Dec. 13, 1966 T. WILDI 3,291,998

PEAK LOAD STABILIZERS

Filed March 13, 1964 2 Sheets-Sheet 1

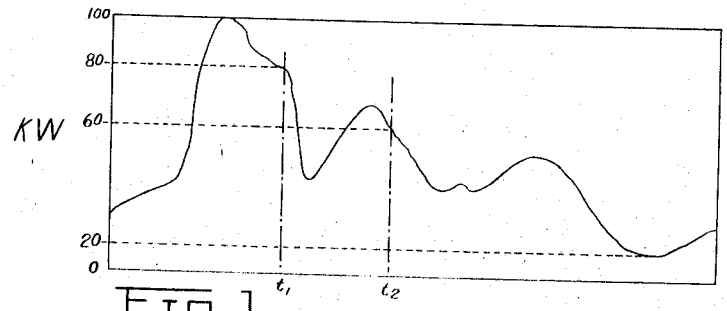


Fig. 1

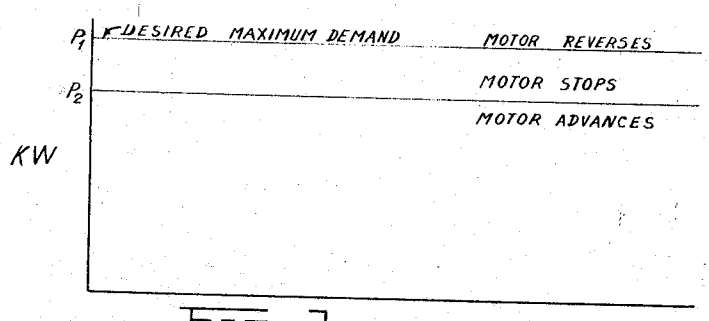


Fig. 2

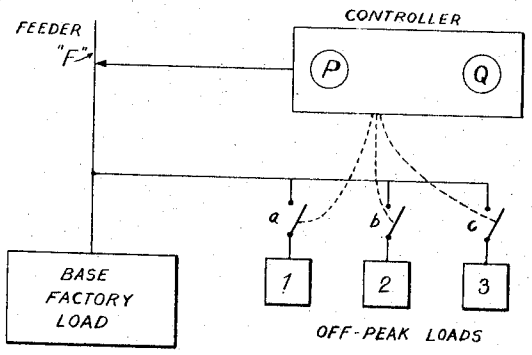


Fig. 3

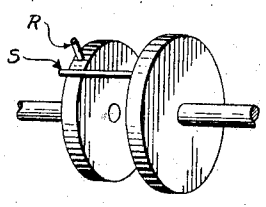


Fig. 5

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Filed March 13, 1964 2 Sheets-Sheet 2

