

[54] **METHOD FOR CALCULATING THE AVERAGE VALUE OF A NOISE CORRUPTED SIGNAL**

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[58] Field of Search. **328/151; 444/1; 235/151.21**

[57] **ABSTRACT**

A method for determining the average load provided by a steel refining furnace so that the control signal for controlling the power distribution system including the furnace load can be modified to avoid response of the control system when there is a loss of arc in the furnace. An average load is calculated for the furnace with that average being maintained until a predetermined period of time has elapsed after a sudden drop in load before the average is modified. As a result, sudden drops in load due to loss of arc are effectively rejected in establishing the average load value and the control signal is modified in accordance with the change in furnace load so that unwanted control is not effected in response to a loss of arc.

2 Claims, 2 Drawing Figures

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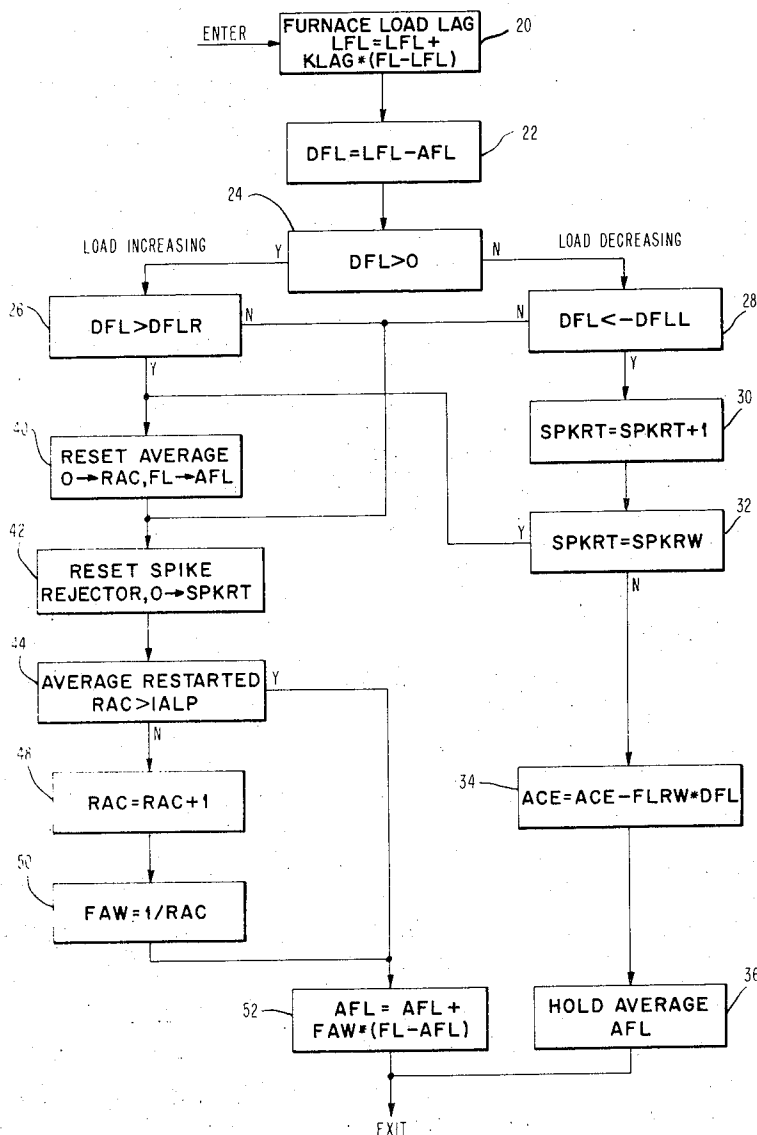
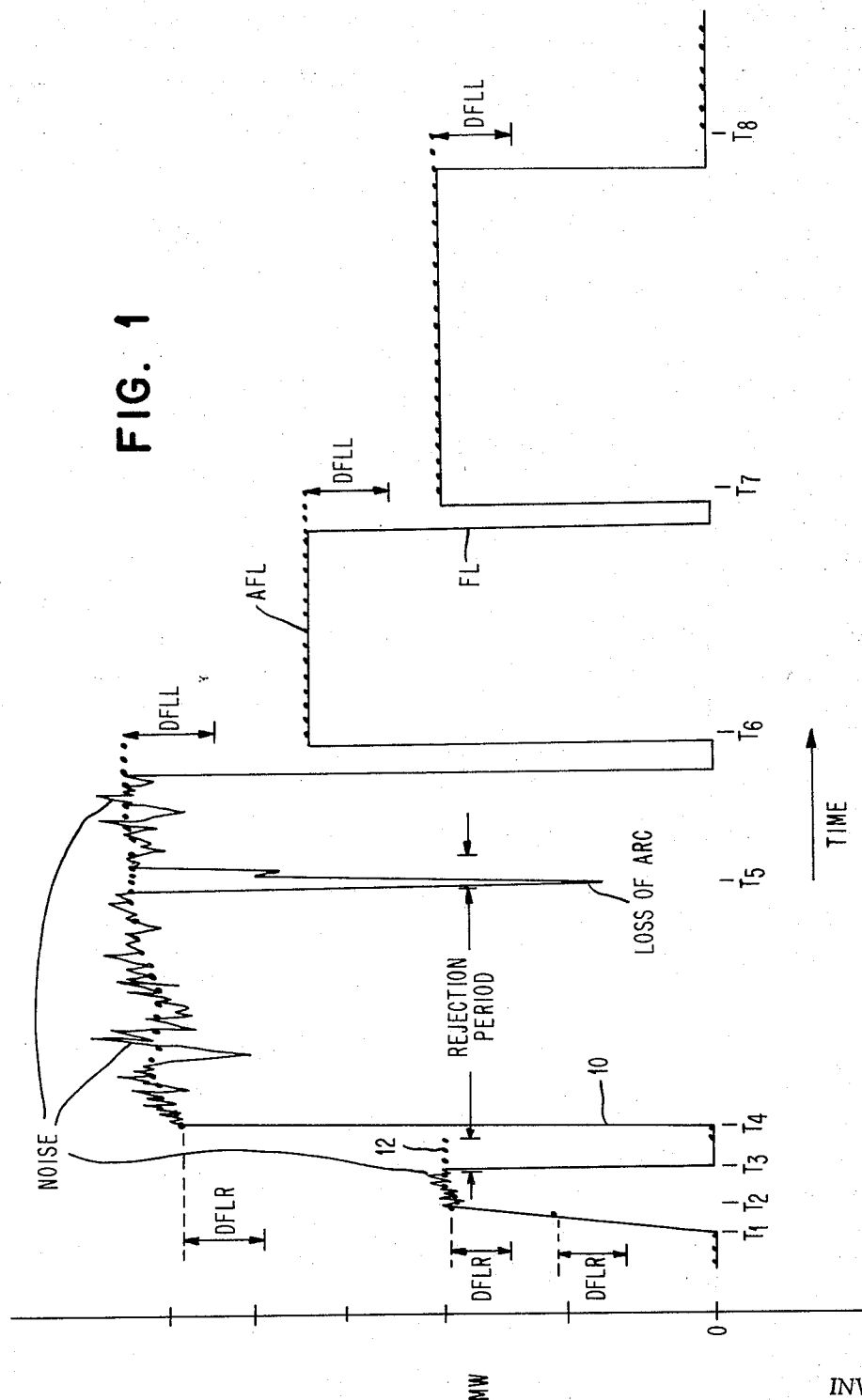


