

DIGITAL INDUCTION MOTOR CONTROL SYSTEMS

The present invention relates to control systems for AC induction motors and, more particularly, to a self-calibrating power factor control system for AC induction motors.

5 A power factor control system for AC induction motors is disclosed in United States Patent No. 4,052,648. The Nola patent is contained in a NASA Technical Support Package dated March, 1979 and entitled "Power Factor Controller, Brief No. MFS-23280". In addition to the
10 Nola patent, the Technical Support package contains schematic diagrams of variations and improvements on the circuitry disclosed in the Nola patent.

As explained in the Nola patent and in the NASA Technical Support Package, the current in an AC induction
15 motor may lag the voltage by a phase angle of 80° when the motor is unloaded and by 30° when the motor is loaded. This phase angle " θ " is used to compute the power factor for the motor, which is defined as $\cos \theta$. Thus, when θ is small the power factor approaches 1. Conversely,
20 where θ is large the power factor approaches zero. Fundamentally, a low power factor means that energy is being wasted. Given the tremendous numbers of AC induction motors in use today, improving the power factor could result in very substantial energy savings. Estimates
25 of potential energy savings are set forth at pages 3 and

10 of the NASA Technical Support Package.

The operation of the Nola power factor controller is described in the NASA Technical Support Package at pages 11 and 15 using the functional block diagram appearing at page 13. The line voltage is sensed and signals corresponding to the line voltage and its complement are produced. The motor current is also sensed and signals corresponding to the motor current and its complement are also produced. An "EXCLUSIVE OR" logic operation is then performed on these voltage and current signals, the result of which is one input to a summing amplifier and low pass filter. The other input is a DC signal, derived from a potentiometer, which corresponds to a commanded phase angle and, therefore, a commanded power factor. The result of this filtering and summing operation is a DC system error voltage which is then compared with a ramp voltage synchronized with the zero crossings of the line voltage. The intersection of the ramp voltage with the DC error voltage is detected by the comparator and used to trigger the triac. As the load on the motor decreases, the phase angle tends to increase. In response the controller decreases the triac duty cycle which reduces the voltage applied to the motor and maintains the commanded phase angle. Conversely, as the motor load increases, the phase angle tends to decrease.

In response the controller increases the triac duty cycle which increases the voltage applied to the motor and maintains the commanded phase angle.

Because of the analog nature of the Nola Circuitry, that system is susceptible to changes during operation, due for example to variations in temperature. In addition, the Nola system requires a separate manual determination and setting of the power factor command potentiometer for each motor.

10 The present invention is intended to overcome the disadvantages of the Nola power factor controller and represents a significant improvement. In the present invention a digital solution to the problem has been found which requires no adjustment. The induction motor control system of the present invention is self-calibrating which means that it is no longer necessary to make a separate manual determination and setting of the power factor command potentiometer for each motor. Indeed, in accordance with the present invention the power factor controller is automatically re-calibrated each time the motor is turned on, irrespective of the load on the motor.

In one embodiment, the present invention employs a clock, a series of counters and a register. A phase angle counter is used to determine the phase angle

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between the voltage and current by counting clock pulses between the zero crossings of motor voltage and current. A delay counter is used to delay the firing of the triac by counting a predetermined number of clock pulses, 5 starting when the current crosses zero. During start-up the delay counter is initially loaded with a count of zero. The count loaded into the delay counter is then periodically incremented until the count in the delay counter equals the count in the phase angle counter. At 10 that point the count in the phase angle counter is stored in the register. This stored count corresponds to the desired phase angle and, therefore, to the commanded power factor. The controller now switches from start-up to run. During the run mode the count in the phase angle 15 counter is compared with the count stored in the register and any difference is used to periodically increment or decrement the count loaded into the delay counter and, therefore, to advance or delay the firing of the triac so as to maintain the actual phase angle equal to the desired 20 phase angle.

The foregoing and further features of the invention may be more readily understood from the following description of a preferred embodiment of the invention, by way of example, with reference to the accompanying drawings 25 in which:-

Fig.1 is a functional block diagram of one illustrative embodiment of the present invention; and

Fig. 2 is a schematic diagram of one implementation of the illustrative embodiment shown in Fig.1.

5 The present invention will now be described with reference to the figures which form a part of the specification. Fig.1 is a functional block diagram of one illustrative embodiment of the invention which will be employed to explain the principles of operation thereof.