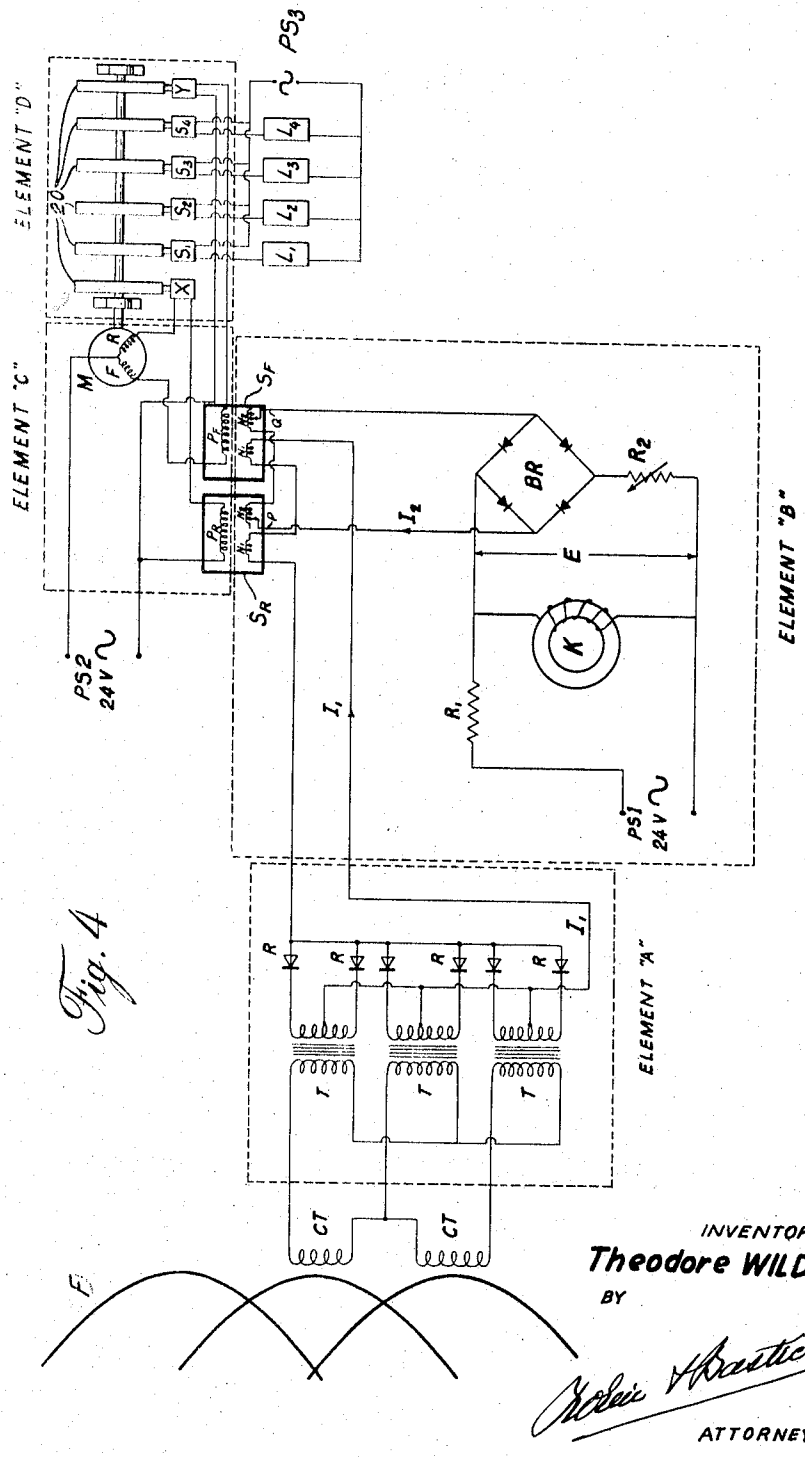


Fig. 4

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PEAK LOAD STABILIZERS

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Electrical loads in factories, institutions and private homes are subject to appreciable daily fluctuation and seasonal variations. Power consumption charges are usually computed on the basic of the maximum demand established by the consumer's basic requirements during the period under consideration. To lessen the effect of instantaneous loads of excessive magnitude, it is customary to use a maximum demand figure that has been "averaged" over periods varying from 15 minutes to perhaps 30 minutes by means of suitable demand meters.

More often than not, the financial charges to the power consumer are combined functions of both the "averaged" maximum demand and the total power consumption during the period for which these charges are computed. The rate systems employed in many instances are such that any energy in excess of the base factory requirement can be purchased at very low cost. Figures of the order of 0.5 cent per kwh. are typical, and these compare favourably with the price of other types of energy which are presently available.

Such rate systems make it advantageous for the consumer to utilize as much electrical power as possible (in lieu of other types of power) provided that the maximum demand is not exceeded at any time. In the ideal case, the electrical user would be inclined to consume energy at a constant rate, equal to the maximum demand. Clearly, such a state of affairs is desirable as it also tends to improve the utility company's load factor.

It is useful at this point to define the base factory load as being that load which is indispensable during periods of full productive operation and which therefore cannot as a whole or in part be switched off without ill effect on the good operation of the industry. An off-peak load is defined as that load which can be switched off temporarily at any time even during fully productive operation without any immediate ill effect on the efficiency or productivity of the said operation.

It is the object of the present invention to provide a control system whereby off-peak loads can be switched on or off automatically in order to keep the demand of electrical energy below or at a pre-set upper limit which is equivalent in most cases to the maximum base factory load defined herein before and not in excess of that upper limit for any significant periods of time, i.e., periods of time that are negligible with respect to the averaging period of a demand meter. The minimum requirements that must be met by such a system are as follows:

The control system must be automatic.

