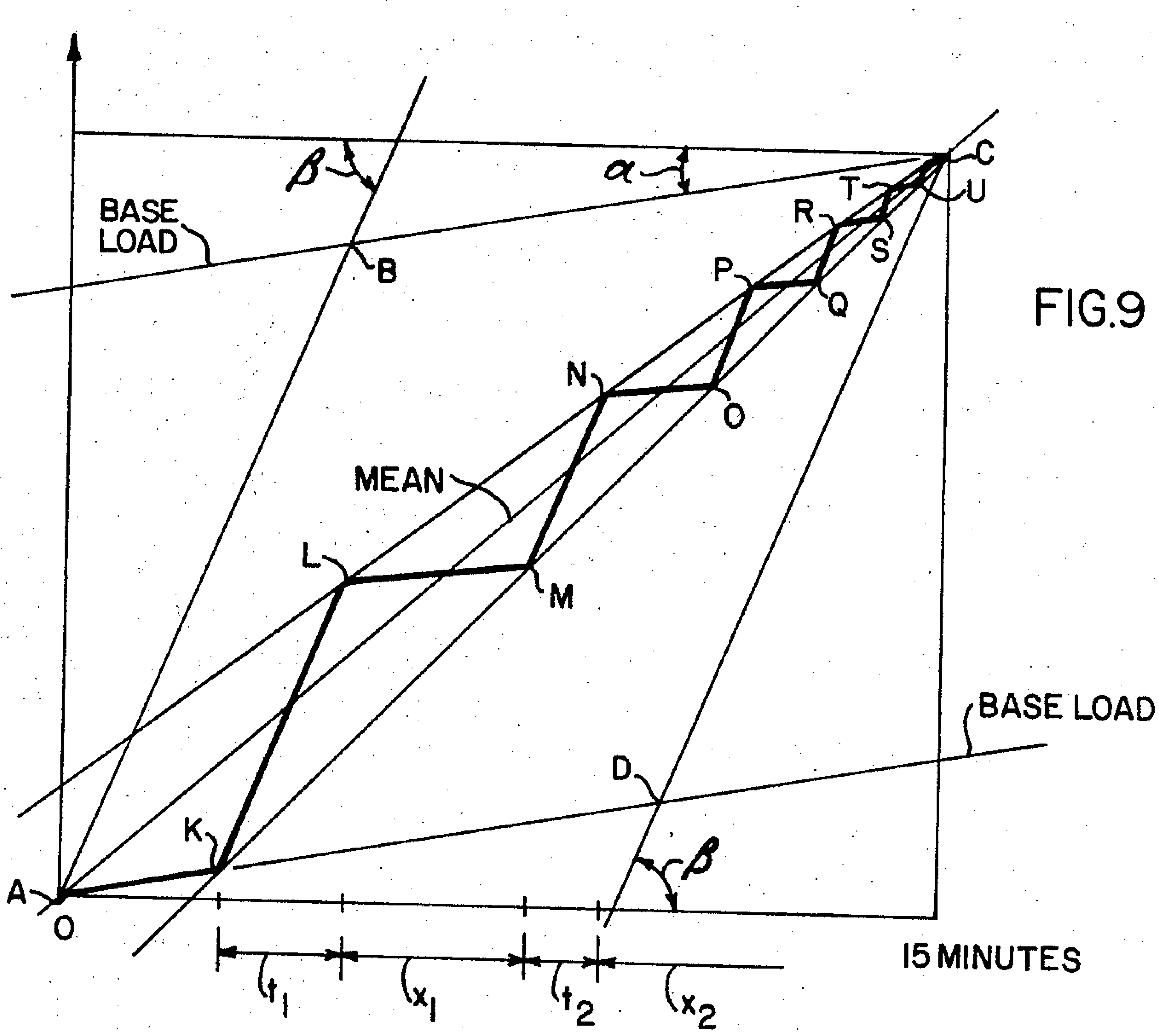

β
α
C
BASE LOAD
B
T
U
R
S
P
Q
N
O
MEAN
L
M
BASE LOAD
D
K
β
A
O
15 MINUTES
t1
x1
t2
x2

FIG.9

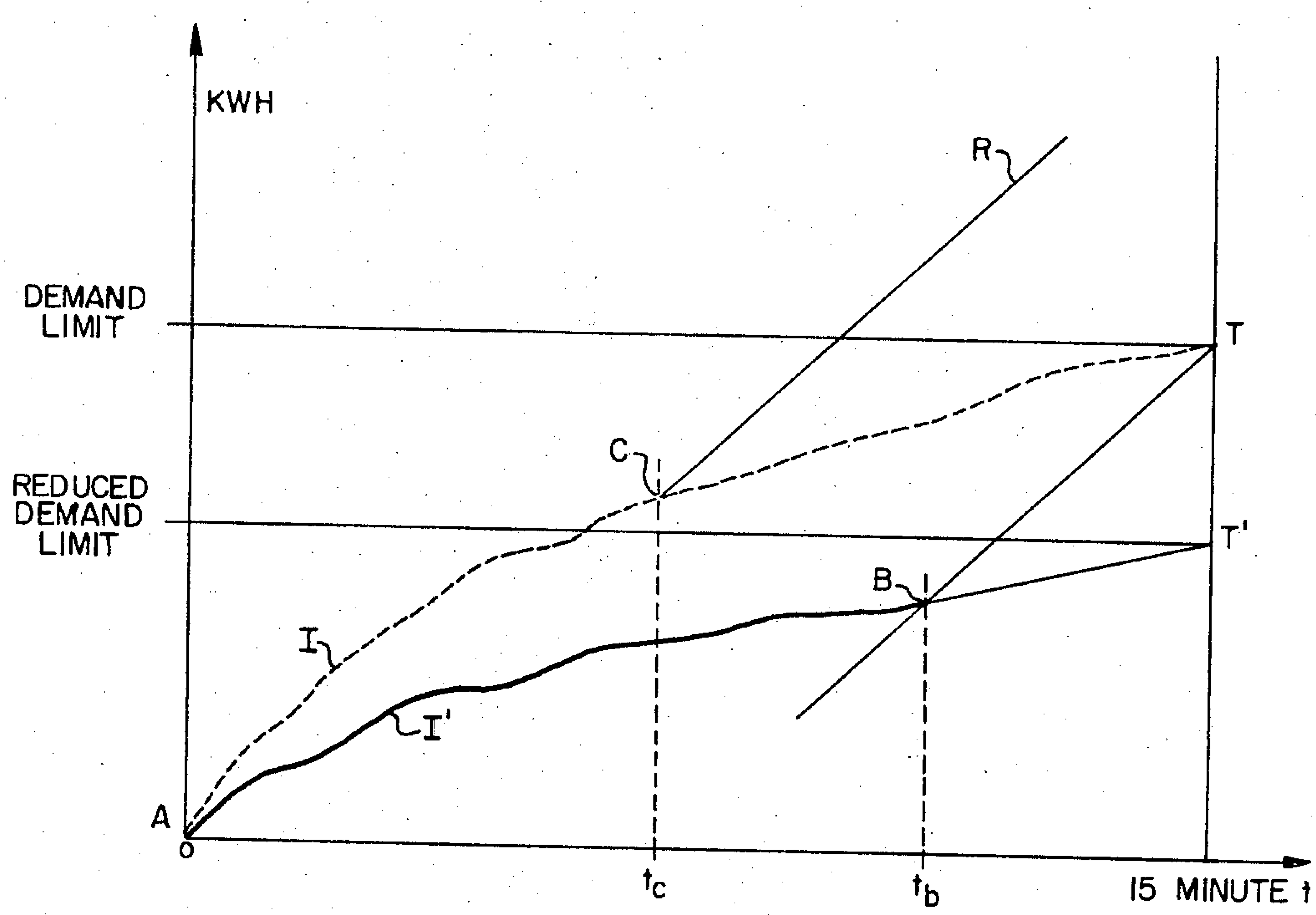

KWH
R
DEMAND LIMIT
T
C
REDUCED DEMAND LIMIT
T'
B
I
I'
A
o
t_c
t_b
15 MINUTE t

FIG. 10

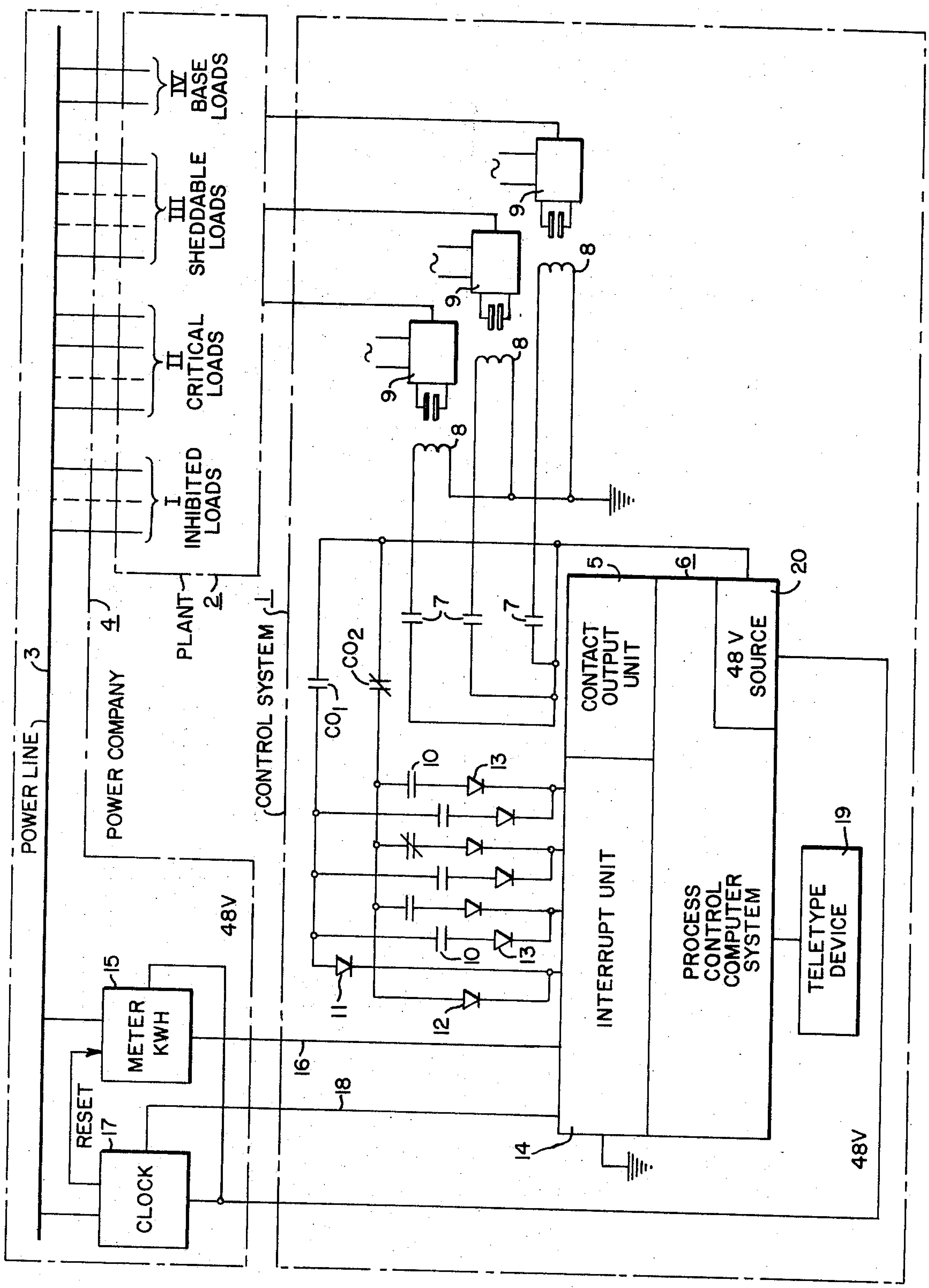

POWER LINE
3
POWER COMPANY
4
PLANT
2
CONTROL SYSTEM
1
I INHIBITED LOADS
II CRITICAL LOADS
III SHEDDABLE LOADS
IV BASE LOADS
9
8
7
CO1
CO2
10
11
12
13
CONTACT OUTPUT UNIT
5
6
48 V SOURCE
20
INTERRUPT UNIT
PROCESS CONTROL COMPUTER SYSTEM
TELETYPE DEVICE
19
14
METER KWH
15
RESET
17
CLOCK
16
18
48V

FIG.11

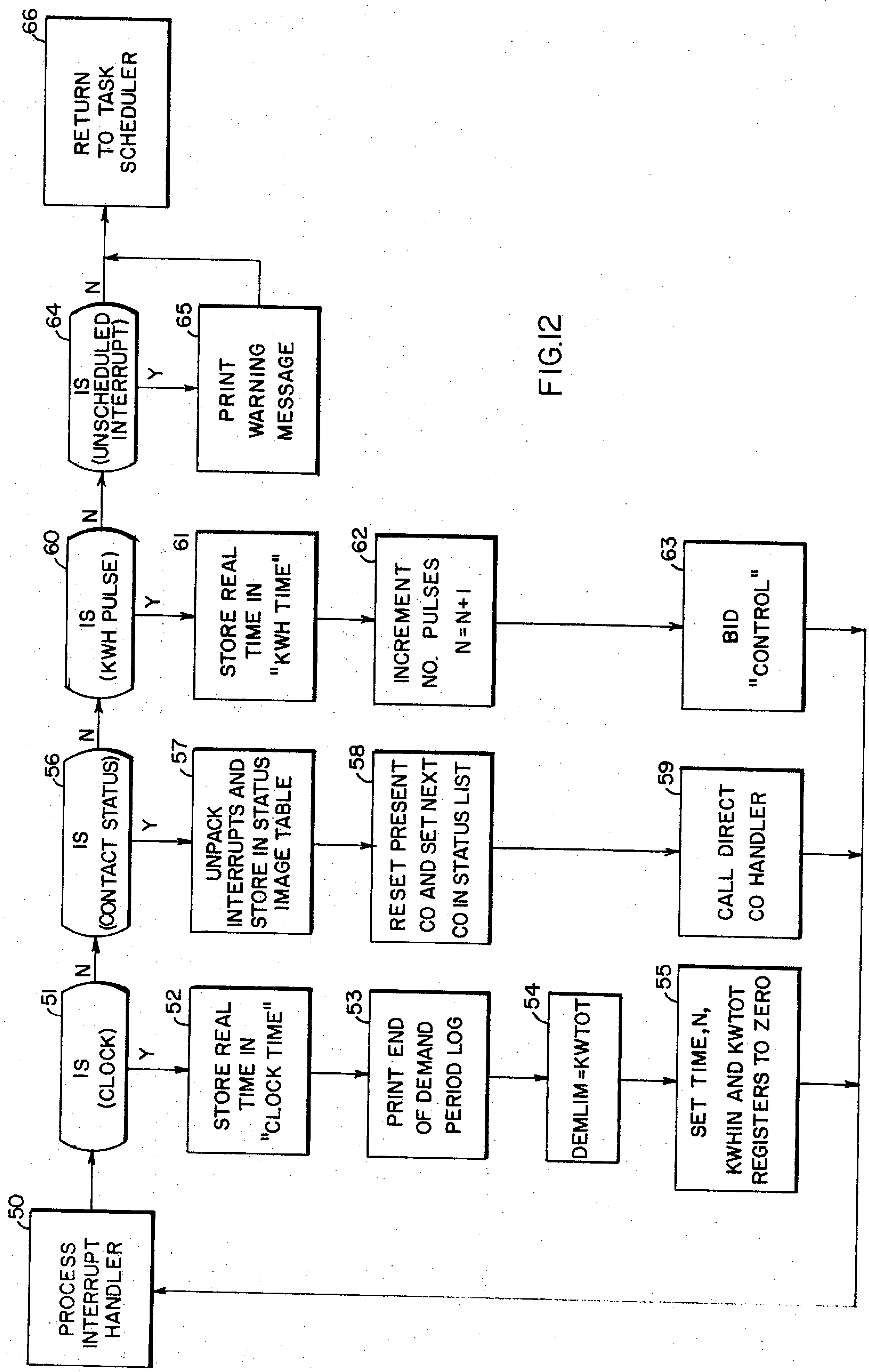

PROCESS INTERRUPT HANDLER
50
IS (CLOCK)
51
Y
N
STORE REAL TIME IN "CLOCK TIME"
52
PRINT END OF DEMAND PERIOD LOG
53
DEMLIM=KWTOT
54
SET TIME, N, KWHIN AND KWTOT REGISTERS TO ZERO
55
IS (CONTACT STATUS)
56
UNPACK INTERRUPTS AND STORE IN STATUS IMAGE TABLE
57
RESET PRESENT CO AND SET NEXT CO IN STATUS LIST
58
CALL DIRECT CO HANDLER
59
IS (KWH PULSE)
60
STORE REAL TIME IN "KWH TIME"
61
INCREMENT NO. PULSES N=N+1
62
BID "CONTROL"
63
IS (UNSCHEDULED INTERRUPT)
64
PRINT WARNING MESSAGE
65
RETURN TO TASK SCHEDULER
66