10 As shown in Fig.1, the power factor controller is adapted for connection to a source of AC power at terminals 10 and 12. Terminal 12, which is preferably connected to the neutral wire, is connected to one lead of motor 16 while terminal 10 is connected to the other lead of

15 motor 16 through switch 18 and triac 20. Switch 18 may, for example, be a treadle-operated ON/OFF switch on an industrial sewing machine. Connected across the AC source is DC power supply 22 which provides regulated DC voltage.

20 Connected to terminal 10 is amplifier 24 which produces a square wave having zero crossings corresponding to those of the line voltage. Connected to a point between motor 16 and triac 20 is amplifier 26 which produces pulse corresponding to the zero crossings of

25 the motor current. The output of amplifier 26 is

connected to the input of one shot multivibrator 28 which produces a pulse each time the motor current crosses zero. Trigger circuit 30 is connected across triac 20 and controls the firing thereof.

5 Clock 32 produces a train of pulses, preferably at a frequency which is not a multiple of the line frequency, which are fed to phase angle counter 34 and delay counter 36. Phase angle counter 34 is connected both to amplifier 24 and to one shot 28. Counter 34
10 starts counting up clock pulses each time the line voltage crosses zero and stops counting each time the motor current crosses zero. The resulting count in counter 34 thus corresponds to the phase angle between the motor voltage and current. Delay counter 36 is also
15 connected to amplifier 24 and one shot 28, as well as to incremental counter 38. Delay counter 36 is loaded with the count contained in incremental counter 38 each time the line voltage crosses zero. Counter 36 starts counting down from this count each time the motor current
20 crosses zero. When counter 36 reaches zero, an output is produced which causes trigger 30 to fire triac 20.

The output of incremental counter 38 is also connected to one input of comparator 40 via switch 46a. The second input to comparator 40 is the output from
25 phase angle counter 34. Comparator 40 determines whether

the count in incremental counter 38 (and therefore the count loaded into delay counter 36) is less than, equal to or greater than that in phase angle counter 34. The output of comparator 40 is connected directly to steering gate 42 and to phase angle register 44 via switch 46b. Steering gate 42 determines whether incremental counter 38 is incremented or decremented. Connected between steering gate 42 and one shot 28 is switch 46c and divide-by-four circuit 48, which may comprise a pair of serially-connected flip-flops. During start-up counter 38 is incremented every other cycle and during run every half cycle.

During start-up the motor is allowed to run for several seconds to get up speed. At this point the count in incremental counter 38 is zero. Comparator 40 therefore causes counter 38 to be incremented every other cycle. This continues until the count in counter 38 equals the count in counter 34. When comparator 40 determines that the count in counter 34 equals the count in counter 38, several things occur. The count in phase angle counter 34 is loaded into phase angle register 44; one input of comparator 40 is disconnected from the output of incremental counter 38 and connected instead to the output of phase angle register 44; the output from comparator 40 is removed from register 44;

and gate 42 is connected directly to the output of one shot 28. The power factor controller has now switched from start-up to run. Henceforth, comparator 40 will compare the count in phase angle counter 34 with that
5 stored in phase angle register 44 and, depending on the results of that comparison, increment or decrement incremental counter 38 every half cycle, thereby either increasing or decreasing the delay in firing triac 20.

It will be appreciated by those skilled in the art
10 that the illustrative embodiment of Fig. 1 may be implemented using discrete components and/or integrated circuit chips. Similarly, the illustrative embodiment of Fig. 1 may be implemented using hard-wired circuits or by means of a programmed digital computer. Also,
15 numerous other systems may be constructed which may differ in form from the illustrative embodiment of Fig.1 but which nevertheless embody the principles of the present invention. For example, if a programmed digital computer were employed to implement the present invention
20 then the functions performed by counters 34, 36 and 38, register 44, comparator 40, gate 42, divider 48 and switches 46a, 46b and 46c might all be performed by that computer. In that event, the comparison of the output from counter 38 or register 44 with that of counter 34
25 could be effected by means of subtraction operation in

the arithmetic logic unit in the computer. If, on the other hand, the illustrative embodiment of Fig. 1 were implemented using hard-wired circuits, then counters 34, 36 and 38 and register 44 might comprise integrated circuit chips and switches 46a, 46b and 46c might comprise reed relays or solid state switches. Comparator 40 might comprise a pair of A/D converters and a pair of oppositely biased operational amplifiers and gate 42 and divider 48 might comprise either discrete components and/or integrated circuit chips.

A preferred method for implementing the illustrative embodiment of Fig. 1 is shown in Fig. 2. In Fig. 2 DC supply 22 comprises a full-wave bridge rectifier and a Texas Instrument ("TI") 7805 regulator integrated circuit chip. Amplifiers 24 and 26 comprise RCA CA 339 operational amplifiers. One shot multivibrator 28 comprises a TI 74121 integrated circuit chip. Clock 32 comprises a TI 74LS193 counter which is used to divide the 400 KHz address latch enable ("ALE") signal down to 28.5 KHz. Trigger 30 comprises a TI 7406 integrated circuit buffer amplifier and a Monsanto 6200 chip comprising a pair of optically coupled SCRs connected as a triac.

In Fig. 2 the functions performed by phase angle counter 34, delay counter 36, incremental counter 38, phase angle register 44, comparator 40, gate 42, divider

48 and switches 46a, 46b and 46c are handled by an Intel 8748 programmable digital microcomputer.

In the computer
5 counters are used to perform the functions of phase angle counter 34 and delay counter 36 and registers are used to perform the functions of phase angle register 44 and incremental counter 38. The function of comparator 40 is accomplished by means of a subtraction operation in the arithmetic logic unit. The
10 functions of gate 42, divider 48 and switches 46a, 46b; and 46c are performed by logic elements under software control.

When a computer is used to implement the functional
15 block diagram of Fig.1 the run mode can be handled slightly differently. Instead of incrementing or decrementing the delay counter by one count every half cycle to maintain the number in the phase angle counter equal to the number in the phase angle register, the delay
20 counter can be altered by that number of counts equal to the difference between the number of counts in the phase angle register. In this manner less time is required to bring the phase angle counter into agreement with the phase angle register. This is particularly advantageous
25 in handling clutched loads. The delay counter can also

be altered by that number of counts equal to half the difference between the number of counts in the phase angle counter and the number of counts in the phase angle register.

5 If the power factor is calibrated as aforesaid and with the motor unloaded. then power savings of on the order of 50% can be obtained when the motor is operated unloaded. If, however, the power factor is calibrated with the motor loaded, then power savings
10 of on the order of 65% are obtained when the motor is operated unloaded. To maximize power savings irrespective of whether the power factor is calibrated with the motor loaded or unloaded, a further refinement of the calibration procedure may be employed which will
15 now be explained.

The phase angle initially measured when the motor has first been turned on and has gotten up speed is defined as θ_1 . Because θ_1 can vary slightly from cycle to cycle, an average value for θ_1 is preferably obtained.
20 The phase angle which exists when the count in the phase angle counter equals the count in the delay counter is defined as θ_2 . The following ratio can then be computed.

$$\frac{\theta_1 - \theta_2}{\theta_1} = N_1$$

25 Based on limited experimentation it has been observed

that when θ_2 is determined with the motor unloaded N_1 is about 0.38. It has also been observed that when θ_2 is determined with the motor loaded, N_1 is about 0.46. When θ_2 is determined with the motor unloaded, power savings of about 50% are obtained with the motor unloaded. When θ_2 is determined with the motor loaded, power savings of about 65% are obtained with the motor unloaded. The following calculations can now be made to adjust θ_2 so as to maximize power savings irrespective of whether calibration occurs with the motor loaded, unloaded or partially loaded. N_1 is first divided by 0.46 to form N_2 and θ_2 is multiplied by N_2 to form θ_3 ; which is the calibrated phase angle which is best calculated to maximize power savings. Accordingly, θ_3 is preferably stored in the phase angle register. Of course if for some reason it is not desired to maximize power savings, using θ_2 as the calibrated phase angle will still result in very substantial savings. When θ_3 is used power savings of on the order of 65% are obtained with the motor unloaded and power savings of up to 25% are obtained with the motor loaded.