FIG. 1

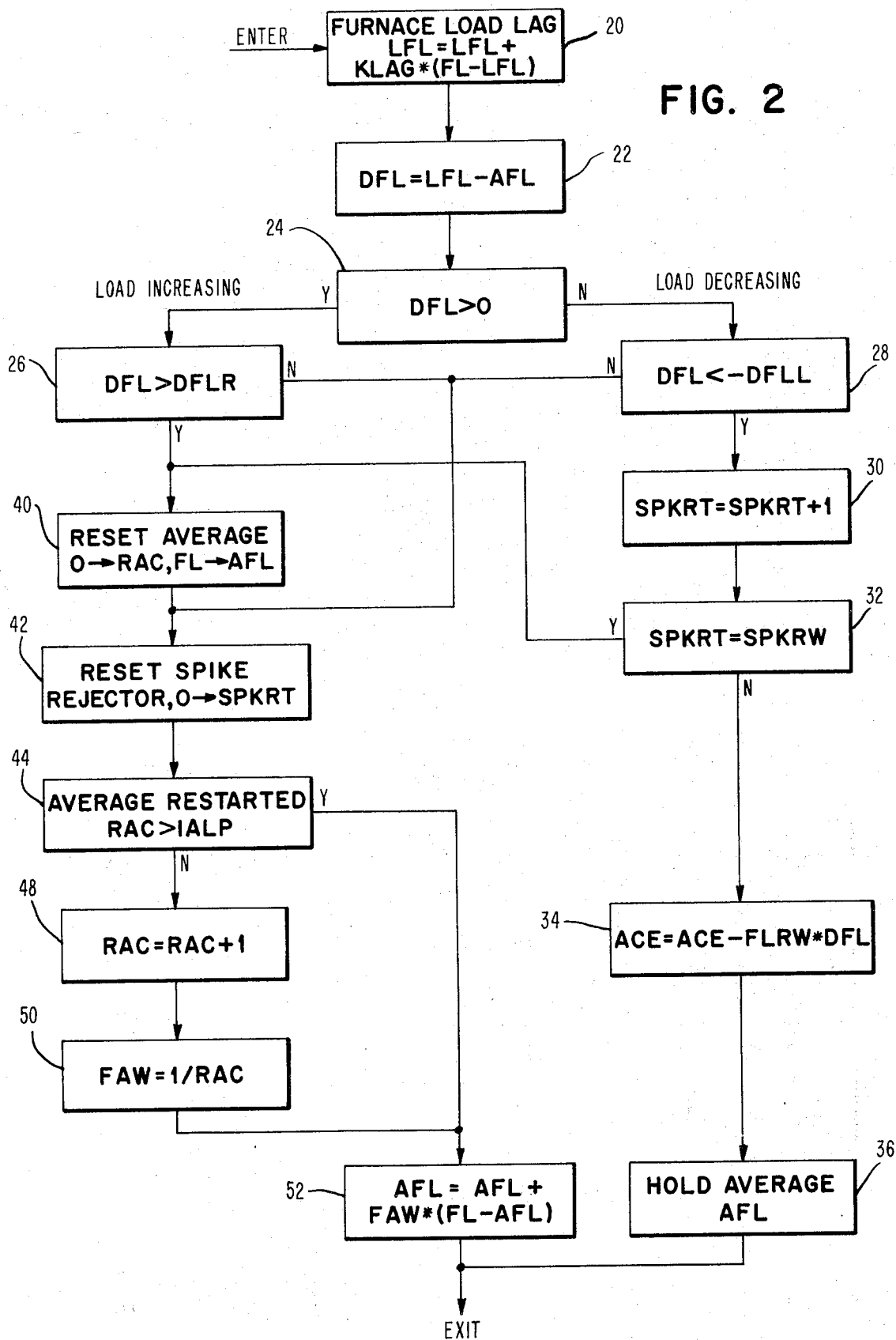


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FIG. 2



METHOD FOR CALCULATING THE AVERAGE VALUE OF A NOISE CORRUPTED SIGNAL

BACKGROUND OF THE INVENTION

This invention relates to a method for determining the average of sampled values of a noise corrupted process measurement so that sudden changes in the value are followed. More particularly, the invention relates to the determination of the average load on an electric arc furnace in which case it is desirable that sudden drops in load due to a loss of arc in the furnace should be ignored and the control signal for the power distribution system supplying the furnace should not be modified in accordance with the extent of the load change during the loss of arc so as to prevent a correspondingly large control response to that transient condition.