FIG.12

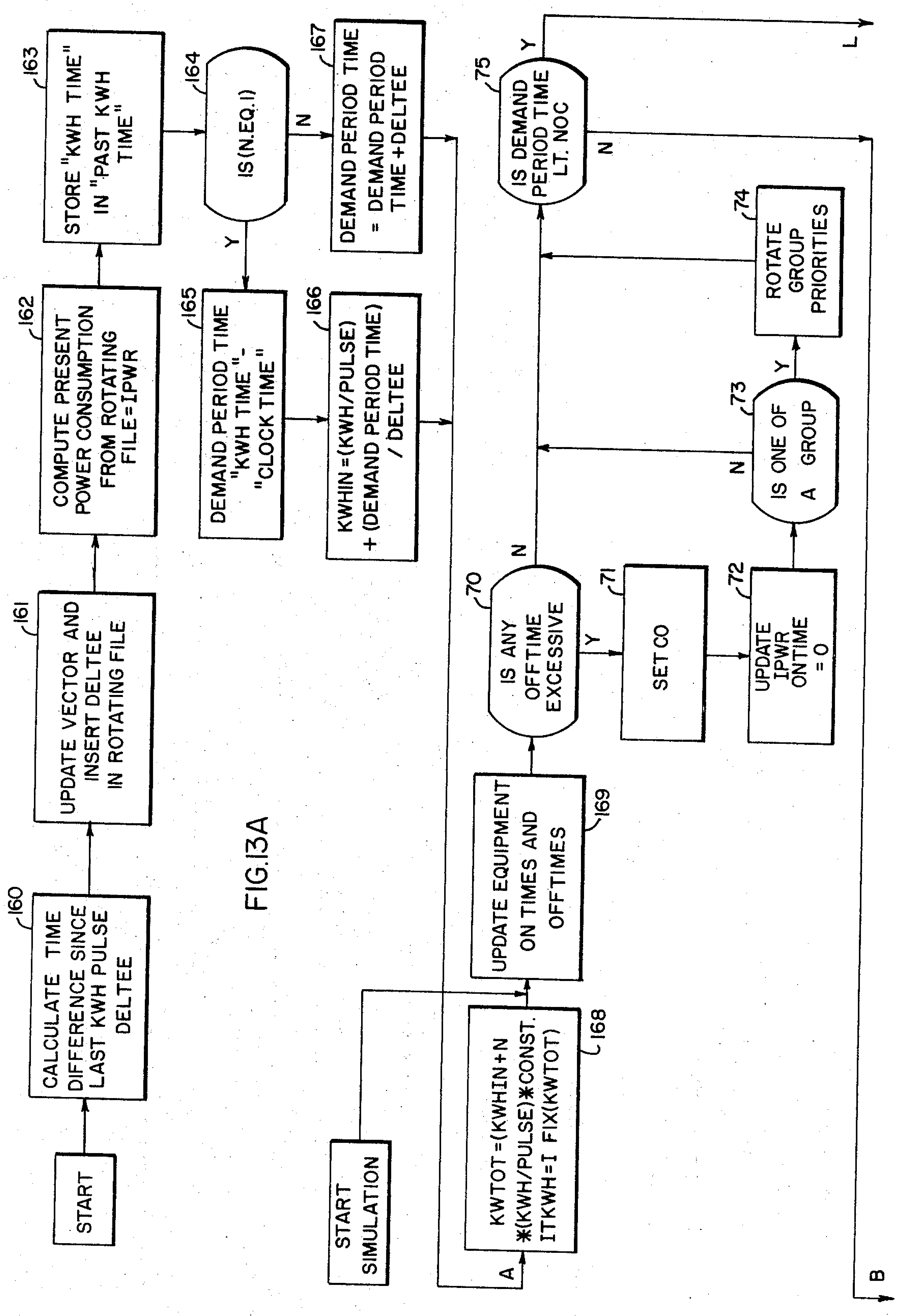
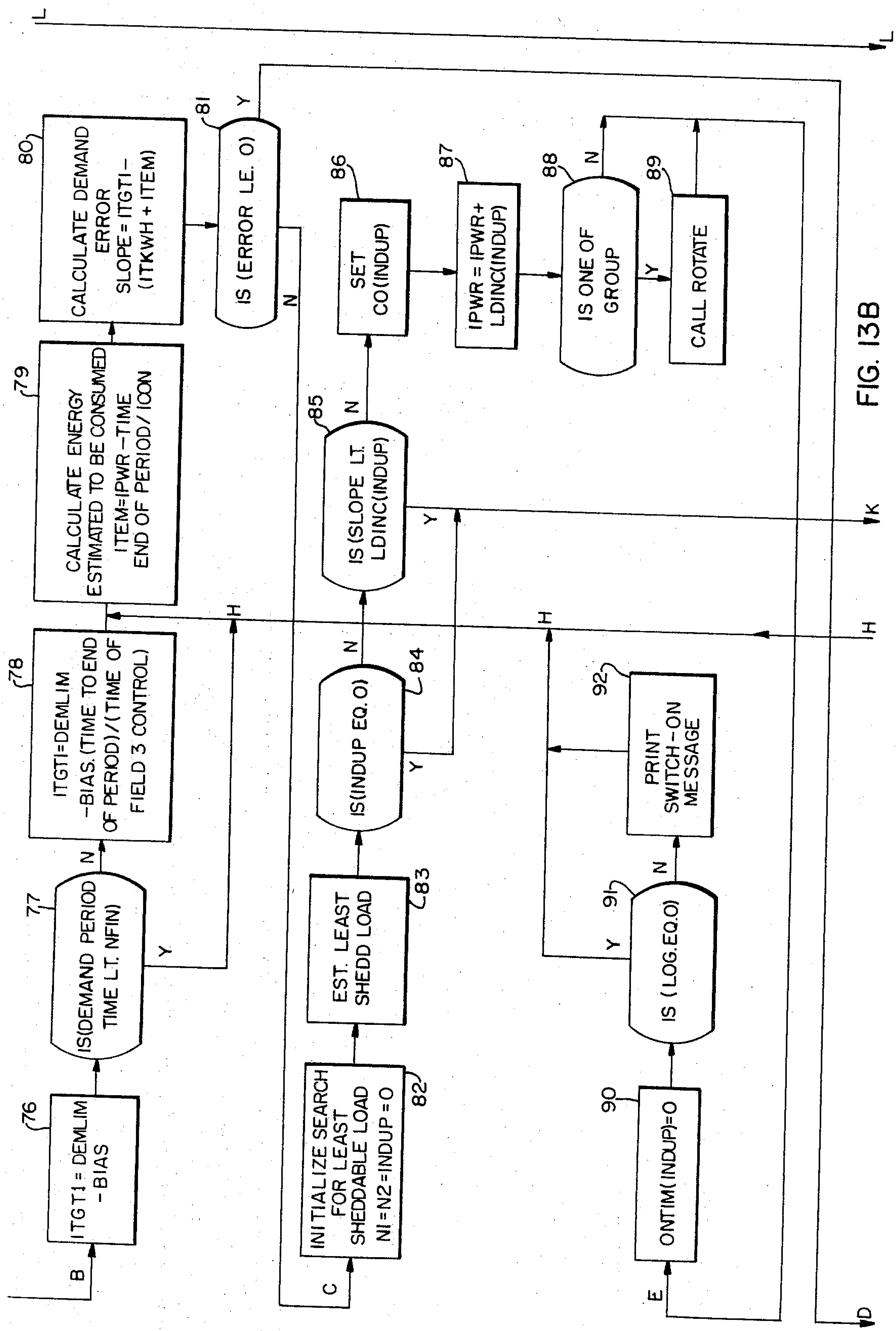

START
CALCULATE TIME DIFFERENCE SINCE LAST KWH PULSE DELTEE
160
UPDATE VECTOR AND INSERT DELTEE IN ROTATING FILE
161
COMPUTE PRESENT POWER CONSUMPTION FROM ROTATING FILE=IPWR
162
STORE "KWH TIME" IN "PAST KWH TIME"
163
IS (N.EQ.1)
164
DEMAND PERIOD TIME "KWH TIME"- "CLOCK TIME"
165
KWHIN=(KWH/PULSE) + (DEMAND PERIOD TIME) / DELTEE
166
DEMAND PERIOD TIME = DEMAND PERIOD TIME + DELTEE
167
START SIMULATION
KWTOT=(KWHIN+N *(KWH/PULSE)*CONST. ITKWH=I FIX(KWTOT)
168
UPDATE EQUIPMENT ON TIMES AND OFFTIMES
169
IS ANY OFFTIME EXCESSIVE
70
SET CO
71
UPDATE IPWR ONTIME =0
72
IS ONE OF A GROUP
73
ROTATE GROUP PRIORITIES
74
IS DEMAND PERIOD TIME LT. NOC
75
Y
N
A
B
L

FIG.13A



L
ITGT1 = DEMLIM -BIAS
IS(DEMAND PERIOD TIME LT. NFIN)
ITGT1=DEMLIM -BIAS.(TIME TO END OF PERIOD)/(TIME OF FIELD 3 CONTROL)
CALCULATE ENERGY ESTIMATED TO BE CONSUMED ITEM=IPWR-TIME END OF PERIOD/ICON
CALCULATE DEMAND ERROR SLOPE = ITGT1-(ITKWH + ITEM)
IS (ERROR LE. 0)
INITIALIZE SEARCH FOR LEAST SHEDDABLE LOAD NI=N2=INDUP=0
EST. LEAST SHEDD LOAD
IS(INDUP EQ. 0)
IS (SLOPE LT. LDINC(INDUP)
SET CO(INDUP)
IPWR = IPWR+ LDINC(INDUP)
IS ONE OF GROUP
CALL ROTATE
ONTIM(INDUP)=0
IS (LOG.EQ.0)
PRINT SWITCH-ON MESSAGE
B
C
E
D
H
K
Y
N
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92

FIG. 13B

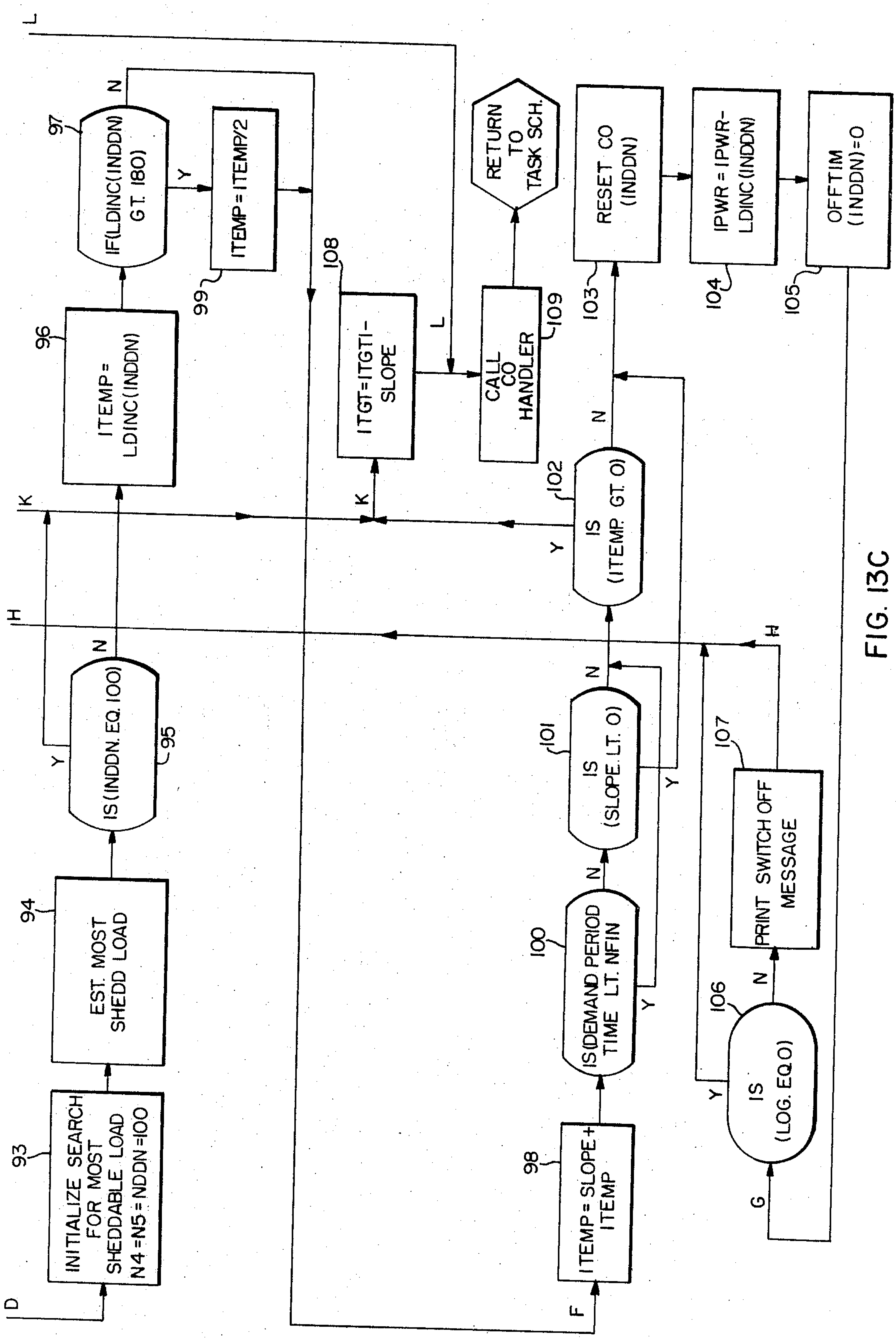

INITIALIZE SEARCH FOR MOST SHEDDABLE LOAD N4 = N5 = NDDN = 100
EST. MOST SHEDD LOAD
IS (INDDN. EQ. 100)
ITEMP = LDINC (INDDN)
IF(LDINC(INDDN) GT. 180)
ITEMP = ITEMP/2
ITGT = ITGT - SLOPE
CALL CO HANDLER
RETURN TO TASK SCH.
RESET CO (INDDN)
IPWR = IPWR - LDINC (INDDN)
OFFTIM (INDDN) = 0
ITEMP = SLOPE + ITEMP
IS(DEMAND PERIOD TIME LT. NFIN
IS (SLOPE. LT. 0)
IS (ITEMP. GT. 0)
IS (LOG. EQ. 0)
PRINT SWITCH OFF MESSAGE
Y
N
D
F
G
H
K
L
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109