The control system must respond to the *total* electrical load, which includes both the base load and the off-peak load.

It should be able to switch off-peak loads in such a way that the maximum demand registered by a demand meter is approached as closely as possible but never exceeded.

The control system should be capable of giving preference to certain off-peak loads.

In addition, the following characteristics are desirable:

The control system should be able to accommodate off-peak loads of equal or of different ratings up to a power ratio of 2 to 1.

It should be able to operate equally well for three-phase balanced or unbalanced power lines.

The load controller should have a calibrated dial, so as to enable the power user to set the desired maximum demand according to his own requirements.

The control system should be relatively inexpensive.

All these requirements were met by the motor controlled peak load stabilizer disclosed in Canadian Patent 664,169, which issued June 4, 1963, to the present inventor. Accordingly the object of the present invention is to provide an improved peak load stabilizer of even greater simplicity, economy and reliability.

The improvements of the present invention over the peak load stabilizer described and claimed in the present inventor's Canadian Patent 664,169, are at least two-fold:

The first advantage results from the fact that the actual setting of a new desired maximum demand does not necessitate the simultaneous setting of a new low demand, at least not as long as the largest off-peak load remains unchanged.

The second advantage results from the fact that the construction of the improved peak load stabilizer avoids the use of all electro mechanical relays and Zener diodes. The improved peak load stabilizer therefor avoids the use of a number of moving components and reference diodes which, as is generally accepted, are the most likely to occasionally fail mechanically or otherwise. The reliability of the peak load stabilizer is therefor increased by the present invention.

In the accompanying drawings:

FIG. 1 shows the typical load curve of a small factory for one day.

FIG. 2 is a graph showing the principle of operation of the controller.

FIG. 3 is a general diagram of the system.

FIG. 4 is a detailed circuit diagram of the system.

FIG. 5 is a drawing of the push-driven coupling between the motor and the cam assembly.

FIG. 1 shows the typical load curve of a small factory for a period of one day. The maximum demand of 100 kw. is attained only once, and it is evident that additional loads could be added for the remainder of that day. At time t_1 for instance, the factory load is 80 kw., and an extra 20 kw. could be added without exceeding the maximum demand. On the other hand, at time t_2 the additional load could be as high as 40 kw., and at other times much higher.

In the ideal case off-peak loads could be added in such a way that the total power consumption would always equal to the maximum demand. Generally electric boilers and space-heating loads which can be shut off temporarily and automatically without inconvenience to the user are ideally suited for off-peak operation.

Returning to FIG. 1, it can be seen that the off-peak available power varies from zero to as much as 80 kw. A single off-peak load of 80 kw. could only be on for a very short time, for as soon as the base factory load is more than 20 kw., the maximum demand would be exceeded.

On the other hand, by breaking up this 80 kw. off-peak load into a number of individual smaller loads, say 8 individual 10 kw. loads, then an appropriate number of these loads can be switched in, so as to approach the maximum demand as closely as possible. For instance, if the base factory load at a given time is 65 kw., then 35 kw. of off-peak power are available. This means that three of the afore-mentioned 10 kw. loads can be switched in without exceeding the desired maximum demand.

On this basis, the total factory load (base and off-peak) can always be kept between 90 kw. and 100 kw., and on the average approximately 95 kw. The invention offers a means of switching these off-peak loads automatically so that the total load is always between say 90 kw. and 100 kw.

It often occurs that one of the off-peak loads is more important than the others. Under these circumstances it is evidently desirable that this particular load be given

preferential treatment i.e., by having it switched on first, and switched off last.

Since some off-peak loads may be thermostatically controlled, it is desirable that another off-peak load be switched on, whenever the thermostat or other auxiliary control temporarily disconnects one of the previously operating loads.

The controller according to the invention is provided with two calibrated tap-switches P and Q (FIG. 3) which can be set as required by the electrical user. Tap-switch P establishes the desired maximum demand P_1 (FIG. 2). Tap-switch Q is set differentially at a power $(P_1—P_2)$ which is such that for any value of P_1 the difference $P_1—P_2$ will remain unchanged and be greater than U, where U is the power of the largest of the individual off-peak loads. It will be appreciated that the setting of Q is done initially and need not be altered thereafter each time a new P_1 is set unless a new off-peak load greater than any of the others is added.

The total power delivered by the feeder F is monitored by the controller. When this power is less than P_2 the motor M in the controller turns so as to close the contactors *a*, *b*, *c* and switch in the off-peak loads **1**, **2** and **3** in that sequence. This sequential closure produces a stepped increase in the power over feeder F. Should the addition of one or more of the off-peak loads now cause the total power to lie between P_1 and P_2, the motor will automatically stop.

Conversely, if the total load subsequently increases to a value in excess of P_1, the motor will reverse, and will thereby progressively open the contactors in the sequence *c–b–a*. As soon as the total power falls below P_1 (due to the disconnection of one or more of the off-peak loads), the motor stops, but the remaining off-peak loads are kept in operation.

It is clear that this motor action will tend to keep the total power consumption level at between P_1 and P_2. Furthermore, it can be seen that $(P_1—P_2)$ must be greater than the power of the largest individual off-peak load, otherwise hunting may result.

The diagram of FIG. 4 shows in detail the main components of a three-phase three-wire controller, which is capable of performing the required operations on 4 individual off-peak loads. It is composed of four principal elements A, B, C and D.

Element A is the power-sensing device. In the interests of economy, it may be made sensitive to the feeder currents only, and tests to date have shown that this is a satisfactory measure of power when the feeder voltage is reasonably constant. Transformers T and rectifiers R convert the alternating currents supplied by the current transformers CT into a direct current. The current transformers CT are connected to the incoming factory feeders. The action of the circuit is thus such as to produce a D.C. current I_1 proportional to the arithmetic sum of the effective feeder currents.

Theoretical calculations show that this sum is closely proportional to the total power even for unequally loaded three-phase lines, provided the feeder voltage is balanced and constant. Thus at unity power factor and a constant balanced line voltage if the line currents are for example, in the ratio of 26 to 36 to 43 the error which results, by taking the arithmetic sum of the root-mean-square currents as a measure of apparent power (in volt-amperes) is only 2%.

Element B comprises a pair of saturable-reactors S_R and S_F, a pair of tap-switches P and Q, a bridge-type rectifier unit BR, a shunt-type voltage-stabilizing device K, a calibrating resistor R_2, and a conventional low-voltage A.C. power supply PS_1. In the actual peak load controller, this A.C. power supply would be obtained from a convenient alternating voltage, as by employing a 5:1 transformer to step-down the 120 v. supply.

The saturable-reactors S_R and S_F have respective power windings P_R and P_F in series with the respective "reverse" and "forward" windings, R and F respectively, of controller motor M. Each of said saturable-reactors S_R, S_F, has a control winding N_1 serially connected to the output of Element A. Thus both control windings N_1 are made responsive to the D.C. current I_1 which represents the actual feeder load. Similarly, each saturable-reactor S_R, S_F has a respective reference winding N_3, N_2 serially connected through respective tap-switches P, Q to the output of Element B. Thus the reference D.C. current I_2 produced by the rectifier bridge BR is caused to circulate via tap-switches P and Q through the respective reference windings N_3, N_2 of saturable-reactors S_R, S_F.

As is well known to those versed in the art, it is a relatively easy matter to design the electro-magnetic circuits within saturable-reactors to assist or oppose one another in such manner that a control current may be arranged to have the effect of either saturating or unsaturating such reactors as desired.

Accordingly, the saturable-reactor S_R is designed to become saturated as the control current I_1 through the control winding N_1 thereof increases. Conversely, the saturable-reactor S_F is designed to become unsaturated as the control current I_1 through the control winding N_1 thereof increases.

Thus when the control current I_1 is low in value (indicating only a light load being drawn by feeders F) the saturable-reactor S_F becomes saturated, whereas the saturable-reactor S_R remains in unsaturated condition, effectively blocking energization of "reverse" winding R of motor M from its supply source **PS2**. On the contrary, saturation of the saturable-reactor S_F results in a low impedance of its power winding P_F, whereby the "forward" winding F of controller-motor M is allowed to become energized from its supply source **PS2**, so as to switch in the off-peak loads.