It will be appreciated by those skilled in the art that, for different types of AC induction motors, it may be desirable to employ a constant having a value other than 0.46 in order to maximize power savings. It

will also be appreciated by those skilled in the art that while the number corresponding to the actual phase angle is preferably produced by starting and stopping a counter following voltage and current zero crossings, 5 a free-running counter could just as easily be employed. In the latter event the number corresponding to the actual phase angle is the difference between the number in the counter at the times of voltage and current zero crossings. In both cases, however, clock pulses are 10 counted to produce a number corresponding to the actual phase angle. Similarly, while the delay counter is shown as counting down to zero it could count up or down from one number to another number, the differences between the numbers being the important thing. These are but 15 several examples of how the form of the present invention could be changed without departing from the principles hereof.

Although shown applied to a single phase AC induction motor, the present invention may be applied to poly-phase 20 AC induction motors as well. Indeed, controlling the power factor of a three phase AC induction motor requires little additional circuitry; two more triacs (or SCRs) and associated triggering circuitry for the two additional phases and, for example, a counter and a shift register 25 for generating fixed delays for energising the other two

phases. Since the relationship among the phases is fixed, controlling the power factor of a three phase AC induction motor only involves determining the calibrated phase angle for one phase and using that same phase
5 angle for the other two phases.



CLAIMS:

1. A digital induction motor control system for controlling an induction motor based on a calibrated phase angle comprising:

(a) a clock for producing a train of pulses;

5 (b) a phase angle counter connected to said

clock for counting said pulses to produce a digital number corresponding to the actual phase angle between motor supply voltage and motor current zero crossings;

(c) variable delay counter means connected to
10 said clock for delaying energization of said motor by counting said pulses, beginning with a first digital number, to produce a firing command when said count has reached a second digital number, said delay occurring following said motor current zero crossing;

15 (d) phase angle storage means for storing a digital number corresponding to a calibrated phase angle;

(e) digital comparator means connected to said phase angle counter and to said storage means for com-
20 paring the actual phase angle in said phase angle counter with the calibrated phase angle in said storage means and for altering at least one of the two numbers in said delay counter means in response to said comparison so as to vary the delay in ener-
25 gizing said motor to maintain the actual phase angle



approximately equal to the calibrated phase angle
irrespective of variations in motor load; and

(f) a switchable device adapted to be electrically
connected in series with a winding of said induction
5 motor and to said delay counter means for energising
said induction motor in response to said firing command
from said delay counter means.

2. Apparatus for automatically deriving a calibrated
phase angle for a digital induction motor control system
10 comprising:

- (a) a clock for producing a train of pulses;
- (b) a phase angle counter connected to said clock
for counting said pulses to produce a digital number
corresponding to the actual phase angle between motor
15 supply voltage and motor current zero crossings;
- (c) variable delay counter means connected to said
clock for delaying energisation of said motor by counting
said pulses, beginning with a first digital number, to
product a firing command when said count has reached a
20 second digital number, said delay occurring following
said motor current zero crossing.
- (d) digital comparator means connected to said phase
angle counter and to said delay counter means for com-
paring the actual phase angle in said phase angle counter
25 with the difference between the two numbers in said delay



counter means and for automatically altering at least one of said two numbers in response to said comparison so as to vary the delay in energising said motor until the number in said phase angle counter and the difference

5 between the two numbers in said delay counter means are approximately equal to thereby derive a calibrated phase angle; and

(e) a switchable device adapted to be electrically connected in series with a winding of said induction
10 motor and to said delay counter means for energising said motor in response to said firing command from said delay counter means.

3. A self-calibrating digital induction motor control system comprising:

15 (a) a clock for producing a train of pulses;

(b) a phase angle counter connected to said clock for counting said pulses to produce a digital number corresponding to the actual phase angle between motor supply voltage and motor current zero crossings;

20 (c) variable delay counter means connected to said clock for delaying energization of said motor by counting said pulses, beginning with a first digital number, to produce a firing command when said count has reached a second digital number, said delay occurring following
25 said motor current zero crossing;



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(d) phase angle storage means connected to said phase angle counter for storing a digital number corresponding to a calibrated phase angle;

(e) digital comparator means connected to said
5 phase angle counter and:

(i) during start-up being connected to said delay counter means for comparing the actual phase angle in said phase angle counter with the difference between the two numbers in said delay counter means and for auto-
10 matically altering at least one of said two numbers so as to vary the delay in energising said motor until the number in said phase angle counter and the difference between the two numbers in said delay counter means are approximately equal to thereby derive said calibrated
15 phase angle;

(ii) during run being connected to said phase angle storage means for comparing the actual phase angle in said phase angle counter with the calibrated phase angle in said phase angle storage means and for altering at
20 least one of the two numbers in said delay counter means so as to vary the delay in energising said motor to maintain said actual phase angle approximately equal to said calibrated phase angle irrespective of variations in motor load; and

25 (f) a switchable device adapted to be electrically



connected in series with a winding of said induction motor and to said delay counter means for energising said induction motor in response to said firing command from said delay counter means.

5 4. A digital induction motor control system according to claims 1, 2, or 3 wherein said phase angle counter counts up and said delay counter means counts down.

10 5. A digital induction motor control system according to claims 1, 2, or 3 wherein said phase angle counter starts counting each time said motor voltage crosses zero.

15 6. A digital induction motor control system according to claim 5 wherein said phase angle counter stops counting and said delay counter means starts counting each time said motor current crosses zero.

✓ 7. A digital induction motor control system according to claim 1 wherein at least one of said first and second numbers is altered twice each cycle.

20 8. A digital induction motor control system according to claims 1 or 7 wherein the difference between said first and second numbers is altered by an amount proportional to the difference between the number in said phase angle counter and the number in said storage means.

25 9. A digital induction motor control system according to claims 1 or 7 wherein the difference between said



first and second numbers is altered by an amount equal to the difference between the number in said phase angle counter and the number in said storage means.

10. A digital induction motor control system
5 according to claim 2 wherein at least one of said first and second numbers is altered once every other cycle.

11. A digital induction motor control system according to claims 2 or 10 wherein the difference between said first and second numbers is altered in uniform increments.

10 12. A digital induction motor control system according to claims 1 or 3 wherein said phase angle storage means comprises a register.

13. A digital induction motor control system according to claims 1, 2 or 3 wherein said comparator means comprises an arithmetic logic unit.
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14. A self-calibrating digital induction motor control system according to claim 3 wherein said number in said phase angle counter is transferred to said phase angle storage means during start-up when said number in said
20 phase angle counter approximately equals the difference between said first and second numbers.

15. A self-calibrating digital induction motor control system according to claim 14 wherein said controller switches from start-up to run when said number in said
25 phase angle counter approximately equals the difference



between said first and second numbers.

16. A self-calibrating digital induction motor control system according to claim 3 wherein said comparator means comprises:

5 means for storing a number corresponding to an initial phase angle θ_1 ;

means for storing a number corresponding to a phase angle θ_2 when the count in said phase angle counter approximately equals the difference between said pre-
10 determined numbers;

means for determining a number $N_1 = (\theta_1 - \theta_2)/\theta_1$

means for determining a number $N_2 = KN_1$, where K is a constant; and

15 means for determining a calibrated phase angle $\theta_3 = N_2\theta_2$.

17. A self-calibrating digital induction motor control system according to claim 16 wherein K is approximately 1/0.46.

18. A self-calibrating digital induction motor control system according to claims 1, 2, 3 or 16 wherein said comparator means comprises a programmed digital computer.

19. A method for operating a digital induction motor control system based on a calibrated phase angle comprising the steps of:

25 (a) generating a train of clock pulses:



(b) counting said clock pulses to produce a digital number corresponding to the actual phase angle between motor supply voltage and motor current zero crossings;

(c) counting said clock pulses to delay energization of said motor, beginning with a first digital number, to produce a firing command when the count has reached a second digital number, said delay occurring following said motor current zero crossings;

(d) digitally comparing said number corresponding to said actual phase angle with a number corresponding to a calibrated phase angle;

(e) altering at least one of said first and second numbers in response to said comparison so as to vary the delay in energizing said motor to maintain said actual phase angle approximately equal to said calibrated phase angle irrespective of variations in motor load; and

(f) energizing said motor in response to said firing command following said delay.

20. A method for automatically deriving a calibrated phase angle for a digital induction motor control system comprising the steps of:

(a) generating a train of clock pulses;

(b) counting said clock pulses to produce a digital number corresponding to the actual phase angle between motor supply voltage and motor current zero crossings;



(c) counting said clock pulses to delay energization of such motor, beginning with a first digital number, to produce a firing command when the count has reached a second digital number, said delay occurring following
5 said motor current zero crossing;

(d) digitally comparing said number corresponding to the actual phase angle with the difference between said first and second numbers;

(e) automatically altering at least one of said
10 first and second numbers in response to said comparison so as to vary the delay in energizing said motor until said number corresponding to said actual phase angle and the difference between said first and second numbers are approximately equal to thereby derive a calibrated phase
15 angle; and

(f) energizing said motor in response to said firing command following said delay.