FIG. 13C

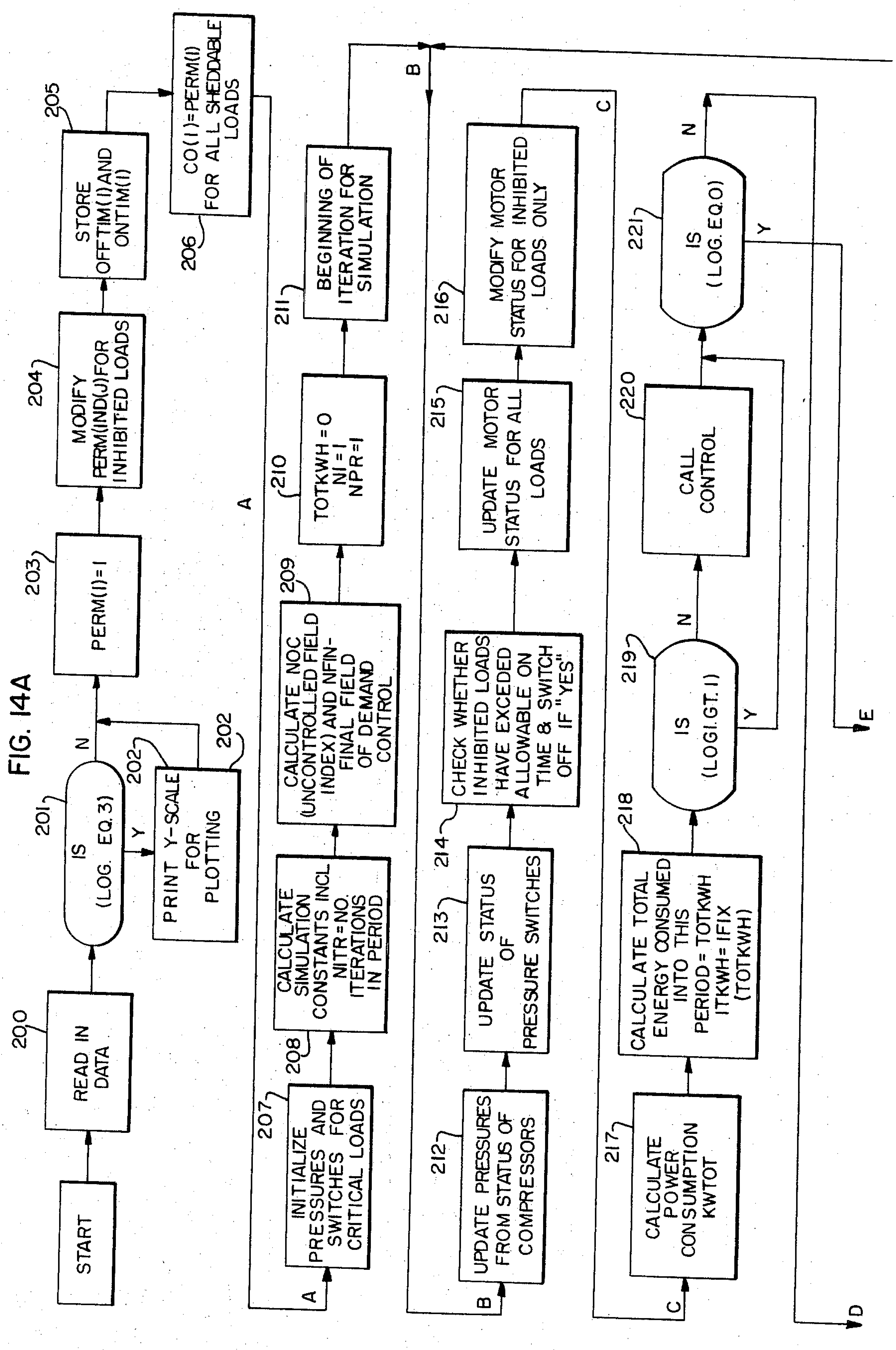

START
READ IN DATA
IS (LOG. EQ.3)
Y
N
PRINT Y-SCALE FOR PLOTTING
PERM(I)=I
MODIFY PERM(IND(J)FOR INHIBITED LOADS
STORE OFFTIM(I)AND ONTIM(I)
CO(I)=PERM(I) FOR ALL SHEDDABLE LOADS
INITIALIZE PRESSURES AND SWITCHES FOR CRITICAL LOADS
CALCULATE SIMULATION CONSTANTS INCL NITR=NO. ITERATIONS IN PERIOD
CALCULATE NOC (UNCONTROLLED FIELD INDEX) AND NFIN-FINAL FIELD OF DEMAND CONTROL
TOTKWH=O NI=I NPR=I
BEGINNING OF ITERATION FOR SIMULATION
UPDATE PRESSURES FROM STATUS OF COMPRESSORS
UPDATE STATUS OF PRESSURE SWITCHES
CHECK WHETHER INHIBITED LOADS HAVE EXCEDED ALLOWABLE ON TIME & SWITCH OFF IF "YES"
UPDATE MOTOR STATUS FOR ALL LOADS
MODIFY MOTOR STATUS FOR INHIBITED LOADS ONLY
CALCULATE POWER CONSUMPTION KWTOT
CALCULATE TOTAL ENERGY CONSUMED INTO THIS PERIOD=TOTKWH ITKWH=IFIX (TOTKWH)
IS (LOGI.GT.I)
CALL CONTROL
IS (LOG.EQ.O)
A
B
C
D
E
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221

FIG. 14A

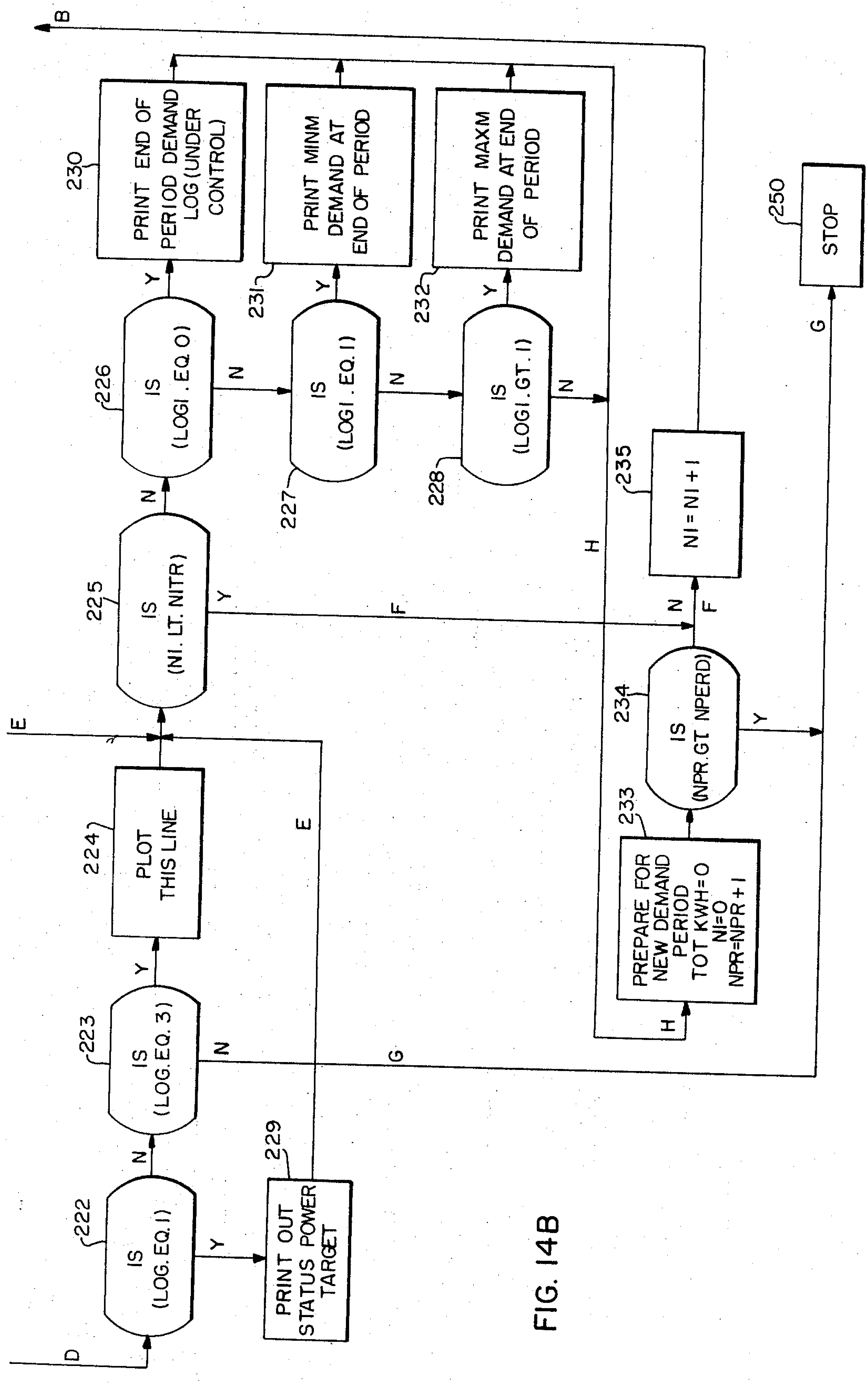

IS (LOG.EQ.1)
PRINT OUT STATUS POWER TARGET
IS (LOG.EQ.3)
PLOT THIS LINE
IS (NI.LT.NITR)
IS (LOGI.EQ.0)
PRINT END OF PERIOD DEMAND LOG (UNDER CONTROL)
IS (LOGI.EQ.1)
PRINT MINM DEMAND AT END OF PERIOD
IS (LOGI.GT.1)
PRINT MAXM DEMAND AT END OF PERIOD
PREPARE FOR NEW DEMAND PERIOD TOT KWH=0 NI=0 NPR=NPR+1
IS (NPR.GT NPERD)
NI = NI + 1
STOP
222
223
224
225
226
227
228
229
230
231
232
233
234
235
250
B
D
E
F
G
H
Y
N

FIG. 14B

CONTROL SYSTEM AND METHOD FOR LIMITING POWER DEMAND OF AN INDUSTRIAL PLANT

BACKGROUND OF THE INVENTION

When a load is connected by an industrial customer on a power system the cost of the energy consumed is generally billed by the power supply company on the basis of the total amount of power having flow within a billing period. The more power that is used, the more is the cost to the customer, and a cost-conscious customer, provided he has the choice, will at times cut the total load or at least reduce it. When a plurality of interruptible loads are connected on the power system, the final cost will depend on the overall distribution of the active loads. It is important for the customer or user to decide what the distribution of the loads should be within a given demand period, as well as between respective demand periods, and for the purpose to selectively control the load distribution. Such decision making is particularly important with electrical loads in view of the practice by the power supply utility companies to charge the cost of supplied power with progressive rates in relation to the higher amounts of total power within a given demand period, and also in relation to the highest level of power reached within the demand period. The rate based on the amount of power is an incentive for the user to maximize the consumption during the period, thereby to help improve the utilization of the generating plants and the power transmission systems. The progressive rate on the total demand accounts for the increased facilities provided by the power company to meet the user's demand and for the capital costs involved.

It is known from an article entitled "Electric Demand Can Be Controlled" published in Power, November 1970, pages 58, 59 by Norman Peach, to use a digital computer control system in order to instantaneously determine within a demand period the trend of power consumption, to forecast the total amount of power at the end of the period and to either add or shed the loads of a plant so as to be able to keep the anticipated demand as close as possible to a predetermined demand limit. While such a control system, or method, provides for a more economical use of the power available from a power supply utility company without exceeding the total amount of KWH permissible at a given rate during the demand period, the prior art control system, and method, do not take into account the constraints imposed by the customer's industrial plant on the use of the loads.

It is an object of the present invention to effect demand control with increased accuracy, thereby to insure all the economic advantages which can be gained by running a load system with as high a load factor as reasonably practical.

It is another object of the present invention to make use of improved digital computer technology at a minimum cost within the economic gain attainable by control of a power demand.

It is a further object of the present invention to keep the anticipated power demand of a load system within limits while respecting the constraints imposed on the loads by the load system.

Still another object of the present invention is to achieve an improved control of a customer user's power demand through anticipation of the power demand with a minimum of control operations.

It is still an object of the present invention to control a power demand in relation to anticipated demand and concurrently in relation to simulated load conditions.

SUMMARY OF THE INVENTION

Briefly, the present invention provides for an improved power demand control system and method for maximizing a customer's power demand rate throughout a finite demand period without exceeding a predetermined demand limit of energy at the end of the period.

A control system is provided for regulating the consumption of power supplied by a power supply system to an industrial load system having a base load and a plurality of interruptible loads and including loads having controllable and non-controllable status. The control system is responsive to time pulses derived from the power supply company meter for equal increments of energy thereby to continuously sample the power consumption. On this basis, the control system computes the anticipated final energy demand which it compares with the desirable demand limit to derive a demand error. In response to the demand error the control system adds or sheds loads selected in accordance with a predetermined priority schedule. The selected loads are controlled to be shed or added against a background of non-controllable loads.

A deadband is introduced during at least a portion of the demand period, and such deadband is made variable under certain conditions, in particular to ease the switching of larger loads.

The control system is operated during a portion of the demand period with a bias relative to the demand limit, and such bias is progressively reduced to zero during another portion of the demand period ending therewith.

Simulation can be used in order to ascertain the effects of control under the established priority and constraints, and such simulation can be used concurrently with actual control to improve decision making and update the information used for decision making, to increase the margin of control or permit emergency measures to be taken under anticipated adverse conditions.

The present invention can be used for control of the consumption of the energy supplied by a power supply company, such as electricity, gas, or like energy. The control system will be described hereinafter in the context of the consumption of electricity from an electrical company.

The loads supplied with energy may be of several types:

a. Lighting and space heating loads which are normally relatively constant and usually part of the base load.
b. Loads which are either ON or OFF with short run up times and reasonable starting curves.
c. Loads with their own ON/OFF controller. Examples of these are air or ammonia compressors, air conditioners, etc.
d. Loads with extended run-up times and large starting currents.
e. Large loads of short duration and relatively infrequent occurrence (e.g., test loads).

f. Arc furnaces and similar industrial process equipment where production penalties are paid for increased shut-down period. Safety requirements need also to be observed (e.g., toxicity of atmosphere).

Most of these loads have established constraints which must be respected when attempting to control separately or concurrently several kinds of loads to limit the power demand.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in the context of the supply of electrical energy by a utility power supply company to an industrial plant, and reference shall be made to the accompanying drawings in which:

FIG. 1 represents the extreme and intermediary KWH/TIME trajectories toward a total value of the KWH established as a limit not to be exceeded when controlling the consumption by shedding or adding loads against a base of unsheddable loads.

FIGS. 2A, 2B, 3A, 3B, 4A, and 4B are curves representing the correlation between KW and KWH consumed during a demand period for three different time distributions of power consumption for the same total of KWH.

FIG. 5 illustrates diagrammatically the principle of calculation of the demand error used in the control system according to the present invention.

FIG. 6 is a diagram showing a strategy of control used in the control system according to the present invention.

FIG. 7 represents control between boundaries in the early part of the demand period irrespective of the demand limit.

FIG. 8 illustrates control on either side of the mean trajectory in relation to two parallel boundaries.

FIG. 9 differs from FIG. 8 in that the two boundaries are coverging toward the demand limit at the end of the period.

FIG. 10 illustrates a particular strategy of control in accordance with the present invention.

FIG. 11 is an overview of the control system according to the present invention.

FIG. 12 is a flow chart explaining the operation of the Process Interrupt Handler which is part of the control system according to the present invention.

FIGS. 13A, 13B and 13C show an illustrative logic flow chart of a program according to the present invention.

FIGS. 14A and 14B show an illustrative logic flow chart of a simulation program that can be used with the control system according to the present invention.

To be in the context of the present invention it will be hereinafter assumed that the power demand results from a plurality of loads which at least in part can only be switched ON or OFF under constraints existing either at all times or occurring at least at the instant of control. However, by ON and OFF, it is understood that the loads, if electrical, need not be switched by electrical connecting or disconnecting. A power consumption can be increased or decreased by mechanical connection or disconnection of the load as well, such as by means of a clutch or valve actuation.

When several loads are available for being switched ON or OFF, to apply the strategies of the prior art just discussed, there is an ambiguity as to response that can be made for proper control, for example, at times a load switched off by the demand controller may already be off. The particular load to be switched on by the demand controller might have been previously put out of service. It is also possible that control of the demand be prevented by an overriding and external control equipment associated with the load, as is usual with air conditioners, chillers, or air compressors, for instance. Other types of constraints can be found in the particular industrial plant of a customer to a power company, and are within the scope of application of the present invention.