Such switching-in of off-peak loads naturally results in increased load through feeders F, which manifests itself as an increased output I_1 from sensing Element A. Sufficient increase in this control current I_1 will eventually cause the saturable-reactor S_F to become unsaturated. For an even higher value of I_1 saturable-reactor S_R will saturate.

By thus becoming unsaturated, saturable-reactor S_F imparts a high impedance to its power-winding P_F, whereby the "forward" winding F of controller motor M is effectively isolated from its supply source **PS2** and motor M will stop. However, for a further increase in I_1, saturable-reactor S_R will saturate, whereby the impedance of its power-winding P_R is substantially reduced, thus allowing energization of "reverse" winding R of controller-motor M from its supply source **PS2**. Motor M will thereby run in reverse direction to switch-out off-peak loads, with a resultant reduction in feeder load and thus ultimately a correspondingly reduced control current I_1.

The setting of tap-switch P thus establishes the maximum demand, or "high" setting of the load stabilizer namely the value of control current I_1 which will cause saturable-reactor S_R to become saturated and allow controller-motor M to "shed" off-peak loads.

Similarly, the setting of tap-switch Q establishes a *differential*, or "low" setting of the load stabilizer, namely the value of the control current I_1 below said maximum demand which will cause saturable-reactor S_F to become saturated and allow motor M to switch-in off-peak loads.

In the event that the control current I_1 has a value between said "low" setting as established by tap-switch Q and said "high" setting as established by tap-switch P, such a value of control current I_1 will be sufficient to unsaturate the saturable-reactor S_F, but, however, insufficient to saturate the saturable-reactor S_R.

Thus whenever the value of control current I_1 lies intermediate the respective settings of tap-switches P and Q, both saturable-reactors S_R and S_F are placed in unsaturated condition, whereby the impedances of their respective power-windings P_R and P_F become so high that

both the "forward" and "reverse" windings of controller-motor M are too weakly excited to cause rotation of said motor M in either direction, whereby said motor stops.

The tap-switch Q thus sets the *difference* between the maximum demand and the lower demand at which switching-in of off-peak loads can be allowed to commence without exceeding said maximum demand. This *differential* setting will usually be arranged to be equivalent to U, the value of the largest individual off-peak load.

As hereinbefore mentioned, the respective reference windings N_3, N_2 of the saturable-reactors S_R and S_F are serially supplied with a constant reference current I_2 through their respective tap-switches P and Q. This reference current I_2 is derived from the bridge-type rectifier-unit BR, the particular value of this constant current I_2 being established by the particular setting of a calibrating resistor R_2 in the input of said rectifier-unit B_R.

To ensure a constant input voltage E across said rectifier-unit BR and its calibrating resistor R_2, said input is shunted by a voltage-stabilizing device K supplied from any suitable A.C. supply source PS1 as shown.

Preferably the shunt-type voltage-stabilizing device K comprises an inductor having a toroidal core of Deltamax steel. The magnetic circuit represented by such a toroidal core will readily saturate in response to fluctuations of the supply source PS1, and result in an averaging out of the rectifier unit input voltage E to a nearly constant value, even if the 24 v. A.C. source PS1 fluctuates within fairly wide limits.

As will be evident to those versed in the art, the saturable reactors S_F and S_R should also incorporate various compensating and neutralizing windings and windings for magnetic filtration purposes, etc.

The low voltage A.C. power supply PS2 and PS3 for the controller, etc., may be obtained from any convenient source in a similar manner to that employed in providing supply source PS1.

The actual motor M of the controller shown in element C is a small 1 r.p.m. shaded-pole machine with "forward" and "reverse" windings. It is arranged to drive element D, which is composed of a group of cams **20** which operate the micro-switches X, S1, S2, S3, S4 and Y. These micro-switches may be used to operate the holding coils of associated magnetic contactors L1, L2, L3 and L4.

The normally-closed contacts X and Y are limit-switches to stop the motor when it has reached the limit of its travel in either the forward or reverse directions respectively.

It will thus be seen that the improved peak load stabilizer of the invention, by eliminating all relays, semiconductor devices (with the exception of diodes), electrolytic capacitors, mechanical relays, etc., greatly enhances the reliability and durability of the stabilizer, and the susceptibility to influence from extraneous factors such as temperature is greatly reduced. Likewise, resort to a 24 v. control circuit provides increased safety and also reduces the possibility of any shorting within the windings of the controller motor.

Moreover, resort to a "differential-low" tap-switch facilitates the necessary adjustment of the stabilizer, particularly when the maximum demand must be varied seasonally as in space-heating applications.

The number of controlled off-peak loads can be increased by adding the necessary cams and micro-switches to element D. The remainder of the circuit requires no further modification. This feature permits the use of spare off-peak circuits for future use, at very little increase in cost.

Off-peak loads of varying degrees of importance can be connected to the appropriate micro-switches. Thus, the action and shape of the cams **20** is such that in the forward direction the sequence is S1–S2–S3–S4, and in the reverse direction the sequence becomes S4–S3–S2–S1. The least important off-peak load is connected to micro-switch S4, and the most important to micro-switch S1.

The shaft which bears the cams is not directly connected to the motor shaft but is push-driven by means of a coupling similar to that depicted in FIG. 5. The motor will only start to rotate the cams when the pin R pushes upon pin S. The purpose of this type of coupling is to prevent the controller from responding to momentary load changes which last for less than about one minute. This type of coupling also restricts the hunting period of the controller to about one minute, in the event that one of the off-peak loads has a rating greater than (P_1-P_2) in FIGURE 2. This arrangement also permits the accommodation of off-peak loads whose individual power ratings are in a ratio of as much as 2:1, without exceeding the desired maximum demand.

Off-peak loads having vastly different ratings (power ratio greater than 2:1) can be accommodated by modifying the shape of the cams.

In conclusion the present off-peak controller has certain features which are attractive to both the electrical utilities and the power consumer. The installation costs are low, and the setting of the upper and differential power limits P_1 and P_2 by means of the tap-switches P and Q presents no particular problem to the average electrical contractor. Power consumption curves from a number of installations have shown that the improved off-peak controller of the present invention maintains the rate of power consumption very close to the desired maximum demand.

The same principles can be employed for the control of off-peak loads in single-phase systems. Only one transformer and two rectifiers are then necessary in element A of FIGURE 4, and the remainder of the circuit is left unchanged.

I claim:

1. An off-peak load control system for a circuit having a feeder line, a base load with a predetermined maximum demand and a plurality of off-peak loads; said system comprising a transformer and rectifier system to convert the alternating currents supplied by the feeder lines into direct current, a pair of saturable-reactors each having control windings to carry said direct current, two tap-switches connected to reference windings of said saturable-reactors at points corresponding respectively to said maximum demand and to a differential minimum defined by said maximum demand less the largest of said off-peak loads, the saturable-reactor connected to said "maximum" tap-switch having a normally unsaturated power-winding, and the saturable-reactor connected to said differential "minimum" tap-switch having a normally saturated power-winding, a switch between said feeder line and each of said off-peak loads, a reversible motor associated with said switches to operate said switches in a given sequence, said motor being connected through said power-windings of said saturable-reactors to operate in a given sense so as to close said switches in said given sequence only when said control direct current is below said minimum and said "minimum" reactor's power-winding is saturated, and to start again in reverse so as to open said switches in inverse sequence only when said control current exceeds said maximum and said "maximum" reactor's power-winding saturates, and to stop whenever said control direct current has a value intermediate said maximum and said minimum.

2. A control system according to claim **1**, comprising a rectifier-unit connected between each tap switch to supply a reference current thereto, a calibrating resistor to establish the required value of said reference current, and means shunting said rectifier-unit and calibrating resistor to stabilize the voltage applied thereto.

3. A control system according to claim **1**, comprising a cam assembly driven by said motor to operate said switches.

4. A control system according to claim **1**, comprising a cam assembly push-driven by said motor to operate said

switches so that the successive opening and closing of said switches is restricted to a specific interval of time.

5. A control system according to claim 1, comprising a limit switch in series with each power-winding of said saturable-reactors to open the circuit of said motor when the motor reaches either of its limit positions.

6. A control system according to claim 2, wherein said shunting means comprises a saturable inductor having a magnetic core of toroidal configuration to provide a constant average output voltage.

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