21. A method for operating a self-calibrating digital induction motor control system comprising the



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steps of:

- (a) generating a train of clock pulses;
- (b) counting said clock pulses to produce a digital number corresponding to the actual phase angle between
5 motor supply voltage and motor current zero crossings;
- (c) counting said clock pulses to delay energization of such motor, beginning with a first digital number, to produce a firing command when the count has reached a second digital number, said delay occurring
10 following said motor current zero crossing;
- (d) digitally comparing said number corresponding to said actual phase angle with the difference between said first and second numbers;
- (e) automatically altering at least one of said
15 first and second numbers in response to said comparison to vary the delay in energizing said motor until said number corresponding to said actual phase angle and the difference between said two numbers are approximately equal;
- 20 (f) storing one of said approximately equal digital numbers as the calibrated phase angle;
- (g) digitally comparing said number corresponding to said actual phase angle with said number corresponding to said calibrated phase angle;
- 25 (h) altering at least one of said first and second

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numbers in response to said comparison so as to vary the delay in energizing said motor to maintain said number corresponding to said actual phase angle approximately equal to said number corresponding to said calibrated phase angle irrespective of variations in motor load; and

(i) energizing said motor in response to said firing command following said delay.

22. A method for operating a self-calibrating digital induction motor control system comprising the steps of:

(a) generating a train of clock pulses;

(b) counting said clock pulses to produce a digital number corresponding to the actual phase angle between motor supply voltage and motor current zero crossings;

(c) storing a digital number corresponding to an initial actual phase angle as θ_1 ;

(d) counting said clock pulses to delay energization of said motor, beginning with a first digital number, to produce a firing command when the count has reached a second digital number, said delay occurring following said motor current zero crossing;

(e) digitally comparing said number corresponding to said actual phase angle with the difference between said first and second numbers;



(f) automatically altering at least one of said first and second numbers in response to said comparison to vary the delay in energizing said motor until said number corresponding to said actual phase angle and the
5 difference between said first and second numbers are approximately equal;

(g) storing one of said approximately equal digital numbers as θ_2 ;

(h) determining $N_1 = (\theta_1 - \theta_2)/\theta_1$

10 (i) determining $N_2 = K N_1$ where K is a constant;

(j) determining $\theta_3 = N_2 \theta_2$;

(k) storing θ_3 as the calibrated phase angle;

(l) digitally comparing said number corresponding to said actual phase angle with said calibrated phase
15 angle;

(m) altering at least one of said first and second numbers in response to said comparison so as to vary the delay in energizing said motor to maintain said actual phase angle approximately equal to said calibrated phase
20 angle; and

(n) energizing said motor in response to said firing command following said delay.

23. A digital method according to claims 19, 20, 21 or 22, wherein said clock pulses are counted up to produce
25 said number corresponding to said actual phase angle and



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said clock pulses are counted down to produce said firing command.

24. A digital method according to claim 23 wherein counting of said clock pulses to produce said number
5 corresponding to said actual phase angle commences each time said motor voltage crosses zero.

25. A digital method according to claim 24 wherein counting of said clock pulses to produce said number corresponding to said actual phase angle ceases and
10 counting of said clock pulses to produce said firing command commences each time said motor current crosses zero.

26. A digital method according to claim 19 wherein at least one of said first and second numbers is altered
15 twice each cycle.

27. A digital method according to claim 19 or 26 wherein the differences between said first and second numbers is altered by an amount proportional to the difference between said number corresponding to said
20 actual phase angle and said number corresponding to said desired phase angle.

28. A digital method according to claims 19 or 26 wherein the difference between said first and second numbers is altered by an amount equal to the difference



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between said number corresponding to said actual phase angle and said number corresponding to said desired phase angle.

29. A digital method according to claim 20
5 wherein at least one of said first and second numbers is altered once every other cycle.

30. A digital method according to claims 20 or 29 wherein the difference between said first and second numbers is altered in uniform increments.

10 31. A digital method according to claim 22 wherein K is approximately $1/0.46$.

32. A system according to claims 1 or 3 wherein said predetermined relationship is one of approximate equality.

15 33. A method according to claims 25, 27 or 28 wherein said predetermined relationship is one of approximate equality.

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