The invention provides for a judicial selection of the loads in order to respect these constraints by eliminating the priorities set among the loads which are found to be in violation of the existing or anticipated constraints. Thus the priorities are not only determined by a predetermined classification of the loads, they are also changed in the course of the control process in order to take into account the history of the loads as it appears from a reappraisal of the availability to be switched ON, or OFF, during the demand limit control process.

The selection of a load not only depends upon the overall status of the different loads, but also upon the behavior of any particular load in the user's plant. The control system according to the present invention, therefore provides for a dynamic allocation of priorities for the selection of the loads to be controlled at any particular time.

The invention also provides for relative control, rather than an absolute control of the loads, any selected and controlled load change being effected independently from the base load and from non-controlled loads.

The control system also takes into account the established constraints. For instance, besides interruptible loads which can be selected to be shed or to be added, there may be in the plant loads having a non-controllable status, which otherwise could defeat the control system. However, the control system according to the present invention limits its own capability of switching loads in order to accept the non-controllable loads as a favorable factor of correction in the demand limit control process. In particular, the control system according to the invention makes use of a deadband to this effect.

The invention moreover calls for the determination of the constraints either off-line or on-line in order to be able to ascertain with improved accuracy the anticipated effect of control and prepare for the right decision in selecting the loads to be controlled at a given instant or for an emergency action by the present control operation. To this effect a special technique of simulation is provided on the basis of actual load behavior in the user's plant, and such technique of simulation is used either as an off-line information providing system to be used preparatory to running of the control system according to the invention, or as an on-line coordinated helper system for constantly revising predictions and updating data during control of the loads in real time.

Finally the invention provides for a control system in which the technique of shedding loads or adding loads to limit the total power demand as desired at the end of any given demand period is modified in order to maximize the needs for particular loads of the user by minimizing the effect of control of the plant's constraints. To this effect, control is not necessarily exerted during a first portion of the demand period, on the assumption that sufficient possibilities of meeting the objectives are still left and are available, as a result of an improved control and improved selection, the the later part of the demand period. Moreover, when control is performed, during a second and major portion of the demand period, the technique involves the use of a deadband, namely the use vector limits within which no switching (on or off) of load is effected. In order to allow switching of larger loads when they are selected under the assigned priorities, the control system provides for a variable deadband. In addition, a temporary target below the objective is imposed for control until a certain time limit relatively close to the end of the demand period and when such limit has been reached the bias so established is progressively reduced to zero until the end of the demand period, at which time the demand limit is substantially achieved.

General Description Of The Limitation Of Power Demand By Control Of Interruptible Loads

Forecasting of the trend toward a total demand at the end of a given billing period is based on the following considerations:

A common form of presenting graphically the variations in power (KW) versus time is shown on FIG. 1 for a demand period of 15 minutes. This diagram is based upon pulses from the demand meter (which actually records KWH versus time), which represent time interval (Δt) for equal increments of energy. FIG. 5 is a similar diagram showing the slope for one point M on the trajectory. The slope is derived from the following relation:

$$\text{Slope} = \text{power} = (\text{KWH})/60 \qquad (1)$$

If nothing would change among the loads, the trajectory from point M would follow MW, until a point W where it intercepts the 15 minutes ordinate, thus below the demand limit C.

Referring again to FIG. 1, the energy curve is shown with the KWH plotted against time during a given demand period. The slope of the curves plotted on this diagram represent power in KW. In this case the base load (non-interruptible) has a slope α. The sum of the base and the switchable loads has a slope β. In order that a control opportunity exist, the slope must at some time be greater than the slope of the mean AC. The possibility of control should first be examined under the assumption of a single load to be switched ON or OFF. The boundaries of acceptable trajectories to meet the requirements with a single load are given by lines ABC and ADC, and there is an infinite number of possible intermediary trajectories, such as *a, b, c, d,* within this envelope. Of course, interception of the 15 minute ordinate between C and E would respect the Demand Limit requirement but would provide a poor load factor. In the absence of any other consideration all of the trajectories have equal economic merit so far as the mere purchase of electrical energy is concerned. The minimum requirement is that $\alpha <$ KW $< \beta$, since the power in KW is for a given point M on the trajectory, the slope from that point.

A trajectory which would give a uniform reduction in power from the maximum ($\underline{S+B}$) to the minimum B would have a power P_t versus time relationship such that:

$$P_t = (S+B) - \frac{S}{t_{max}} . t \quad \text{with } B < P_t < (B+S) \qquad (2)$$

wherein t_{may} is 15 minutes, S the maximum power of all switchable loads ON and B the power of the base load. It can be shown that when a point M follows one of the trajectories of FIG. 1, in general:

$$\text{Target} = \frac{1}{60} \left[\int_0^t P_t \, dt + P_t \, (t_{max} - t) \right] \qquad (3)$$

Other continuous relationships between P_t and t are possible.

However, the power factor is a further requirement as can be seen from FIGS. 2A, 2B, 3A, 3B, 4A and 4B. For instance, an industrial load system may have a base load B comprised of a number of small loads such as lighting, small meters, etc., and a total switchable load S consisting of a number of smaller loads. FIGS. 2 to 4 represent three different load distributions which could be obtained under the same maximum demand but with three different load factors. Three different trajectories can be found on FIG. 1 which would correspond to these three different distributions of power. FIG. 2A shows a power P1 maintained up to time t_1 and a lower power P2 maintained from time t_1 to the end of the demand period. FIG. 3A shows a power P2 maintained from initial time 0 to an instant t_1 and a higher power P1 consumed between time t_1, and a later time t_2, the power P2 being again supplied from time t_2 during the remaining portion of the demand period. FIG. 4A is similar to FIG. 2A but with an inverse distribution of the powers P1 and P2 before and after time t_1. The trajectory to a common level of HWH at C is ABC for FIG. 2A, as shown by FIG. 2B, ABDC for FIG. 3A is shown in FIG. 3B and ABC for FIG. 4A as shown on FIG. 4B. Since the power consumed is constant during each of the time intervals, the integrated power follows a demand curve which is linear, the slope being P1, or P2, depending upon the level of power maintained during the particular time interval.

FIG. 5 illustrates the principle of calculation of the error for any point M along the trajectory during a demand period of 15 minutes. A clock installed by the power supply company determines the initial time of each demand period, or the final time of a preceding demand period). The watthour meter provides a "KWH pulse" which represent the magnitude of the power which has been consumed during a certain instant Δt corresponding to a full rotation of the disc of the meter, thus representing a constant increment or unit of energy (KWH). Thus, the Δt interval appearing along the time axis is essentially variable. This time interval is detected as a representation of the slope at point M and it represents the power P_t in KW hour/hour. If the load of the plant is maintained in the same condition until the end of the 15 minute period, the energy curve will follow the tangent MW. However, the Demand Limit should be at C therefore, there is an error CW by default. Which in terms of power is

$$\Delta P = [(60)\times CN/15-t] - P_t$$

as is evident from the geometry of triangles MNC and MWC. Having determined Slope $= \Delta P/60$ by triangulation, and the sign of the error, depending upon whether the intersection point W is above or below the target C, control is effected by selectively adding or sheeding suitable loads in the plant. In order to more closely follow the target, a deadband is provided on either side of the trajectory by defining two angles ϕ and θ which should not be exceeded. The headband will contain excessive control but will leave free control of the loads as long as the projected tangent remains within two limits MU and MV (FIG. 5) so defined. In accordance with the present invention such deadband is made variable as will be explained later. The upper limit MU will represent the "decrease vector" and the lower limit MV of the deadband will represent the "increase vector" for control.

Since in the early part of the demand period the possibility of control is greater than in the later part, a differential treatment of the load control during the period is beneficial. Referring to FIG. 6 from time 0 to time ti no control is effected. This allows for a maximum utilization of the loads in the plant at an early time in the period when all possibilities of control to meet the target T are available. After this first field, the control system from time ti to time t_{end} provides control in a second field in accordance with the general principles explained hereabove with reference to FIG. 5. Thus, at position M on the trajectory followed from time zero, the slope of the tangent indicates at W that the loads as they stand would bring total power consumption under the target T by as much as TW. Improved control is obtained when the distance from the point to the target has a reduced slope. It has been suggested therefore to create a bias relative to the target either by having an offset at the beginning of the trajectory, or by lowering the target such as at C on FIG. 6. This is the type of control achieved in the second field, e.g., between time ti and time t_{end}. Therefore the control system is operative to calculate and correct an error from W to C rather than from W to T. When attempting to control the demand to correct the slope of MW by switching ON loads, there is a possibility that MW raises itself as far as to exceed the "increase load vector MV." The load will not be switched ON in such case. However, under the pressure imposed on the system by the non-controllable loads which may be switched ON nevertheless, it is possible that the vector MW still reaches a slope above the temporary target C or even the desired demand limit T. In such case the control system is operative to switch OFF loads against the "decrease load vector" MU.

Assuming that at time t_{end} the trajectory reaches point M_2, as shown on FIG. 6, there is still an error RC, although very small. At this instant the second field is terminated and a third field of control operation is established in the control system operation during which the bias CT is progressively reduced to zero at the end of the demand period of 15 minutes. Therefore, the trajectory will pass for instance by point M_3 as shown, heading toward the real target T at the end of the third period. This differential treatment of error anticipation and load control during the demand period affords a more judicial selection of the loads and a more effective control of the total demand.

Other strategies of control are possible. Instead of continuous control toward a target, a discontinuous strategy can be followed. For instance, as shown in FIG. 7 the trajectory is first only restricted to the area bounded by OX, OY and ZZ which have been selected irrespective of the demand limit T. T becomes a permanent target once one of the boundaries ZZ and YY, has been reached.

FIG. 8 illustrates another strategy for adding or shedding a load. It is seen here that control is effected so that the sum of the on-times is equal to the time necessary to reach B from A.

$$t \geqslant t_1 + t_2 + t_3 \qquad (5)$$

$$X \leqslant X_1 + X_2 + X \qquad (6)$$

Should the accumulated KWH intercept line BC, (as at P) only the base load must be left switched on if the limit C is not to be exceeded. In addition to satisfying relations (5) and (6), it may be stipulated at the plant that the minimum ON time should be more than "t_{min}" and that the ON/OFF ratio for a given cycle should be less than "t_{max}" before the load can be switched ON again. Thus, once the load has been switched ON, it will remain ON until

$$t_i > t_{min}$$

and once OFF, it will not be able to be switched OFF again unless

$$t_i / X_i < t_{max}.$$

Such a strategy can be implemented by setting up constraints YY and ZZ on either side of the mean curve AC, the distance from the mean curve being chosen in order to make the ON times and OFF times, and ON/OFF ratios compatible with the slopes of the two load conditions. Particular care has to be exercised so that proper action is taken whenever the KWH curve intercepts BC. This is achieved by calculating the slope λ of MC the line joining the point M on the trajectory to C, and switching OFF a load other than base load once $\alpha = \alpha$.

FIG. 9 shows an alternate strategy with pivoted limits. This strategy is taught in the U.S. Pat. No. 3,621,271 issued on Nov. 16, 1971 to Carl J. Snyder. While $t_i / X_i < t_{max}$ is being observed, $t_i > t_{min}$ would not be, since the system would tend towards more frequent switching at the end of the demand period in the case of a single switched load.

THE DEMAND CONTROL SYSTEM OPERATION

Referring to FIG. 11 there is shown an overview of the control system 1 according to the present invention applied to the control of the loads of a plant 2 supplied with electrical power on the power supply lines 3 of a power supply company 4.

The loads are classified in the four categories of I base load, II inhibited loads, III sheddable loads, and IV critical loads.

The base load represents equipment which is constantly present or at least, if the equipment is switched on and off, such occurrence has in its narrowness a sufficient pattern to equate to a fairly steady load. Therefore, the base load is by definition a non-sheddable load. If control of the base load is not possible, the base load affects by its presence the control of the sheddable loads, since it accounts for a portion of the KWH consumed at any given time. Typical of the base load are the lighting and heating loads, and also certain groups of motors and equipment.

An inhibited load is defined as a load which will be permitted to be switched ON during the first minute of any demand period but will be switched OFF after a certain duration has elapsed and will be inhibited from being switched on again until after the next demand period has begun. For these loads the control system needs to know the duration of ON time from the beginning of a given demand period, and at a given instant whether the load is available for use or not. If the load is available, it will be qualified as permissive.

The sheddable loads are by definition the loads which may become available on a priority basis to be switched ON, or OFF, by the control system. This is a general quality of the loads which are not a base load provided they have not a "non-controllable" status. Thus, the constraints of the present industrial plant may limit such "sheddability."

The present invention provides for selection and control of the loads within such constraints in order to maximize the utilization of the power supplied and minimize the cost of the energy. Therefore, a sheddable load essentially is, within the concept of the invention, a load which can be switched ON or OFF during a certain demand period without affecting the operation of the plant.

An important limitation in the control of an interruptible load is the ON time and the OFF time. It is not advisable to start-up a load too often, for instance, for a motor this may have a damaging effect on the windings. Also electrical surges caused by starting, are costly. It might also be economically desirable not to leave an equipment off during an excessive time interval. When an excessive off time exists, such equipment must be switched on and another alternative has to be sought if the shedding of some load is the control action required at that time. The ratio between ON time and OFF time may also introduce a limitation, requiring to keep ON a load.

One important consideration in the control system operation according to the invention is that while sheddable loads may be available for switching, it is possible to spread the ON times and OFF times within a given demand period and between demand periods in order to spread wear.

The last category of load is the critical load. These are loads which are ON and OFF under external requirements at the plant. For instance the air conditioners and the compressors follow local conditions. Local control might override action by the control system. Switching ON or OFF of such loads although required by the demand control system, could be ineffective since the running time for such a load is not known in advance. For this type of load switching ON/OFF is constantly monitored.

Referring again to FIG. **11** the loads are controlled by a contact output unit **5**, which is part of a process control computer system **6**. The contact output unit **5** does operate a plurality of load contact outputs **7**, each of which closes the energizing circuit of a corresponding relay **8** to actuate the switching element **9** of a load. Such switching element may be the starter of an electrical motor, the plunger of the valve of a compressor, etc.

When a load is in the switched ON condition, a corresponding status contact interrupt **10** is closed as shown on FIG. **11**, with the contacts being arranged so as to correspond to the loads. There is shown in FIG. **11** two such groups of contacts with one group being associated with a diode **11** and one scan contact output **C01**, and the other group being associated with a diode **12** and another scan contact output **C02**. Respective diodes **13** are connected in circuit with corresponding status contact interrupts **10** to establish a circuit from a **48V** source **20** provided by the computer system, to ground with the associated diode, **11** or **12**. As shown on FIG. **11**, concurrent closing of one scan contact output such as **C02** and one particular status contact interrupt **10**, such as shown on the Figure, permits identification by the interrupt unit **14** of the status of the particular contact as being one of Group **2** (**C02** on the Figure).

In order to control the power demand by shedding or adding loads, the control system **1** is responsive to the power consumption continuously recorded by the meter **15** of the power supply company. The process control computer receives over a line **16** the KWH pulse which as a Δt characterizes the consumption at any particular instant within the demand period. The power supply company also provides a clock **17** which determines the beginning and the end of each demand period. In the instant case it is assumed that each such demand period lasts 15 minutes. For each turn of the disc of the meter **15** there is a pulse generated which will be hereinafter called "KWH pulse." The succession of these pulses represent on a time scale the power consumed for one turn of the disc. The process control computer system **6** through the interrupt unit **14** assesses the status of the status contact interrupts **10**, and more generally monitors all the input data fed into the computer system regarding the individual loads in the plant with their constraints, effectuates calculations, makes decisions, which are converted, after each of the above-mentioned KWH pulses, into whatever load control action is necessary through the controlled operated of the relays **8**.

Included as part of the control system **1**, is the process control computer system **6**. This computer system can be a digital computer system, such as a Prodac 2000 (P2000) sold by Westinghouse Electric Corporation. A descriptive book entitled "Prodac 2000 Computers Systems Reference Manual" has been published in 1970 by Westinghouse Electric Corporation and made available for the purpose of describing in greater detail this computer system and its operation. The input systems, associated with the computer processor are well known and include a conventional contact closure input system to effectuate scanning of the contacts or other signals representing the status of the equipment. Also operator controlled and other information input devices and systems are provided such as the teletypewriter **19** shown in FIG. **11**. The contact closure output system is also conventional and part of the Prodac 2000 general purpose digital computer system sold.