In the normal control system, a simple filtering of the noise would be all that would be necessary; however, when the measured value is subject to wide fluctuations, an intolerable delay, in response to such fluctuations, would occur using a simple filtering technique. In order to provide a control response to sudden changes in the measured value, means must be provided for recognizing those sudden changes so that the filtering may be modified whereby the delay in responding to such a change can be minimized.

In the case of the arc furnace, special situations arise which make it desirable to delay the response to sudden changes in furnace load. For example, during the loss of arc in an electric steel refining furnace, control response would be disadvantageous in that the very large load drop usually associated with a loss of arc is a transient condition which lasts only for a short time relative to the system response time and is therefore not amenable to correction by the usual control systems wherein the governor adjustments on the generators are modified in response to load changes in the system as evidenced by the deviation of the area control error from zero. The control systems for load distribution may, for example, be of the type shown in my U.S. Pat. No. 3,510,637 which issued May 5, 1970.

It is therefore an object of this invention to provide a method for determining the average of a sample value of a noise corrupted measurement so that the calculation of the average is subject to modification in response to large changes in the value measured.

It is a further object of this invention to provide a method for determining the average load on an arc furnace so that the calculation of the average is not subject to modification in response to the transient load change which occurs due to a loss of arc in the furnace.

It is still a further object of this invention to provide means for modifying the control signal for the power distribution system which includes the electric furnace so as to prevent the control system from attempting to change the generation in the system in response to the load change resulting from the loss of arc, unless the load change is of a greater duration than expected.

SUMMARY OF THE INVENTION

This invention provides a method for determining at the end of each sampling period in a sampled data system an average for a noise corrupted process measurement subject to changes in value which are large compared with the magnitude of the noise. The steps of the method include the computation of the average as an exponential average of the sampled values and the re-

starting of that average at a value corresponding with the sampled value after the sampled value has deviated from the previously calculated average by an amount which is greater than a maximum value preset to represent the expected maximum value for the noise.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a representative load profile for an electric arc furnace.

FIG. 2 is an algorithm setting forth the steps which can be programmed on a general purpose digital computer to carry out the novel method of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, there is shown a load profile for an electric steel refining furnace which has, for purposes of this description, been exaggerated and simplified. That load profile is shown as the continuous line 10 while the average values of the furnace load calculated in accordance with the method of this invention is shown by the dotted line 12, with each dot representing the value established as a result of a particular sample of the existing furnace load.

At time T_1 the furnace load FL comes on. It would normally be measured on a line connected to the furnace itself or on a tie line to a group of leads which includes the furnace. As will be evident from FIG. 1, previous to the time T_1 the average value of the furnace load and the sampled value of the furnace load are both zero. When the furnace load increases beyond the average AFL by an amount greater than DFLR, as at T_2 , the average is updated to the current value of the furnace load.

Between the times T_2 and T_3 the load fluctuates rapidly over a relatively small range as a result of arcing. During that time period the average remains substantially constant at its new value, namely the average value of the load between T_2 and T_3 .

At the time T_3 the furnace is turned off for the addition of scrap and the furnace remains off until the time T_4 ; however, as shown by FIG. 1, the average value which is calculated by the method of the present invention remains at the value it had just prior to the time T_3 until a particular time period after the drop in the load. That time period is adjusted to be sufficient so that any drop in load due to a loss of arc would have recovered by a reforming of the arc prior to the expiration of that period. Thus, that time period can be considered as a rejection period during which a drop in load is not taken into account in the computation of the average load. It will be noted, however, that after that period has expired, the average load then becomes the existing furnace load, for the load drop is assumed to be such that its duration will make control response feasible. For example, just prior to the time T_4 , the computer average becomes zero.

When the furnace comes back on at the time T_4 at a higher load level, the average again follows the existing value of the load since, as the load changes by a sufficient amount DFLR, the average is restarted with the current value.

As shown during the period between T_4 and T_5 , the computed average generally follows the average of the noisy signal representing the furnace load during that part of the melting period in the furnace.

At the time T_5 the load on the furnace decreases rapidly as a result of a loss of arc in the furnace and then it recovers as the arc is reestablished so that the duration of the load drop after the time T_5 is less than that period assigned as the rejection period, and therefore the calculated average is not modified in response to the load drop, as shown.

After the time T_5 , the melting phase continues until just prior to the time T_6 at which time a tap change occurs so that the refining of the furnace batch may begin at the time T_6 at a reduced load level. Associated with the tap change is a load drop greater than the value $DFLL$, which represents the change limit in the decrease direction which must be exceeded to indicate a loss of arc, and thus the rejection period is started. Since the rejection period does not elapse before the time T_6 , the average load takes on the value of the sampled load after the time T_6 ; thus, the average continues at the value calculated before the tap change until the end of the rejection period. Then during that part of the refining period up to the load drop just prior to the time T_7 which represents another tap change, the average remains at the constant refining level. After the second tap change, which is similarly accomplished before the rejection period elapses, the new average is established at the furnace load FL sampled just after T_7 .

Between the time T_7 and T_8 , the furnace load remains constant as does the average value computed for the furnace load except that just prior to T_8 the furnace load is reduced to zero by furnace shut-down for the end of the heat. As noted in FIG. 1, the average remains at its previous value until the rejection period has elapsed following the drop in load at shut-down. The average is then calculated as zero just after the time T_8 .

In order to provide for a computer average furnace load which will be modified only in response to load changes which do not represent arcing noise or a loss of arc in the furnace as shown in FIG. 1, the method illustrated by the algorithm of FIG. 2 may be followed in the programming of a general purpose digital computer. By using that method there will also be provided a modification of the control error for the load distribution system which includes the furnace so as to take into account the fact that control action is not desired during a loss of arc since the expected quick recovery makes it undesirable to provide control response prior to arc recovery. Control is, however, allowed where load changes have occurred which persist beyond the period established as the rejection period; for example, between T_3 and T_4 in FIG. 1.

The first step in the algorithm of FIG. 2 involves the introduction of a lag factor in connection with the sampled values of the furnace load. It is necessary to introduce this lag in order to coordinate the furnace load measurement with the normal tie line load measurements which are incorporated into the computation of the control error for the particular load distribution area in which the furnace is located, since the normal measurements made from the tie line inherently involve a lag because of the type of apparatus used. Therefore, the lagged furnace load LFL , as a result of the present sample of the furnace load FL , is calculated as shown in the block 20. By adding to the previous lagged furnace load LFL , the product of the lag factor KL and the quantity $FL - LFL$, representing the difference between the sampled load and the previous value for the lagged furnace load.

Utilizing the computed value LFL , the change in furnace load DFL is computed as shown in block 22 by subtracting from LFL the average furnace load AFL , calculated as a result of the computation of the average furnace load based on the previous sample of FL .

After computing DFL , the value DFL is then examined for polarity as shown in block 24. If DFL is greater than zero, the program then proceeds to the step described in block 26 whereas if the value DFL is not greater than zero, as would be the case for a decreasing load from the furnace, the program would proceed to the step described in block 28 where the value DFL is examined to see if it is less than $-DFLL$ which represents that limit value established for a decreasing load which would normally be exceeded by a loss of arc in the furnace but which would not be exceeded by the normal noise in the load profile during the melting period.