Although FIG. **11** shows electrical loads which are sheddable or which can be picked up by the demand control system, it should be understood that switching of an electrical load is not the only control action within the scope of the present invention. If it is found not necessary or desirable to limit the demand by switch the actual electrical load on or off in every case, the same result can be obtained by other alternatives. For instance, fan loads can be reduced to some 20% of normal by closing the inlet vanes or damper by means of a servomotor, rather than switching off the motor. This operation could be performed relatively frequently and for short periods (for example towards the end of a demand period as a fine trim), whereas there is a limited number of starts per hour allowed for larger motors. When the load involves eddy current couplings or pneumatic clutches, the mechanical loads can be disconnected from their motors. With air compressors having inlet valves, these may be held open by the pressure control equipment when the pressure is high. The control of compressors to maintain demand below the desired level would operate in parallel with the pressure control system with the same goal. These alternatives avoid increasing the cost of maintenance of plant equipment.

The computer system used in the control system according to the invention includes both Hardware and Software. For instance the interrupt unit **14** is associated with an interrupt handler (**50** in FIG. **12**). Software is being used as a convenient means of quickly and efficiently performing operations as required in monitoring data, doing calculations, making decisions and translating treatment of information into control action within the short time intervals determined by the recurrent transmission of KWH pulses from the power supply company meter **15.**

It is observed that the inputs consist of interrupts which are successively handled by the process interrupt handler (see FIG. **12**). One interrupt will receive the 48V DC pulse generated by the external clock and is used to reset the demand meter owned by the power company. This same pulse will reset the associated registers in the computer when it is received. Another interrupt will receive a train of 48V DC pulses transmitted by the meter **15,** each pulse representing KWH (or KVAH) consumed. Another interrupt could be reserved for a second KWH meter if needed. Three other interrupts (the scan contact interrupts **10** of FIG. **11**) will receive a status which corresponds to the status of one load contact in the plant and belongs to one group of three associated with one scan contact output (**C01, C02** on FIG. **11**).

The normal operator interface with the system will be via a teletypewriter **19.** This device will also provide a log of system performance together with any other messages that may be required. Via the typewriter keyboard the operator will also be able to change the values of various constants relating to the system as a whole or to individual items of equipment. The time and data and onpeak and off-peak demand levels can also be changed using the same keyboard.

Having considered the Hardware aspect of the control system according to the invention, consideration will now be given to the software components of the computer system referring in particular to the flowcharts of FIGS. **12, 13A, 13B, 13C, 14A** and **14B.** Referring to FIG. **12,** the operation of the interrupt handler **50** of the computer system is described. This program will receive T (at step **51**) an interrupt from the clock at the beginning of each demand period together with a KWH pulse (at step **60**) from the KWH (or KVAH) meter **15** for each revolution of the disc.

In response to a clock pulse, the decision at step **51** is a yes, and the data are transferred to a buffer. These data include time (step **52**) the demand limit desired at the end of the demand period (coded as DEMLIN) which is set in the total kilowatt register (KWTOT). At step **53,** the program puts data to be printed out for the preceding demand period. The next step (**55**) is to clear all registers in which accumulated values are stored including time into period and KWH during the period (time, number of pulses N, KWHIN, and KWHTOT registers). Prorated values of time and KWH are stored in those registers when the KWH pulse does not coincide with the clock pulse. The chain returns to the process interrupt handler **50.**

If the interrupt relates to a contact status, as seen at step **56,** the interrupt is stored at step **51** at the proper location to provide a status image of the array of contact interrupts **10** (FIG. **11**). The present contact output is reset and the next contact output is set in the status list (at step **58**). At step **59** the contact output handler which corresponds to the contact output unit **5** (FIG. **11**) is bid, and the chain returns to the process interrupt handler **50.** If the interrupt is the KWH pulse from the meter, as seen at step **60,** this data is stored as real time in a "KWH TIME" register. For each turn of the disc of the meter, e.g., for equal increments of energy, one KWH pulse is received. The count is effected at step **62** ($N = N + 1$), and whenever required, there is a bid for control at step **63.** This chain returns also to the process interrupt handler **50.** Besides the preceding interrupts which directly determine operation of the control system, there may be other interrupts received, as seen at step **64.** Such "unscheduled" interrupts cause at step **65** the printing of a warning message, and there is a return to the task scheduler of the computer system.

FIGS. 13A, 13B, 13C show a flowchart of the main control program, which is provided to explain the operation of the control system according to the present invention.

When control starts, "DELTEE," e.g., the Δt between two successive KWH pulses, is determined by difference. This is step **160.** Then a rotating file is updated by adding the last of three successive vectors corresponding to three successive times t_1, t_2, t_3 being for the latest Δt at step **161.** At step **162,** the present power consumption (IPWR) is computed from the rotating file, and from the present status IPWR is translated at step **163** into the "Past KWH TIME" register. At step **162** the present power consumed is calculated by averaging for three successive points on the trajectory corresponding to times t_1,

$$P_t = [a\ (a(k/t_1) + (1-a)(k/t_2) + (1-a)(k/t_3)] \tag{7}$$

or

$$P_t = k\ [a(a/t_1 + 1 - a/t_2) + 1 - a/t_3] \tag{8}$$

where $0.1<a<0.4$ and t_1 is in hours and k − KWH/pulse.

It is recalled here that while each KWH pulse is received for the same increment of energy (one turn of the disc of the KWH meter), the "DELTEE" represents the power consumed since the time between each pulse depends upon the speed of the disc rotation. It is necessary to compute the total time into the demand period and the total energy consumed within the period. The first is obtained by integrating the DELTEES corresponding to all KWH pulses received during the period. The energy consumed is equal to the number of pulses multiplied by the meter factor (KWH/pulse). The decision at step **164** (since N is normally greater than 1) is to go to step **167.** where the demand period time is found to be the sum of the Δt's in the period.

The DELTEE corresponding to the first pulse after the clock pulse (N=1) belongs in part to the last demand period and only in part to the new demand period. In such case, the decision at **164** is to go through steps **165** and **166** which provide a prorated value of the KWHIN in proportion to the fraction of DELTEE pertaining to the new demand period. Accordingly, step **165** provides the time difference between KWH Time and clock time, and at step **166** the prorated value KWHIN is computed.

Looking to A on FIG. **13A**, the next step is to compute KWTOT, e.g., the energy consumed during the present demand period until the particular iteration, converted to equivalent power at the end of the period. KWTOT is equal to N (number of pulses) *KWH/pulse *Constant plus the fraction prorated at step **66,** if there is one, e.g., KWHIN. Since computation is done with a floating point for increased accuracy, conversion to integer is effected as indicated by ITKWH = IFIX (KWTOT) (**168**).

Then, at step **169** the system looks at the status of the ON times and OFF times of the loads, while adding the Δt (DELTEE) and it is determined at step **70** whether any load exceeds the OFF time assigned to it. In such case, a decision is made at **70** to set the contact output to switch the particular load ON (step **71**) thereby not to violate the constraint. Since the load has been switched ON, the ON time of this particular load is set to zero (step **72**). Also, the energy estimated to be consumed in the overall industrial load system (IPWR) must be updated in order to take into account the load so picked up. However, if the load exceeding its OFF time belongs to a class, or priority including several other loads in order to reduce wear, all the loads of the same class, or priority, are rotated. Rotation is effected at step **74.**

The next decision is at **75** depending upon whether the system is under the first field previously mentioned, e.g., a first portion of the demand period for which no control is effected (NOC). When the first field terminates, the second field begins which is a field of control, namely at B after step **75.** If in response to the decision **75** the control system operates in the no control condition (NOC), the system goes to **109.** As a result, the contact output handler will ascertain the status of the contacts. Considering now the chain starting at B for control operation, the second and third fields of controls (from t_i to t_1 and from t_1 to **15** minutes) should be explained again by reference to FIG. **6.** C represents the BIAS in the second field of control, T the original target corresponding to the desired Demand Limit (DEMLIN). The target (ITGTI) in the second field is represented by C, e.g., DEMLIN-BIAS. The control system (FIG. **13B**) is set accordingly at step **76.** A decision is made at step **77** to choose between the second and third field of control depending upon whether the time in demand period has reached t_e (NFIN) or not. If we are still in the second field, the flowchart goes from **77** directly to step **79.** If the third field is required, at step **78,** the BIAS is reduced at each iteration until the end of the period. Accordingly, a fraction is used to reduce the BIAS by a ratio between the time left in the period and the duration of the third field. This amounts to a displacement of the target for each point on the trajectory. At steps **79** and **80** the demand error is calculated. ITGTI represents the ordinate of the target (C in the second field, I in the third field, T at the end of the demand period). The ordinate of N (see FIG. **6**) is ITKWH obtained at step **168.** The ordinate of W is ITKWH + ITEM (e.g., WN). Therefore, the error due to W being too low, or too high, relative to the target is Slope = IGTI − (ITKWH + ITEM). First, at step **79** ITEM is calculated, using data obtained at step **162** (IPWR = present power consumption), and computing the second term in equation (**3**), e.g., P_t ($T_{max} - t$). Knowing ITKWH and ITEM, the demand error is calculated at step **80.** Then the sign of the error Y or N at **81** will tell whether the projected point W lies above or below the target. If it is above, the error is negative and loads have to be switched OFF. The flow chart goes to D. If point W lies below the error is positive and loads must be switched ON. The flow chart goes to C.

First, the situation when the error is positive will be considered, by taking the flow chart from C on, in order to find (1) whether there is a load to be switched ON, (2) whether a selected load can be switched ON by step **86.**

The computer system then first looks for a load. Step **82** initializes a search for the least sheddable load.

In the table of priorities, the loads are classified from the least sheddable to the most sheddable (which can be understood as from the first to be switched ON to the last to be switched ON). In other words, the search goes from one end of the table when the search is to switch ON a load, and from the opposite end if the search is to switch OFF a load. (The last situation would be at D on the flow chart).

As a general consideration at this point (valid also for OFF switching at D) in a table can be stored or reserved in memory the following characteristics associated with each item of equipment to be of the switchable load type:

- Equipment Identity No.
- Power Consumed When Starting
- Starting Period
- Power Consumed When Running
- Group Priority
- Subgroup Priority
- Maximum Allowable Off Time
- Minimum On/Off Time Ratio
- Minimum Time Between Starts
- Availability For Use By The Demand Control System
- Address of Associated Contact Output
- Amount of Time 'Off' since Being Switched Off - Updated Each sec., or after
- Amount of Time On Since Being Switched On each KWH Pulse.

The group priority is assigned by the user, the most sheddable loads being low numbers. Priority, or group, numbers increase with the importance of the load to the overall plant operation. The programs associated with this table will be called immediately after the switching decision subroutine, or once per second to effect: a search through the table to determine the identity of the next load to be switched and the power difference this will make. In the case of large starting currents, a check can be made to see whether starting this motor will cause the maximum demand to be exceeded. If so, the next motor in the sequence will be selected. Similarly, it can be presumed that if the sum of OFF plus ON time is less than the minimum between starts, another unit will be selected for switching on. In the case of large loads not directly controlled by the computer but for which the computer provides a permissive contact, a check will be made to determine whether the maximum time into the period has not been exceeded and close or open this contact accordingly (see Step **70** on FIG. **13**A). If loads have imposed a maximum off time and a minimum on/off time ratio, the computer system would include a program to (1) switch that load ON regardless, whenever the off time has exceeded the maximum allowable off time; (2) prevent the load from being switched OFF unless the ON/-OFF time ratio is greater than the minimum allowed.

Returning to C on the flow chart (FIG. **13**B), step **82** provides for indexation of the priority order (N_1) and of the subpriority order (N_2) for a load to be switched ON (INDUP). At step **83** the search is established accordingly. If the search has not provided at least sheddable load, the decision at step **84** is to go to K, e.g., a no control chain leading to a bid for the CO handler at **109.** At step **108,** the projection W on the final ordinate of the tangent from the point M on the trajectory (see FIG. **6**) is determined as ITGT by the difference between the target and the error. Such information can be conveniently logged for the following reason. ITGT = Ordinate of target (C, if in the second field of control) − error (CW). This is the way ITGT is determined at step **108.** But ITGT is also equal to: WN + ordinate of N (See FIG. **6**). Since WN = ITEM and ordinate of N = ITKWH, both known by steps **168** and **79,** then ITGT is known from previous computations. However, when late in the demand period ITEM becomes very small, therefore a log of ITGT provides a value which tends to be ITKWH equal to the final demand at the end of the demand period.

At step **109** the CO handler of the computer is called upon to check the contact outputs and there is a return to the task scheduler of the computer system.

If however, a load to be switched ON has been found (NO at **85**) (INDUP), the deadband is put into effect at step **85.** If the deadband (LDINC) includes vector MW, then no control is effected (YES at **85**) and the flow chart goes again to K (again a log of ITGT and a bid for the CO handler). However, if there is a NO at **85** then MW is outside the deadband (LDINC), control is possible and action is bid at step **86.** At step **87** the new present power consumed IPWR is calculated by including the added power LDINC and due rotation is effected within a group of loads at step **89** if the load is one of a group.

Having called for the load to be ON, the ON time (ONTIM) for the particular load (or for the rotated group of loads if steps **88, 89** are followed) is initialized at **90** (E), while at step **91** a decision is made to print the "Switch-On" message (**92**) if the control operation requires it.

Considering now the decision at **85** to switch a selected load ON (if N) or not to switch (if Y), the error CW (FIG. **6** for second field of control) is compared with the increase of power LDINC expected. Control will occur only if LDINC is less than the error. If the selected load can be switched (**85**) the control action is determined at step **86** and the increased amount of power is accounted for in the new IPWR (step **87**).

When the demand error (**81**) is negative a load must be switched OFF because ITGT is above the target. In such case the flow chart goes to D (FIG. **13**C). Steps **93** and **94** correspond to the steps **82, 83** encountered at C for the positive demand error. The search here is for the most sheddable load, thus from the opposite end of the table of priorities and subpriorities (N_4, N_5) as opposed to steps **82, 83** for ON switching. When no load to be switched OFF is found, the program indicates **100** as a flag. If this is the case, the flow chart goes to K, and no control is exercised as previously indicated with respect to steps **108, 109.** If there is such a load (INDDN), the decision (**95,** N) is to test the relation of LDINC (the correlative decrease of power if the particular load were effectively switched OFF) to ITEMP which determines the deadband. Two situations happen at this stage depending upon whether the load exceeds 180 KW (Y) or not (N) and the decision is made at **97.** If it is a Y, ITEMP is made half of what it is at step **96.** In other words **96** can be read as making the deadband ITEMP = LDINC and **99** as making the deadband ITEMP = ½ LDINC. Assuming **97** leads to N, then ITEMP is made equal to LDINC. This means that at step **98** the slope (CW if in the second field) which is negative is in fact subtracted from LDINC. This difference is a residual error sign of which (in the second field **100** goes to **102**) is checked for decision at **102** to control (**103**) or not (**108**) switching of the particular load. Again, if the vector or W is within the deadband (between MV and MC) there will be no control. If MW is outside the deadband, then the load will be switched OFF. If control is in the third field (**101**) then the system merely looks to the error (negative here) to switch (Y) or not the loads OFF.

Once a load is shed (at step **103**) the present power IPWR is updated (**104**). At step **105**, the OFFTIM (computed off-time of the load) is updated at each iteration. A decision is made thereafter to log the information (step **106**) and to print a switch-OFF message (step **107**). After each control operation (shedding or pick-up), the energy estimated to be consumed is estimated (at step **79**) and the demand error is again calculated in order to establish whether a new load should be switched ON (at C) or OFF (at D).

Once counting of time and power consumption has started for a given demand period, a first field is established during which the load system is left to its own constraints without control (**75,108,**NOC). Since there is no control, the slope varies only with the loads. There is no need for a calculation of the slope at any point of the trajectory. Although there is no control during the first field, the status of certain of the interruptible loads may have changed during that time. For instance, in the particular example of the embodiment described, the OFF time of certain loads may have become excessive, and according to step **70**, the contact output of such load would have been set (**71**). Therefore, the control system calls for the CO handler which is the software counterpart of the contact unit **5** (FIG. **2**). Thus a bid is made (**109**) for the CO handler in order to implement the status of the contact outputs established by the previous iteration. The system then returns to the task handler. The first field ends at time t_i (FIG. **6**) and a second field is established thereafter (N,**75**).

It should be observed here that there is a difference between (1) the switching ON of a load which has been OFF for an excessive OFF time, such as operated by the system at **70** and **71** (FIG. **13**A) and (2) the switching ON of a selected load such as at **86** on FIG. **13**B. When there has been an excessive OFF time, the system indeed provides for the switching ON of the load. However, such switching is not really a "controlled" switching in the sense that (a) there is no selection made of the load, no prediction made of the KWH and no decision is done to switch under predetermined conditions which suppose alternative situations; and (b) the additional load created at **70** and **71** might go against the overall objective to limit the demand. in contrast, when switching ON a load at **86,** a selection (**82,83**) is made and the decision to switch is based on an anticipation (**80**) of an error. Therefore, when referring to switching such as at **70,** e.g., under the constraints assigned to the load, the load should be considered as in a "non-controllable" status.

An important application of the control system according to the present invention can be found when the industrial plant includes among other interruptible and switchable loads, one load for instance, which could not be switched without causing overshooting of the target T, such as at CR at point C of the trajectory I on FIG. **10.** By reducing the demand limit to T during a portion of the demand period, for instance from time 0 to time t_b, the control system will operate more rigidly against the constraints (DEMLIN at step **76** on FIG. **13**B) and the trajectory followed will be I', as shown on FIG. **10.** The demand control system described hereabove, is capable of determining at which time t_b the projected line representing the load which could not be switched will intersect the last ordinate at T, the desired demand limit. To do this it is sufficient for instance, that the computer system at **76** (FIG. **13**B) identifies the target (T' first, then T) and determine an error on selection (**82**) which is zero.

A last remark can be made regarding the overall operations of the control system according to the invention. Since loads in a non-controllable status spontaneously are switched ON when their OFF time has been exceeded, when a flag **100** has appeared to indicate that no load is available to be shed, the system will by itself become effective for control, since more loads will become available at the next iterations.

Associated with the main control program just described, is a simulation program which can also be used separately as a source of information to study the condition of control according to the invention for a given set of loads and constraints in the particular plant. The simulation program runs on a P - 2000 computer. The simulation program is based upon equal time intervals. It simulates for instance the behavior of air compressors and similar controlled devices, and the instantaneous power consumption as a function not only of the switchable loads, but also with a base load having noise superimposed.

The following notations are used by the program:

RAND - random no. generator for base load noise
CONTROL - the principal demand control algorithm
ROTATE - designed to rotate group priorities every time any one unit in a multiple-unit group is started
PRINT - prints a message every time CONTROL switches a unit on or off in its effort to maintain the demand limit
SCALE - sets up Y-scale values when plotting is requested (KW)
LINYY - sets up Y-scale marks
PLOTT - plots up to nine selected loads (KW)
INDX - alpha form of time index (secs) to be printed on every tenth plotted line.

The main data base used with the control algorithm CONTROL is an integer matrix called DAT(N,**11**) where N is the total number of controlled loads in the system.

Loads are classified as inhibited. The number of inhibited loads being INHL; others are sheddable, the number of which is SHLD. Compressors and similar critical loads are a subset of SHLD, arranged as a continuous group starting from the first sheddable load. The number of critical loads is CRLD. The group of DAT (N,**11**) are therefore assigned as follows:

TABLE I

(limited to seven of the 11 columns provided on the card because several of the data are computed by/the program).

Title	1	2	3	4	5	6	7	8
110	20	50	4700					
120	1	3	0					
130(Base Load)	2000	2	17	2				
140	3	1	2	19				
150	0	1	0					
160	6	2	2	2	8	1	2	
Load Ref.								
170	932	149	450					Inhibited Loads
180	2238	0	450					
190	112	100	160	3	1			Critical Loads
200	112	100	160	3	2			
210	410	200	80	6	1			Sheddable Loads
220	410	200	80	6	2			
230	186	180	80	5	0			
240	75	180	100	4	1			
250	75	180	100	4	2			
260	75	180	100	4	3			
270	75	180	100	4	4			
280	75	180	1000	4	5			
290	75	180	100	4	6			
300	75	180	100	4	7			
310	75	180	100	4	8			
320	37	300	100	1	1			
330	37	300	100	1	2			
340	336	300	160	2	1			
350	105	300	160	2	2			

Inhibited Loads

An inhibited load is defined as one which will be permitted to be switched on during the first minutes of any demand period but will be switched off after the duration DURN has elapsed and will be inhibited from being switched on again until the next demand period has begun. With inhibited loads the columns are in principle assigned as follows:

1. LDON - power drawn when load is on (KW)
2. LDOFF - power drawn when load is off (KW)
3. DURN - Duration of on-time for this load from beginning of period (secs.)

4–5. Not used

6. PERM - Permissive flag indicating whether this load is available for use or not (1 or 0). (see steps **203** and **204** on FIG. **14**). Therefore this column is in the present case not used in Table I.

7–8. Not Used

9. Cϕ — Status of contact output (1 or 0)
10. MOSTAT - The logical AND of CO and PERM (1 or 0)
11. CWRD - Reserved for the future CO control word assigned to this unit (Hexadecimal notation).

However, the program here also computes the data of column 9, 10 and 11, therefore these columns are not used in Table 1.

There must be at least one inhibited load in the system even if this is a dummy with zero power on and off.

Sheddable Loads

Sheddable loads are defined as loads which will be switched "on" if they have been off longer than an assigned off time (OFFTIM); but having been switched on, will remain on until a given ON/OFF ratio (ONRATO) has been exceeded. If the off time is critical, off time will be computed, not inferentially from cϕ status, but from the actual motor or equipment status (MOSTAT) as scanned directly by the computer.

With sheddable loads of both types the columns are unprinciple assigned as follows:

6. PERM - permissive indicating whether this load is available or not (0 or 1)
7. OFFTIM - Computed off time for this unit, updated at each iteration if the unit is off (secs)
8. ONTIM - computed on time to this unit, updated at each iteration if the unit is on (secs)
9. Cϕ - status of control algorithm output (1 or 0)
10. MOSTAT - status of equipment (if a critical load) or logical .AND. of Cϕ and PERM (1 or 0)
11. CWRD - reserved for the future control word for the Cϕ assigned to this unit.

Here too certain clauses of Table I are not used in the card because the program makes the computation. A typical set of input data is shown on Table I the data being read-in in **1016** format. The description of the card reference numbers on the attached coding sheet is as follows:

110 — ITIME — estimated between KWH meter pulses (secs)

BIAS — initial low bias to be applied to the desired limit (KW)

DEMLIN — demand limit desired at end of period (KW)

120 — LOG — type of output where:

0 = appropriate demand period summary only is desired

1 = print out of equipment status, power consumption and predicted target at such iteration in addition to summary

3 = plot of selected loads as well as summary

NPERD — no. of consecutive demand periods to be studied

LOGI = 0 = exercise demand control

1 = establish minimum demand which would be obtained if all constraints are rigidly exercised

2 = establish maximum demand if no constraints or controls are exercised.

The program is written so that if LOG = 3, the LOGI is forced to be zero regardless of what is on its data input card.

130	BASE -	base load (KW)	
	INHL -	number of inhibited loads	
	SHLD -	number of critical loads	
	CRLD	number of critical loads	
140	NN -	number of loads for which PERM(I) is to be controlled by data on card immediately following (otherwise PERM(I) = 1)	
	IND(I) -	index of loads from 1 to NN	
150	TEMP(I) -	status of PERM(I) for loads with index IND(I) (1 or 0)	
160	MGRP -	number of priority groups in the total system	
	MAX(I) -	maximum number of units in each group 1 through MGRP	
170	LDON(I) -	Power drawn when Cϕ closed (KW) and	These two cards are for the two inhibited loads
180	LDOFF(I) -	power drawn when Cϕ opened (KW)	
	DRUN(I) -	duration of on time in any period	(secs.)
190	LDINC(I) through OFFMAX (I)	data for each of the 17 sheddable loads	
350	ONRATO(I)		
	PRIOR(I)		
	SUBPRI(I)		

1. LDINC - increase in power drawn when Cϕ is closed (KW).
2. OFFMAX - maximum off time (secs.)
3. ONRATO - minimum on/off ratio expressed as a percentage (e.g., 100 = 100%, 20 = 20%, etc.)
4. PRIOR - main group priority assigned to this unit 1 = most sheddable — 99 = least sheddable
5. SUBPRI - subgroup priority

The simulation starts at step **200** by reading data from the data file. The data have been hereabove listed (see Table I). A logic table will be used hereinafter with the flow chart of FIG. **13** reading as follows:

TABLE II

Simulation Interval - ITIME secs.

Demand Period = Demper mins.

No. of Periods = NPERD
Log = 0 = Summary of Period Only
Log = 1 = Print out of each iteration plus summary
Log = 3 = Plot of each iteration plus summary
Log = 0 = On control
Log = 1 = Compute demand limit with all constraints operating
Log = 1 = 2 = Not Under Control (NOC)

If, at step **201**, Log. Eq. **3**, (see Table II) the decision is to print the y-scale of a graph to be plot (step **202**). The reset step, at **203** is to check PERM(I) = 1. Then at **204** PERM(I) is modified according to data on the cards for the inhibited loads PERM(IND(I)). At step **205** the ON Time and OFF Time are stored and finally at **206** the contact outputs for all sheddable loads are set with the permissive flag for all permissive loads (CO(I) = PERM(I)). The preceding steps are necessary in order to prepare for actual simulation. After this, for critical loads the conditions of operation are initialized. In the instant case, the load is a compressor and the pressure and pressure switches are initialized. For instance the margin of pressure for ON and OFF may be 90 psi to 100 psi. This step is seen at **207.** The next step (**208**) is the calculation of the constants to be used in the simulation.

At step **209,** the program determines the index after which Demand control should begin to be exercised. This is the end of the first field for which no control is effected (NOC) and the beginning of the second field. At step **209,** the program also determines the index after which the third field of control should begin (NFIN). At step **210** is initialized the energy consumed during demand period converted to equivalent power at the end of the period. (TOTKWH), with the iteration index (NI) equal to one and the index of the present demand period (NPR) equal to one. Thereafter iteration for simulation begins (step **211**).

At step **212** pressure from the status of Compressors are updated and at step **213** the same is done for the pressure switches. At step **214,** a check is made whether the inhibited loads have exceeded the allowable ON Time in which case they are switched off. At step **215** the status of all the motors is updated, while for inhibited loads the motor status is modified (step **216**).

On the preceding basis, the energy consumed during the present demand period up until the iteration, converted to equivalent power at the end of the period, (TOTKWH) is calculated (step **217**) and the total energy consumed into the period is thereafter calculated at step **218.**

If Log 1. GT1, (step **219**) is a NO, then the system calls for control (**220**) which step appears on FIG. **13** between steps **168** and **169.** If Log 1 equals 0 (step **221**) which means that the system is on control, it is a YES, and the flow chart goes to the printing line marked D, but after step **224,** without plotting.

If the system is on control the flow chart goes to D which provides over steps **222** and **229** for a print out of the status, the power and the target for each iteration plus summary. At step **225** a determination is made whether the iteration index (NI) is equal to the total number of iterations at I Time (seconds) intervals for a demand period which is "DEMPER" minutes long. As a result, over steps **226, 230,** or **227, 231, 232** either an order is given to print the end of period demand log under control (**230**), or to print the minimum demand at the end of the period (**231**), or to print the maximum demand at the end of the period (**232**). If we are during the demand period, the decision at step **225** is to print in accordance with step **229** already considered.

From the lines of steps **226** to **228,** in the alternative, the flow chart goes to **233** to prepare for a new demand period (TOTKWH=0, NI=0 and NPR=NPR+1). Therefore, if the index of the present demand period (NPR) reaches the number of consecutive demand periods to be studied (NPERD) then the simulation goes to a stop (step **250**). Otherwise there is another iteration (N1=NI+1) at step **235,** which is also the step taken from the YES decision at **225.**

GENERAL DESCRIPTION OF INSTRUCTION PROGRAM LISTING

In the Appendix there is included an instruction program listing that has been prepared to control the operation of an industrial load system in accordance with the here-disclosed control system and method. The instruction program listing is written in the machine language of the PRODAC P2000 digital computer system, which is sold by Westinghouse Electric Corporation for real time process control computer applications. Many of these digital computer systems have already been supplied to customers, including customer instruction books and descriptive documentation to explain to persons skilled in this art the operation of the hardware logic and the executive software of this digital computer system. This instruction program listing is included to provide an illustration of one suitable embodiment of the present control system and method that has actually been prepared. This instruction program listing at the present time has not been extensively debugged through the course of practical operation for the real time control of an industrial load system. It is well known by persons skilled in this art that most real time process control application programs contain some bugs or minor errors, and it is within the skill of such persons and takes varying periods of actual operation time to identify and correct the more critical of these bugs.

This instruction program listing included in the Appendix was prepared in relation to the flow-charts shown in FIGS. **12, 13**A, **13**B, **13**C, **14**A and **14**B.

```
X E BINARY
U E
X D TEMP
U D
X D TEMP
U 4 D
• FTN4
LIST,S,B
C       INTEGER SIMULATION PROGRAM FOR DEMAND CONTROL
        INTEGER DAT(30,11),BASE,INHL,SHLD,CRLD,IND(20),PS(20)
```

```
      INTEGER LDØN(10),LDØFF(10),DURN(10),TEMP(10)
      INTEGER LDINC(30),ØFFMAX(30),ØNRATØ(30),PRIØR(30),SUBPRI(30)
      INTEGER PERM(30),ØFFTIM(30),ØNTIM(30),CØ(30),MØSTAT(30),CWRD(30)
      INTEGER BIAS,DEMLIM,KW(30),MAX(22)
      INTEGER CR,LP
      INTEGER LINB(71)
      REAL PR(20)
      CØMMØN /CØMDAT/LDINC,ØFFMAX,ØNRATØ,PRIØR,SUBPRI,PERM,ØFFTIM,ØNTIM,
     1CØ,MØSTAT,CWRD
      CØMMØN /CØNINP/INHL,SHLD,CRLD,TIMEIT,BIAS,DEMLIM,LØG,NPERD,
     1CØNST,ICØN,NITR,ITIME,NØC,NFIN,NI,KWTØT,ITKWH,INDDN,INDUP,ITGT,
     2LINE,LØG1
      CØMMØN /DATBL/NN,IND,TEMP,BASE
      CØMMØN /EQUIP/LP,CR
      CØMMØN /RØTDAT/IMIN,IMAX,MGRP,MAX
      CØMMØN /PLØT/KW,KMIN,KMAX,IBASE,IDUFF,LINB
      EQUIVALENCE (DAT(1,1),LDINC(1)),(DAT(1,1),LDØN(1))
      EQUIVALENCE (DAT(1,2),LDØFF(1)),(DAT(1,3),DURN(1))
      LP=6
      CR=1
      LØG=1
      YFL=0.
      DEMPER=15.
      IMIN=INHL+1
      IMAX=INHL+SHLD
      DØ 3 I=IMIN,IMAX
    3 PERM(I)=1
C     PREPARE SIMULATIØN
C   FIRST SET UP ØVER-RIDE PERMISSIVES FØR 'NN' LØADS WITH INDEXES IND(I)
      DØ 4 I=1,NN
      J=IND(I)
    4 PERM(J)=TEMP(I)
C  NØW MAKE CØ'S FØR INHIBITED LØADS EQUAL TØ PERMISSIVES
      DØ 6 I=1,INHL
    6 CØ(I)=PERM(I)
C  INITIALIZE ØN- AND ØFF-TIMES AND CØ'S FØR ALL SHEDDABLE LØADS
      DØ 5 I=IMIN,IMAX
      ØFFTIM(I)=80
      ØNTIM(I)=100
    5 CØ(I)=PERM(I)
C  INITIALIZE AIR CØMPRESSØR PRESSURES PR(I) AND STATUS ØF
C       PRESSURE SWITCHES PS(I)
      PR(IMIN)=90.
      I1=IMIN+1
      PR(I1)=95.
      PS(IMIN)=1
      PS(I1)=1
      TIMEIT=FLØAT(ITIME)
      CØNST=(60./DEMPER)*(TIMEIT/3600.)
      ICØN=IFIX(1./CØNST+.1)
      NITR=IFIX(DEMPER*60./TIMEIT+.1)
C     NØC AND NITR ARE CØNSTANTS USED IN CØNTRØL ALGØRITHM
C     FØR SUSPENSIØN ØF CØNTRØL AT BEGINNING AND CHANGE ØF PØLICY AT END
      NØC=0
      NFIN=NITR-(NITR*20)/90
      TØTKWH=0.
      NI=1
      NPR=1
      CALL DATIN
      IF(LØG.GT.2) GØ TØ 41
      GØ TØ 42
   41 LØG1=C
      CALL SCALE
      CALL LINYY
      WRITE(LP,300)LINB
  300 FØRMAT(1H ,71A1)
   42 CØNTINUE
C     BEGINNING ØF SIMULATIØN LØØP
 1000 CØNTINUE
```

–Continued

```
C     CALCULATE PLANT CONDITIONS - PRESSURE
      DO 7 I=IMIN,I1
      IF(CO(I).EQ.0) GO TO 7
C   CALCULATE PRESSURES
      IF(MOSTAT(I).EQ.1) PR(I)=PR(I)+2.*TIMEIT/10.
      IF(MOSTAT(I).EQ.0) PR(I)=PR(I)-3.*TIMEIT/10.
C   CALCULATE STATUS OF PRESSURE SWITCHES
      IF(PR(I).LE.90.) PS(I)=1
      IF(PR(I).GE.100.) PS(I)=0
    7 CONTINUE
C     INHIBITING CONTROL
      DO 13 I=1,INHL
      IF(PERM(I).EQ.0) GO TO 13
      ITD=DURN(I)/ITIME
C   CHECK WHETHER THIS ITERATION WILL CAUSE MAXIMUM ON TIME RATIO
C    OF INHIBITED LOADS TO BE EXCEDED
      IF(NI-ITD) 61,61,62
   61 CO(I)=1
      GO TO 13
   62 CO(I)=0
   13 CONTINUE
C     CALCULATE CONTACTOR STATUS
      DO 8 I=1,IMAX
    8 MOSTAT(I)=PERM(I)*CO(I)
      DO 9 I=IMIN,I1
    9 MOSTAT(I)=MOSTAT(I)*PS(I)
C     CALCULATE PLANT CONDITIONS - POWER
      CALL RAND(YFL)
C   'IBASE' REPRESENTS BASE LOAD PLUS NOISE
      IBASE=BASE+IFIX(600.*YFL)
      KWTOT=IBASE
C   COMPUTE POWER DRAWN BY INHIBITED LOADS
      DO 10 I=1,INHL
      IF(MOSTAT(I).EQ.1) KW(I)=LDON(I)
      IF(MOSTAT(I).EQ.0) KW(I)=LDOFF(I)
      IF(PERM(I).EQ.0) KW(I)=0
   10 CONTINUE
C   COMPUTE POWER DRAWN BY SHEDDABLE LOADS
      DO 11 I=IMIN,IMAX
      KW(I)=0
      IF(MOSTAT(I).EQ.1) KW(I)=LDINC(I)
   11 CONTINUE
C   SUM TOTAL POWER CONSUMPTION OF THE PLANT
      DO 12 I=1,IMAX
   12 KWTOT=KWTOT+KW(I)
C   CALCULATE PRESENT ENERGY CONSUMED, CONVERTED TO EQUIVALENT
C     DEMAND AT END OF THE PERIOD
      TOTKWH=TOTKWH+CONST*FLOAT(KWTOT)
      ITKWH=IFIX(TOTKWH)
      IF(LOG1.GT.1) GO TO 22
C   JUMP AROUND THE NEXT STATEMENT ONLY IF THE DEMAND LIMIT IS TO
C     BE ESTABLISHED ASSUMING NO CONTROL BEING EXERCISED
      CALL CONTROL
   22 IF(LOG.EQ.0) GO TO 14
      IF(LOG.EQ.1) GO TO 18
      IF(LOG.EQ.3) GO TO 19
      GO TO 21
C    PLOTTING INSTRUCTIONS
   19 CALL PLOTT
      WRITE(LP,300)LINB
      GO TO 14
C   PRINT OUT OF EQUIPMENT STATUS, POWER AND PREDICTED DEMAND LIMIT
   18 WRITE(LP,15)NI,(MOSTAT(J),J=1,IMAX),INDDN,INDUP,KWTOT,ITGT
   15 FORMAT(1H0,I4,1X,19I2,I5,I4,2I6)
   14 IF(NI.LT.NITR) GO TO 1010
      IF(LOG1.EQ.0) GO TO 31
C   SUMMARY PRINT OUTS FOR MINIMUM AND MAXIMUM DEMAND LEVELS
      IF(LOG1.EQ.1) WRITE(LP,32) ITKWH
      IF(LOG1.GT.1) WRITE(LP,33) ITKWH
   32 FORMAT(1H0,26HMINM DEMAND PERIOD POWER =,I6,3H KW)
```

```
   33 FØRMAT(1H0,26HMAXM DEMAND PERIØD PØWER =,I6,3H KW)
      GØ TØ 34
   31 II=ITKWH/4
C  DEMAND PERIØD LØG AFTER BEING UNDER DEMAND CØNTRØL FØR THE PERIØD
      WRITE(LP,16)DEMLIM,ITGT,II
   16 FØRMAT(1H0,34HEND ØF DEMAND PERIØD LØG: TARGET  ,I6,2HKW,3X,
     18HACTUAL  ,I6,2HKW,3X,7HENERGY ,I6,3HKWH//)
   34 CØNTINUE
C  PREPARE FØR A NEW DEMAND PERIØD
      TØTKWH=0.
      NI=0
      NPR=NPR+1
      CALL DATIN
      IF(LØG.GT.2) GØ TØ 411
      GØ TØ 421
  411 LØG1=0
      CALL SCALE
      CALL LINYY
      WRITE(LP,300)LINB
  421 CØNTINUE
      IF(NPR.GT.NPERD) GØ TØ 21
 1010 NI=NI+1
C  RETURN TØ THE BEGINNING ØF THE ITERATIØN
      GØ TØ 1000
C  STØP WHEN 'NPERD' PERIØDS HAVE BEEN RUN
   21 CØNTINUE
      WRITE(LP,553)
  553 FØRMAT(1H ,18HTYPE IN LETTER 'S'//)
      END
S
LIST,S,Ø
C  RANDØM NUMBER GENERATØR SUBRØUTINE
C
      SUBRØUTINE RAND(A)
      DATA MP,MSK,M/3,$7FFF,4579/
      DATA ACØN,BCØN/65536.,2147483647./
      IF(A.NE.0.) GØ TØ 1
S     LDA   M
S     STA   IA
S1    LDA   IA
S     STZ   4
S     MPY   MP
S     STA   IB
S     LDA   IA
S     ADD   4
S     NJP   )2
S     JMP   )3
S2    INC   IB
S     AND   MSK
S3    STA   IE
S     LDA   IB
S     STA   IA
      YF1=FLØAT(IA)
      IF(YF1.LT.0.) YF1=ACØN+YF1
      YF2=FLØAT(IE)*ACØN
      A=(YF1+YF2)/BCØN
      RETURN
      END
S
LIST,S,Ø
      BLØCK DATA
      INTEGER IND(20),TEMP(10),MAX(22)
      INTEGER LDINC(30),ØFFMAX(30),ØNRATØ(30),PRIØR(30),SUBPRI(30)
      INTEGER PERM(30),ØFFTIM(30),ØNTIM(30),CØ(30),MØSTAT(30),CWRD(30)
      INTEGER SHLD,CRLD,BIAS,DEMLIM,BASE
      CØMMØN /CØNINP/INHL,SHLD,CRLD,TIMEIT,BIAS,DEMLIM,LØG,NPERD,
     1CØNST,ICØN,NITR,ITIME,NØC,NFIN,NI,KWTØT,ITKWH,INDDN,INDUP,ITGT,
     2LINE,LØG1
      CØMMØN /CØMDAT/LDINC,ØFFMAX,ØNRATØ,PRIØR,SUBPRI,PERM,ØFFTIM,ØNTIM,
     1CØ,MØSTAT,CWRD
      CØMMØN /DATBL/NN,IND,TEMP,BASE
      CØMMØN /RØTDAT/IMIN,IMAX,MGRP,MAX
```

–Continued

```
      DATA BASE/2000/
      DATA ITIME,BIAS,DEMLIM/20,50,4700/
      DATA LOG,NPERD,LOG1/1,10000,0/
      DATA INHL,SHLD,CRLD/2,17,2/
      DATA NN,IND/3,1,2,19,17*0/
      DATA TEMP/0,1,0,7*0/
      DATA MGRP,MAX/6,2,2,2,8,1,2,16*0/
      DATA LDINC/932,2238,112,112,410,410,186,75,75,75,75,75,75,
     175,75,37,37,336,105,11*0/
      DATA OFFMAX/149,0,100,100,200,200,180,180,180,180,180,180,
     1180,180,180,300,300,300,300,11*0/
      DATA ONRATO/450,450,160,160,80,80,80,100,100,100,100,100,100,
     1100,100,100,100,160,160,11*0/
      DATA PRIOR/0,0,3,3,6,6,5,4,4,4,4,4,4,4,4,1,1,2,2,11*0/
      DATA SUBPRI/0,0,1,2,1,2,0,1,2,3,4,5,6,7,8,1,2,1,2,11*0/
      END
S
LIST,S,O
C
C  MAIN DEMAND CONTROL ALGORITHM
C
      SUBROUTINE CONTROL
      INTEGER INHL,SHLD,CRLD
      INTEGER LDINC(30),OFFMAX(30),ONRATO(30),PRIOR(30),SUBPRI(30)
      INTEGER PERM(30),OFFTIM(30),ONTIM(30),CO(30),MOSTAT(30),CWRD(30)
      INTEGER BIAS,DEMLIM,SLOPE,MAX(22)
      INTEGER CR,LP
      LOGICAL IFL
      COMMON /COMDAT/LDINC,OFFMAX,ONRATO,PRIOR,SUBPRI,PERM,OFFTIM,ONTIM,
     1CO,MOSTAT,CWRD
      COMMON /CONINP/INHL,SHLD,CRLD,TIMEIT,BIAS,DEMLIM,LOG,NPERD,
     1CONST,ICON,NITR,ITIME,NOC,NFIN,NI,KWTOT,ITKWH,INDDN,INDUP,ITGT,
     2LINE,LOG1
      COMMON /ROTDAT/IMIN,IMAX,MGRP,MAX
      COMMON /EQUIP/LP,CR
      DATA I100,I32TH/100,32000/
      IPWR=KWTOT
C     FORCE LOAD ON IF OFF EXCESSIVELY AND RESET TIME COUNTERS
      DO 1 I=IMIN,IMAX
      IF(PERM(I).EQ.0) OFFTIM(I)=0
      IF(MOSTAT(I).EQ.0) GO TO 3
      ONTIM(I)=ONTIM(I)+ITIME
      GO TO 1
    3 OFFTIM(I)=OFFTIM(I)+ITIME
      IF(OFFTIM(I).LE.OFFMAX(I)) GO TO 1
      CO(I)=1
      IPWR=IPWR+LDINC(I)
      IF(SUBPRI(I).EQ.0) GO TO 6
      CALL ROTATE(PRIOR,SUBPRI,I)
    6 ONTIM(I)=0
    1 CONTINUE
      IF(LOG1.EQ.0) GO TO 91
C    DO LOOP NO. 92 CAUSES UNITS TO BE SWITCHED ON IF THE 'ONRATO' HAS
C      BEEN EXCEDED AND THE ASSOCIATED CONSTRAINT IS TO BE EXERCISED
C     RIGIDLY (I.E. LOG1=1)
      DO 92 J=IMIN,IMAX
      ITEM=OFFTIM(J)
      ITT=ONTIM(J)
S     STZ   4
S     MPY   I100
S     OJP   )61
S     JMP   )62
S61   LDA   I32TH
S62   DIV   ITEM
S     STA   ITEM
      IF(ITEM.LT.ONRATO(J)) GO TO 92
      CO(J)=0
      OFFTIM(J)=0
      ONTIM(J)=0
   92 CONTINUE
      RETURN
```

–Continued

```
   91 CONTINUE
C     CALCULATE TARGET AND EXERCISE CONTROL
      IF(NI.LE.NOC) GO TO 1000
      ITGT1=DEMLIM-BIAS
      IF(NI.LE.NFIN) GO TO 13
      ITGT1=DEMLIM-(BIAS*(NITR-NI))/(NITR-NFIN)
   13 CONTINUE
  200 IFL=.FALSE.
S     STZ   4
S     LDA   NITR
S     SUB   NI
S     MPY   IPWR
S     DIV   ICON
S     STA   ITEM
      SLOPE=ITGT1-(ITKWH+ITEM)
      IF(SLOPE.LE.0) GO TO 219
C     SEARCH FOR LEAST SHEDDABLE LOAD
      N1=0
      N2=0
      INDUP=0
      DO 11 I=IMIN,IMAX
      IF(PERM(I).EQ.0) GO TO 11
      IF(I.EQ.INDDN) GO TO 11
      IF(PRIOR(I).LT.N1) GO TO 11
      IF(CO(I).EQ.1) GO TO 11
      IF(PRIOR(I).NE.N1) GO TO 12
      IF(SUBPRI(I).LE.N2) GO TO 11
   12 INDUP=I
      N1=PRIOR(I)
      N2=SUBPRI(I)
   11 CONTINUE
      IF(INDUP.EQ.0) GO TO 1000
      IF(SLOPE.LT.LDINC(INDUP)) GO TO 1000
      CO(INDUP)=1
      IPWR=IPWR+LDINC(INDUP)
      IF(SUBPRI(INDUP).EQ.0) GO TO 14
      CALL ROTATE(PRIOR,SUBPRI,INDUP)
   14 ONTIM(INDUP)=0
      IF(LOG.NE.1) GO TO 200
      INDPR=0
      CALL PRINT(INDPR,INDUP,IPWR)
      GO TO 200
  219 CONTINUE
C     SEARCH FOR MOST SHEDDABLE LOAD
      N4=100
      N5=100
      INDDN=100
      DO 7 I=IMIN,IMAX
      IF(PRIOR(I).GT.N4) GO TO 8
      IF(CO(I).EQ.0) GO TO 8
      IF(PRIOR(I).NE.N4) GO TO 9
      IF(SUBPRI(I).GE.N5) GO TO 8
    9 IF(IFL) GO TO 10
      IF(OFFTIM(I).LT.1) GO TO 10
      ITEM=OFFTIM(I)
      ITT=ONTIM(I)
S     STZ   4
S     MPY   I100
S     OJP   )65
S     JMP   )66
S65   LDA   I32TH
S66   DIV   ITEM
S     STA   ITEM
      IF(ITEM.LT.ONRATO(I))GO TO 8
   10 INDDN=I
      N4=PRIOR(I)
      N5=SUBPRI(I)
    8 CONTINUE
    7 CONTINUE
  900 IF(INDDN.EQ.100) GO TO 120
      ITEMP=LDINC(INDDN)
      IF(ITEMP.GT.180) ITEMP=ITEMP/2
      ITEMP=SLOPE+ITEMP
      IF(NI.LT.NFIN) GO TO 121
```

–Continued

```
      IF(SLOPE.LT.0) GO TO 130
  121 IF(ITEMP.GT.0) GO TO 1000
  130 CO(INDDN)=0
      IPWR=IPWR-LDINC(INDDN)
      OFFTIM(INDDN)=0
      IF(LOG.NE.1) GO TO 200
      INDPR=1
      CALL PRINT(INDPR,INDDN,IPWR)
      GO TO 200
  120 IF(NI.EQ.NFIN) WRITE(LP,111)
  111 FORMAT(1H ,30HCONSTRAINTS MAY BE OVER-RIDDEN//)
      IF(IFL) GO TO 1000
 1000 CONTINUE
      ITGT=ITGT1-SLOPE
      RETURN
      END
S
LIST,S,O
C
C  SUBROUTINE TO ROTATE PRIORITIES
C
      SUBROUTINE ROTATE(PRIOR,SUBPRI,IND)
      INTEGER PRIOR(30),SUBPRI(30),MAX(22)
      COMMON /ROTDAT/IMIN,IMAX,MGRP,MAX
      N1=PRIOR(IND)
      DO 1 I=1,IMAX
      IF(PRIOR(I).NE.N1) GO TO 1
      SUBPRI(I)=SUBPRI(I)-1
      IF(SUBPRI(I).EQ.0) SUBPRI(I)=MAX(N1)
    1 CONTINUE
      RETURN
      END
S
LIST,S,O
C
C  PRINT OUT OF MESSAGE AS CONTROLLER SWITCHES LOADS
C
      SUBROUTINE PRINT(IND,LD,IPWR)
      INTEGER LP,CR
      INTEGER A(4),B(4)
      COMMON /EQUIP/LP,CR
      DATA A/1HU,1HP,1H ,1H /,B/1HD,1HO,1HW,1HN/
      IF(IND.EQ.0) WRITE(LP,1) A,LD,IPWR
      IF(IND.EQ.1) WRITE(LP,1) B,LD,IPWR
    1 FORMAT(1H ,4A1,2X,6HUNIT# ,I3,2X,6HPOWER ,I5,3H KW)
      RETURN
      END
S
LIST,S,O
C
C  SET UP OF SCALE VALUES FOR PLOT OF LOADS
C
      SUBROUTINE SCALE
      INTEGER KW(30),IBASE
      INTEGER CR,LP
      INTEGER LINB(71)
      REAL A(5)
      COMMON /PLOT/KW,KMIN,KMAX,IBASE,IDUFF,LINB
      COMMON /EQUIP/LP,CR
      A(5)=6500.
      A(1)=0.
      DIFF=(A(5)-A(1))/4.
      DO 1 I=2,4
    1 A(I)=A(1)+DIFF*FLOAT(I-1)
      KMIN=IFIX(A(1))
      KMAX=IFIX(A(5))
      IDUFF=KMAX-KMIN
      WRITE(LP,2)A
    2 FORMAT(1H0,G9.3,6X,G9.3,7X,G9.3,8X,G9.3,5X,G9.3)
      RETURN
      END
S
LIST,S,O
C
```

–Continued

```
C  SET UP ØF Y ØRDINATE SCALE MARKS
C
      SUBRØUTINE LINYY
      INTEGER KW(30),IND(5),IBASE
      INTEGER LINB(71),Y,HØR
      DATA Y,HØR/1HY,1H-/,IND/1,18,36,54,71/
      DØ 1 I=1,71
    1 LINB(I)=HØR
      DØ 2 I=1,5
      J=IND(I)
    2 LINB(J)=Y
      RETURN
      END
S
LIST,S,Ø
C
C  CHARACTER SET UP IN LINE BUFFER AS FUNCTIØN ØF 9 INPUTS
C  AND PERFØRMS PLØTTING FUNCTIØN
C
      SUBRØUTINE PLØTT
      INTEGER SHLD,CRLD,BIAS,IBASE,DEMLIM,KW(30),IB(9),IND(9)
      INTEGER LINB(71),CHAR(9),BLANK,EYE
      CØMMØN /CØNINP/INHL,SHLD,CRLD,TIMEIT,BIAS,DEMLIM,LØG,NPERD,
     1CØNST,ICØN,NITR,ITIME,NØC,NFIN,NI,KWTØT,ITKWH,INDDN,INDUP,ITGT,
     2LINE
      CØMMØN /PLØT/KW,KMIN,KMAX,IBASE,IDUFF,LINB
      DATA BLANK,EYE/1H ,1HI/,IND/2,3,4,7,8,18,1,1,1/
      DATA CHAR/1H),1H(,1H*,1H+,1H@,1H#,1H%,1H&,1H$/
      DATA I72/72/
      ITEM=NI/50
      ITEM=ITEM*50
      IF(ITEM.EQ.NI) GØ TØ 1
      IF(NITR.EQ.NI) GØ TØ 1
      DØ 2 I=1,71
    2 LINB(I)=BLANK
      LINB(1)=EYE
      GØ TØ 3
    1 CALL LINYY
      MULT=ITIME*NI
      CALL INDX(MULT)
    3 DØ 44 J=1,6
      IND1=IND(J)
   44 IB(J)=KW(IND1)
      IB(3)=IB(3)*9+100
      IB(4)=IBASE
      IB(5)=IB(5)*10+100
      IB(6)=IB(6)*10+250
      IB(7)=KWTØT
      IB(8)=ITKWH
      IB(9)=DEMLIM
      DØ 4 I=1,9
      ITEM=IB(I)
S     STZ   4
S     SUB   KMIN
S     MPY   I72
S     DIV   IDUFF
S     STA   IN
      IF(IN.GT.71) IN=71
      IF(IN.LT.1) IN=1
    4 LINB(IN)=CHAR(I)
      ITEM=NI/10
      ITEM=ITEM*10
      IF(ITEM.NE.NI) GØ TØ 150
      MULT=ITIME*NI
      CALL INDX(MULT)
  150 CØNTINUE
      RETURN
      END
S
LIST,S,Ø
C
C   SET UP ØF NØ. ØF SECØNDS TØ THIS ITERATIØN
C
      SUBRØUTINE INDX(MULT)
```

–Continued

```
      INTEGER KW(30),IBASE
      INTEGER LINB(71),NUMB(10)
      COMMON /PLOT/KW,KMIN,KMAX,IBASE,IDUFF,LINB
      DATA NUMB/1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,1H0/
      ITEM=MULT
      K=1
      IF(ITEM.GE.10) K=2
      IF(ITEM.GE.100) K=3
      DO 2 J=1,K
      K1=10**(K-J)
      DO 1 I=1,10
      ITEM=ITEM-K1
      IF(ITEM.GE.0) GO TO 1
      ITEM=ITEM+K1
      I1=I-1
      IF(I1.EQ.0) I1=10
      LINB(J)=NUMB(I1)
      GO TO 2
    1 CONTINUE
      WRITE(LP,4) MULT
    4 FORMAT(1H ,12HFAULT: SECS=,I6)
      GO TO 20
    2 CONTINUE
      RETURN
   20 CONTINUE
      END
S
LIST,S,0
      SUBROUTINE DATIN
      INTEGER SHLD,CRLD
      INTEGER LP,CR
      INTEGER J1(3),PERM(30),BASE,BIAS,DEMLIM,D(30,11)
      INTEGER A(8),M(3,5)
      INTEGER BLANK,B(10)
      COMMON /EQUIP/LP,CR
      COMMON /COMDAT/D
      COMMON /CONINP/INHL,SHLD,CRLD,TIMEIT,BIAS,DEMLIM,LOG,NPERD,
     1CONST,ICON,NITR,ITIME,NOC,NFIN,NI,KWTOT,ITKWH,INDDN,INDUP,ITGT,
     2LINE,LOG1
      EQUIVALENCE (D(1,6),PERM(1))
      DATA A/1HB,1HU,1HT,1HD,1HA,1HP,1HL,1HE/
      DATA B/1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,1H0/
      DATA BLANK/1H /
  100 WRITE(LP,28)
      WRITE(LP,1)
      CALL ENPACK(M,N,A,B)
      IF(N.NE.1) GO TO 100
   28 FORMAT(1H )
    1 FORMAT(1H ,14HENTER MNEMONIC)
      J=0
      DO 2 I=1,8
      IF(M(1,5).NE.A(I)) GO TO 2
      J=I
    2 CONTINUE
      IF(J.EQ.0) GO TO 100
      IF(J.EQ.8) GO TO 1000
      GO TO(101,102,103,104,105,106,107),J
  101 WRITE(LP,201)
      GO TO 150
  102 WRITE(LP,202)
      GO TO 150
  103 WRITE(LP,203)
      GO TO 150
  104 WRITE(LP,204)
      GO TO 150
  105 WRITE(LP,205)
      GO TO 150
  106 WRITE(LP,206)
      GO TO 150
  107 WRITE(LP,207)
  150 CONTINUE
  201 FORMAT(1H ,18HENTER BASE LOAD KW)
  202 FORMAT(1H ,21HENTER UNDER-TARGET KW)
  203 FORMAT(1H ,39HENTER TIME INTERVAL BETWEEN PULSES SECS)
```

–Continued

```
204 FORMAT(1H ,21HENTER DEMAND LIMIT KW)
205 FORMAT(1H ,44HENTER UNIT# AND AVAILABILITY (STATUS 1 OR 0))
206 FORMAT(1H ,48HENTER UNIT CHARACTERISTICS, UNIT#, COLUMN#,VALUE)
207 FORMAT(1H ,34HENTER LOG TP.,# PERIODS, SUMM. TP.)
    IF(J.LE.4) K=1
    IF(J.EQ.5) K=2
    IF(J.GT.5) K=3
    WRITE(LP,5) K
  5 FORMAT(1H ,3X,6HENTER ,I1,22H INTEGER DATA ELEMENTS)
260 CALL ENPACK(M,N,A,B)
    IF(N.EQ.K) GO TO 230
200 WRITE(LP,28)
    WRITE(LP,60)K
    GO TO 260
 60 FORMAT(1HO,17HWRONG|  RE-ENTER ,I1,22H INTEGER DATA ELEMENTS)
230 DO 111 I=1,K
    I1=6
    ITOT=C
    DO 11 M1=1,5
    I2=I1-M1
    IF(M(I,I2).EQ.BLANK) GO TO 11
    DO 12 M2=1,10
    IF(B(M2).EQ.M(I,I2)) GO TO 13
 12 CONTINUE
    GO TO 200
 13 IF(M2.EQ.10) M2=0
    ITOT=ITOT+M2*(10**(M1-1))
 11 CONTINUE
    J1(I)=ITOT
111 CONTINUE
    GO TO(301,302,303,304,305,306,307),J
301 BASE=J1(1)
    WRITE(LP,401)BASE
    GO TO 100
302 BIAS=J1(1)
    WRITE(LP,402)BIAS
    GO TO 100
303 ITIME=J1(1)
    WRITE(LP,403)ITIME
    GO TO 100
304 DEMLIM=J1(1)
    WRITE(LP,404)DEMLIM
    GO TO 100
305 IF(J1(2).GT.30) GO TO 200
    IF(J1(1).GT.1) GO TO 200
    II=J1(2)
    PERM(II)=J1(1)
    WRITE(LP,405) J1(2),PERM(II)
    GO TO 100
306 IF(J1(1).GT.10000) GO TO 200
    IF(J1(2).GT.11) GO TO 200
    IF(J1(3).GT.30) GO TO 200
    II=J1(2)
    IJ=J1(3)
    D(IJ,II)=J1(1)
    WRITE(LP,406) J1(3),J1(2),D(IJ,II)
    GO TO 100
307 LOG=J1(3)
    NPERD=J1(2)
    LOG1=J1(1)
    WRITE(LP,407)LOG,NPERD,LOG1
    GO TO 100
401 FORMAT(1H ,13HBASE LOAD IS ,I6,3H KW)
402 FORMAT(1H ,8HBIAS IS ,I4,3H KW)
403 FORMAT(1H ,18HPULSE INTERUAL IS ,I4,5H SECS)
404 FORMAT(1H ,16HDEMAND LIMIT IS ,I6,3H KW)
405 FORMAT(1H ,7HUNIT # ,I2,9H  STATUS ,I1)
406 FORMAT(1H ,7HUNIT # ,I2,10H COLUMN # ,I2,8H  VALUE ,I6)
407 FORMAT(1H ,9HLOC TYPE ,I1,13H NO. PERIODS ,I3,10H  SUMMARY ,I1)
1000 CONTINUE
    RETURN
    END
```

–Continued

```
S
LIST,S,8
C
      SUBROUTINE ENPACK(M,M1,A,B)
      INTEGER LIN(50),M(3,5),BLANK,COMMA,A(8),B(10)
      INTEGER LP,CR
      DATA LP,CR/6,1/
      DATA BLANK,COMMA/1H ,1H,/
      DO 50 I=1,50
   50 LIN(I)=BLANK
      DO 51 I=1,3
      DO 51 J=1,5
   51 M(I,J)=BLANK
      READ(CR,1) LIN
    1 FORMAT(50A1)
      N1=51
      M1=0
      M3=0
      IFL=0
  100 N1=N1-1
      IF(N1.EQ.0) RETURN
      IF(LIN(N1).EQ.BLANK) GO TO 22
      IF(LIN(N1).EQ.COMMA) GO TO 22
      GO TO 2
   22 M3=M1+1
      IF(M3.GT.3) RETURN
      GO TO 100
    2 DO 10 J=1,8
      IF(LIN(N1).EQ.A(J)) GO TO 11
   10 CONTINUE
      GO TO 12
   11 IFL=1
      GO TO 4
   12 DO 3 J=1,10
      IF(LIN(N1).EQ.B(J)) GO TO 4
    3 CONTINUE
      M1=0
      RETURN
    4 IF(M3.EQ.M1) GO TO 5
      M1=M3
      M2=6
    5 M2=M2-1
      IF(M2.GT.0) GO TO 6
      M1=0
      RETURN
    6 M(M1,M2)=LIN(N1)
      IF(IFL.EQ.0) GO TO 100
      RETURN
      END
X A LIB5
U 8 A
X D TEMP
U 5 D
X E BINARY
U 4 E
. LDR5
 OG,1600,HD,,0,3,LD
 LD,LD,LD,LD,LD,LD,LD
 LD,LD,LD,LD
 LB,MP,UN,PP,XT
X E BINARY
U 5 E
N

L
U D
U 4
U 5
U 8
U 6 6
U 5 5
U 4 4
U 3 3
U 2 2
U 1 1
```

I claim:

1. In a control system for holding to a demand limit at the end of a billing period the power demand of an industrial plant having a plurality of interruptible loads, including means for providing an indication of power consumption of said loads during a billing period; means responsive to said means for providing an indication of power consumption for predicting a demand at the end of said billing period; means responsive to said demand predicting means for providing a demand error relative to said demand limit; means for selecting a suitable amount of power; comparator means responsive to said demand error providing means and to said power selecting means for establishing a residual error relative to said demand limit; and means responsive to the output of said comparator means for load control; the combination of:

means for setting switching constraints to at least part of said loads thereby to define among said interruptible loads and at times during said billing period, loads of controllable status and loads of non-controllable status;

said load control means including means for switching a load of a switchable amount of power in response to the sign of the output of said comparator means;

means for indicating the switching status of said loads at anytime during said billing period;

said power selecting means including priority means operative with a priority list of loads of controllable status and in accordance with the output of said switching status indicating means;

said power selecting means being operative in response to said residual error during successive decision periods within said billing period to provide a switchable amount of power from said priority list;

said switching means being operative in response to said power selecting means during such said decision period and operative in response to said constraint setting means before such said decision period; and,

wherein said demand predicting means is responsive to operation of said constraint setting means before any such said decision period.

2. The control system of claim 1 with means for establishing said residual error relative to a biased said demand limit,

said comparator means being selectively operable relative to said demand limit and to said biased demand limit;

wherein said comparator means and said switching means are operated relative to said biased demand limit during a first period within said billing period and wherein a predetermined priority load is selected by said priority means during a second period following said first period;

with said comparator means and said switching means being operated relative to the unbiased said demand limit during said second period.

3. The control system of claim 1 with means for preventing operation of said switching means during an initial period of said billing period;

with means for establishing a bias to said demand limit during an intermediary period following said initial period; and

with means for reducing said bias progressively to zero during a final period following said intermediary period and ending with said billing period.

* * * * *