If the change in the furnace load DFL indicates a decreased furnace load which exceeds the deviation limit $DFLL$, then the step shown in block 30 is carried out, namely, the incrementing of the rejection timer by 1, so as to obtain a new value for $SPKRT$ which represents the time elapsed following a large load drop. After incrementing that timer, the program proceeds to the step described in block 32 wherein the value established for the timer is examined to see if it equals $SPKRW$, which represents the rejection time period established for large downward load drops and is thus the time period during which any loss of arc is expected to have been reestablished.

If $SPKRT$ does not equal $SPKRW$, the load drop which occurred has not existed for a sufficient duration of time so as to give assurance that it is not caused by a loss of arc in the furnace and therefore it must be assumed that it could have resulted from an arc loss and therefore that a control response to the load decrease should not be made in accordance with the magnitude of the load drop. It might, however, be advantageous to modify to a moderate extent the control error for the area, namely ACE , so that the additive effects of random load changes by the system load and by the furnace melt noise are not ignored. Thus, as shown in block 34, the area control error ACE is modified by subtracting the product of a weighting factor $FLRW$ and the load drop DFL . Normally, the weighting factor $FLRW$ would be in the range of 0.8 to 1, depending upon the relative magnitude of the load drop to be rejected as compared with the magnitude of the noise.

By modifying the area control error so that the full effect of the load drop is not evidenced by a change in value of the control error, ineffective control can be prevented as previously pointed out. After the modification of the area control error, the program then proceeds to the step described in block 36 which indicated that the average furnace load AFL , which had been previously calculated, is maintained and the program then exists.

Considering the other alternative paths in the program illustrated by the algorithm of FIG. 2, we can examine the result of the change in furnace load DFL being positive so as to indicate an increase and cause the program to proceed to the step described in block 26. As shown in block 26, the change in load DFL is examined to see if it exceeds the increase limit $DLFR$, which has a value established to be comparable to the change in load expected from the noise; thus, if DFL is

greater than DFLR indicating that there has been a load increase which is beyond that expected as a result of the melt noise, that the program proceeds to the step shown in block 40 where it is indicated that the average is restarted. As indicated, the value AFL is reset to be equal to the presently sampled furnace load FL and at the same time a zero is put into the memory position reserved for the signal RAC, which represents the count of the Restart Average Counter which counts the number of samples which are being used in establishing the average furnace load AFL following its being reset to a value FL.

After the location of the average and the zeroing of the Restart Average Counter, the program then proceeds to carry out the step described in block 42 by resetting the spike rejector. A zero is placed into the memory location reserved for the value SPKRT, representing the timer whose value is incremented as set forth previously in the block 30. In other words, the time accumulated by the timer which establishes the rejection period is replaced by zero and any rejection period which was in the process of being timed out is terminated.

After setting a zero in the memory location for SPKRT, the program proceeds to the step of block 44 which indicates that the next step is a restarting of the average. As shown in this block, the value RAC is examined to see if it exceeds a value representing $1/\alpha$ represented by the mnemonic IALP.

In the algorithm of FIG. 2, upon the establishment of a new value for the average furnace load, as for example in the step of block 40, the consecutive samples are averaged on a linear or equally weighted basis until the number of samples equals IALP after which the averaging is done on an exponential basis in order to remove as much as possible from the average value the effect of the noise. The α factor is related to the size of the lag introduced in the exponential averaging by the equation $\alpha = 1 - e^{-T_s/\tau}$

where: T_s is the sample period in seconds and τ is the time constant of the lag in seconds.

Typical values for τ in this application are 1-3 minutes which corresponds to an α between 0.33 and 0.011. When the ratio of T_s/τ is small, α can be approximated by that ratio. Therefore, for this application the approximation $IALP = 1/\alpha \approx \tau/T_s$ and greatly simplifies the tuning required to adapt the algorithm to a particular system.

It will be evident from the algorithm of FIG. 2 that if RAC is not greater than IALP, the linear averaging is carried out by following the steps of the program which first include that shown in block 48; namely, an incrementing of RAC by 1 to give a new value of RAC. The program then proceeds to the step of block 50 where the reciprocal of the new value RAC is calculated and is identified as FAW, which represents the furnace average weighting factor. From the block 50 the program then proceeds to the step of block 52 where the new value for the average furnace load is computed as the sum of the previous value for the average furnace load plus the product of FAW and the quantity $FL - AFL$ which is the present sampled furnace load minus the previous average furnace load. From the step of block 52 the program then exists.

What is claimed is:

1. In a sampled data system the method for automatically modifying the control signal for a power distribu-

tion system which includes an electric steel refining furnace as part of its load so that the control signal will not change significantly as a result of loss of arc in the furnace, comprising the steps of:

automatically computing the average value of the furnace load as a linear average of the sampled furnace load measurements after the sampled value deviates from the previously calculated average by an amount which is greater than a preset maximum representing the expected maximum value from furnace melting noise,

automatically computing the average as an exponential average of the values of the furnace load after said linear average attains a value substantially equal to the value which would be computed as the exponential average for the last sampled value and the previously calculated average so long as the deviation of the value from the previously calculated average is less than said preset maximum, and

automatically maintaining the average at its last value and changing the value of the control signal by a weighted value directly related to the difference between the last sampled furnace load measurement and the previous average value of the furnace load so as to modify said control signal in magnitude and polarity so that the change in furnace load, due to the loss of arc, will not produce a comparable change in the control signal, said maintenance of the average and changing of the value of the control signal being carried out during a preset maximum time period representing the expected maximum time duration of a loss of arc when that period follows a deviation of the sampled value of the furnace load beyond a preset maximum and so long as that deviation exceeds said preset maximum.

2. The method for automatically modifying the control signal for a power distribution system which includes an electric steel refining furnace as a part of its load so that the control signal will not change significantly as a result of loss of arc in the furnace, comprising the steps of:

automatically comparing a previous average value for periodic samples of the furnace load with the presently sampled value for the furnace load;

automatically incrementing a timer when said comparison indicates that the change in the furnace load from its previous average constitutes a decrease beyond that preset deviation limit which when exceeded indicates a loss of arc in the furnace;

automatically setting the average at the present sampled value of load when,

said comparison indicates a change in furnace load from the previous average of magnitude sufficient to constitute an increase beyond a deviation limit set to be comparable to the change in load expected from furnace melting noise, and said timer has incremented to a preset value representing the expected maximum time duration of a loss of arc;

automatically averaging the furnace load values sampled since restarting the average at the sampled value when said comparison indicates that the change in the furnace load from its previous average constitutes a change of insufficient magnitude

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to exceed either said increase or decrease limit;
and
automatically holding the average at the previous average and changing the value of the control signal by a weighted value directly related to the difference between the presently sampled furnace load and the previous average value of the furnace load

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so as to modify said control signal in magnitude and polarity so that the change in furnace load due to the loss of arc will not produce a comparable change in the control signal when said timer has not incremented to said preset value.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,771,167 Dated November 6, 1973

Inventor(s) Charles W. Ross

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

- Col. 2, line 28, "leads" should read --loads--.
line 46, "in the load" should read --in load--.
line 57, "computer" should read --computed--.
line 60, "tha" should read --the--.
- Col. 3, line 35, "computer" should read --computed--.
line 53, "values" should read --value--.
- Col. 4, line 56, "indicated" should read --indicates--.
line 59, "exists" should read --exits--.
line 63, After "increase" insert --in load--.
- Col. 5, line 13, "location" should read --resetting--.
line 17, "loaction" should read --location--.
line 65, "exists" should read --exits--.
- Col. 6, line 9, "meximum" should read --maximum--.

Signed and sealed this 1st day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents