

POWER CONVERTING SYSTEM

1 The present invention relates to a system for
converting electric power between ac and dc by using a
controlled rectifier circuit such as a full-wave bridge
circuit.

5 Conventionally, various kinds of systems have
been put into practical use for converting electric
power between single-phase or three-phase ac and dc by
using a single-phase or three-phase full-wave bridge
circuit. The dc output voltage of such a full-wave
10 bridge circuit is controlled by variably controlling the
firing phase angle of phase-controllable controlled
rectifier means, such as thyristors, connected the
respective arms of the bridge circuit.

 Generally, as such a thyristor gate controlling
15 method, it is widely known that under the condition that
the firing phase angle of a group of thyristors
connected to the positive arm of a full-wave bridge
circuit is made equal to that of another group of
thyristors connected to the negative arm of the same,
20 the phase angle is caused to be variable whereby the
output voltage is controlled to take a value from zero
to maximum.

 In this method, however, the lower the output
dc voltage, the larger the phase lagging of the ac current
25 with respect to the ac voltage, so that the reactive

1 power increases to deteriorate the power factor as well
as to increase ripple components, thereby affecting the
power source.

To improve such defect in the range of low dc
5 output voltages, U.S. Patent No. 4,245,293 discloses a
power converter system in which the firing phase angle
of the positive side thyristor group and that of the
negative side thyristor group are caused to be differ-
ent from each other in the range of lower output voltages,
10 so that both the thyristor groups may operate in a
shorted mode. According to this system, however, low
frequency ripple components of about 150 Hz may be
induced in the output current, while considerable
improvement has been made in power factor, etc. Thus,
15 further improvement in power factor is demanded.

Another system is disclosed to make improvement
in power factor in an article entitled "A Pulsewidth
Controlled AC-to-DC Converter to Improve Power Factor
and Waveform of AC Line Current" in IEEE TRANSACTIONS ON
20 INDUSTRY APPLICATION, VOL. IA-15, No. 6, NOVEMBER/
DECEMBER 1979. In this system, a switching element
capable of cutting-off a current is connected to the
positive arm of a full-wave bridge circuit. The
element is caused to effect a chopping operation with a
25 fixed repetition rate but a variable chopping pulse-
width, so as to control the output voltage to have a
desired value. According to this system, since the ac
voltage is in phase with the ac current, the power

1 factor may be made to approach a value 1. Further, the
dc output voltage may include little component of the
sixth higher harmonics of the power source so that the
ripple components in the output current may be suffi-
5 ciently suppressed.

According to this method, however, in order
to continuously control the output voltage from a high
value to a low one, it is necessary to continuously
control the pulse-width for chopping the above-mentioned
10 element from a wide value to a very narrow one. How-
ever, it is difficult to effect such control and there
is a limit in narrowing the chopping pulse-width. By
using currently available transistors or gate-turn-off
thyristors (hereinafter abbreviated as GTO), it is
15 impossible to control the output voltage to take a value
lower than one tenth of the rated one, in view of the
above-mentioned minimum chopping pulse-width.

In spite of this, there are numerous uses
which require the control to lower the output voltage
20 to a value below one tenth of the rated one. For
example, in a high speed elevator system driven by a
dc motor, it is required to continuously control the
speed to a value below one thousandth of the rated one.
In such a case, it is apparent that the above-mentioned
25 system can not be applied thereto and therefore the
first-mentioned system cannot but be used in which the
respective firing phase angles of the positive and
negative side thyristor groups of the full-wave

thyristor bridge circuit are controlled.

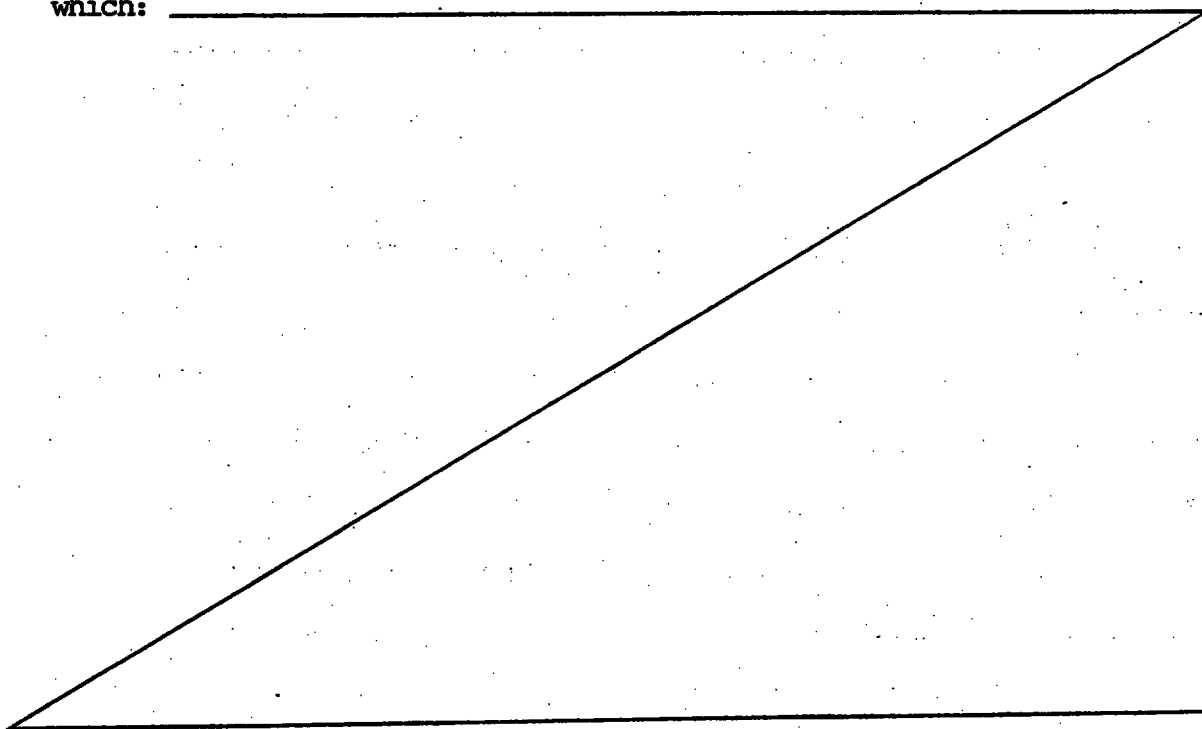
An object of the present invention is, therefore, to provide a power converting system between an ac side and a dc side having a simple construction and capable of controlling the output voltage
5 over a wide range with an improved power factor.

According to the present invention there is provided an electric power converting system in which electric power is converted between ac and dc by using a controlled rectifier circuit including phase-controllable controlled rectifier means, said system comprising switching means
10 for chopping a dc output of said controlled rectifier circuit, means for controlling a phase angle of said rectifier means in accordance with a desired output voltage, and means for controlling a pulse-width for chopping said switching means in accordance with said desired output voltage.

15 Preferably the power converting system is capable of effecting stable control over the entire controlling range.

Furthermore, in the lower desired output voltage range the phase angle of the rectifier means is variably controlled while maintaining the above-mentioned pulse-width at a fixed value, and in
20 the higher desired output voltage range the pulse-width is variably controlled while maintaining the phase angle at a fixed value.

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings, in which:



1 Figs. 1 to 4 are useful for explaining the
principle of operation of the present invention, of which
Fig. 1 is a schematic diagram of a basic circuit of a
power converting system, Fig. 2 shows wave-forms for
5 explaining the operation of Fig. 1 circuit, Fig. 3 is a
characteristic diagram of the pulse-width and phase
angle with respect to the output voltage command, and
Fig. 4 illustrates a schematic diagram of a function
generating circuit for obtaining the characteristic as
10 shown in Fig. 3;

Fig. 5 is a general schematic diagram of a
particular embodiment of the power converting system
according to the present invention;

Fig. 6 shows wave-forms for explaining the
15 operation of Fig. 5 system;

Fig. 7 illustrates a circuit configuration
of a dc motor to which an embodiment of the power
converting system of the present invention is applied;

Fig. 8 illustrates a basic circuit configura-
20 tion of another embodiment of the power converting system
of the present invention;

Fig. 9 shows wave-forms for explaining the
operation of Fig. 8 circuit;

Fig. 10 illustrates a basic circuit configura-
25 tion of still another embodiment of the power converting
system of the present invention;

Fig. 11 shows wave-forms for explaining the
operation of Fig. 10 circuit;

1 Fig. 12 illustrates a basic circuit configuration of a further embodiment of the power converting system of the present invention;

Fig. 13 shows wave-forms for explaining the
5 operation of Fig. 12 circuit; and

Fig. 14 illustrates a basic circuit configuration of another embodiment of the power converting system of the present invention.

The principle of operation of the present
10 invention will be first described by referring to Figs. 1 to 4.

Though the description will be made here about such a case where GTOs are used as controllable switching means having a current cutting-off capability in a power
15 converter system which is illustrated by way of example and in which power conversion is made between a three-phase ac power source and a dc side, the principle of operation of the invention will be readily understood even in such a case as will be described later where
20 a single-phase ac source and/or other different switching means are used.

Fig. 1 shows an embodiment of a basic circuit configuration according to the present invention. In the figure, a full-wave bridge circuit is constituted by
25 thyristors U_1 , U_2 , V_1 , V_2 , W_1 and W_2 , the ac terminal of the full-wave bridge circuit being connected to a three-phase ac source E_a , while a chopper circuit constituted by gate-turn-off thyristors GTO_1 and GTO_2

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- 1 being connected between the dc terminal of the same
bridge circuit and a load L.

The respective gates of the thyristors U_1 to
 W_2 , GTO_1 and GTO_2 are controlled so as to control the
5 voltage across the load L comprising a resistor RL , an
inductance LL and a dc voltage source EL .

Now, it is assumed that the time constant
 LL/RL of the load L is sufficiently longer than the
period of wave of the ac source and that the voltage of
10 the dc source EL takes a value somewhat lower than the
output dc voltage E_o . For example, such conditions as
above are provided in such a case where for the
purpose of controlling a dc motor, the armature circuit
of the motor is the load L.

15 Fig. 2 is a wave-form diagram for explaining
the operation of the circuit of Fig. 2 and illustrates
respective wave-forms of the phase voltages U, V, and W,
the output voltage E_o and the U-phase current I_U .
Here, it is assumed that the thyristors U_1 to W_2 are
20 gate-controlled with a phase angle α . For example, with
respect to the thyristor U_1 , the phase angle α is
represented by an angle of lag from a point of time at
which the voltage of U-W phase is changed in polarity
from a negative value to a positive one and therefore
25 referred to as a control lag angle hereinafter. It is
further assumed that the thyristors GTO_1 and GTO_2 are
chopped with a period T and a pulse-width P and with
the same period and a pulse-width (T-P), respectively.

1 Fig. 2(b) shows wave-forms when the thyristors
GTO₁ and GTO₂ are chopped under the condition that the
control lag angle α is zero.

 In this case, for example, as shown by a loop
5 (1) in Fig. 1, when the thyristor GTO₁ is fired a
current flows through the thyristors U₁ and V₂ so that
the load current I_L passes through the ac power source
E_a. Then, if the thyristor GTO₁ is turned off and at
the same time the thyristor GTO₂ is fired, the load
10 current I_L flows through the path as shown by the loop
(2) without passing through the power source E_a. As
this time, the output voltage E_o is zero. Thus, the
output voltage E_o has a pulse-like wave-form defined
with a pulse-width P as shown in Fig. 2(b). Therefore,
15 the output voltage E_o and the U-phase current IU may
be controlled by arranging the pulse-width to be
variable.

 In this case, the phase lag of the phase
current with respect to the output voltage E_o is very
20 small so that the power factor may approach 1.

 Since there is a limit, however, in narrowing
the pulse-width P, it is difficult to control the
output voltage E_o to take a value lower than about one
tenth of the rated one.

25 According to this embodiment, therefore, the
output voltage E_o may be continuously controlled to
zero by controlling first the pulse-width P to its
minimum value and controlling then the control lag

- 1 angle α to change its value while maintaining the pulse-width P at its minimum value.

Fig. 2(c) shows wave-forms in the case where the control lag angle α is caused to be about 90° ,
5 namely the output voltage is caused to be about zero, under the condition that the pulse-width P is maintained at its minimum value. In particular, in Fig. 1, the thyristors U_1 to W_2 are selectively fired with the control lag angle 90° on one hand and the thyristor GTO_1
10 is chopped with the minimum value of the pulse-width P during the conduction period of the thyristors U_1 to W_2 which is determined in accordance with the control lag angle 90° . Thus, as shown in the figure, the reactive power can be sufficiently reduced so as to improve the
15 power factor in the low output range.

The relationship between the output voltage and each of the phase angle α and the pulse-width P , as discussed above, will be illustrated in Fig. 3. In particular, Fig. 3 shows the relationship between the
20 voltage command S_V and each of the pulse width S_P and the phase angle S_α . Along the axis of abscissa the voltage command S_V is expressed by the ratio of a desired output voltage to the rated one, while along the axis of ordinate the pulse-width P is expressed by
25 the ratio thereof to the full-conduction width and the phase angle α is expressed by the control lag angle. As seen in Fig. 3, the output voltage is continuously controlled from zero to the rated voltage by controlling

1 the pulse-width S_p and the phase angle S_α in such a manner that in the range where the command voltage is higher than one tenth of the rated voltage, the pulse-width S_p is varied with the control lag angle S_α at zero
5 degree, while in the range where the command voltage is lower than one tenth of the rated one, the phase angle S_α is varied with the pulse-width S_p maintained at its minimum value.

Although various methods can be considered to
10 obtain the values of the pulse-width P and the phase angle α in accordance with the voltage command S_v , an example among them will be illustrated in Fig. 4. The circuit of Fig. 4 is constituted by function generators F_α and F_p respectively having characteristics with
15 respect to the voltage command S_v as illustrated in the figure, the respective outputs S_α and S_p of which generators have the characteristics as illustrated in Fig. 3. Thus, the output voltage may be controlled in accordance with the voltage command S_v by controlling
20 the respective gates of the GTO₁ and GTO₂, and U_1 and W_2 by using the outputs S_α and S_p of the function generators F_α and F_p as the pulse-width command and the phase angle command, respectively.

In particular, if the control lag angle α is
25 controlled to change from 90° to 0° while maintaining the pulse-width P fixedly at 0.1, the output voltage may vary from zero to $0.1 \times \frac{3\sqrt{2}}{\pi} E_a$. Thereupon, if the pulse-width P is controlled to change from 0.1 to 1.0,

- 1 the output voltage increases to its maximum value $\frac{3\sqrt{2}}{\pi} E_a$.

For the control of negative output voltage, when the control lag angle α is varied from 90° to 180° ,
5 the output voltage changes from zero to $-0.1 \times \frac{3\sqrt{2}}{\pi} E_a$. Thereupon, when the pulse-width P is varied from 0.1 to 1.0, the negative output voltage value increases to $-\frac{3\sqrt{2}}{\pi} E_a$.

Referring to Figs. 5 and 6, a particular
10 embodiment of the invention based on the principle of operation as discussed above will be described here.

Fig. 5 is a schematic diagram of an embodiment of a power converter system according to the present invention, and Fig. 6 is a time chart of wave-forms
15 useful for explaining the operation of the system of Fig. 5.

In the drawings, a gate pulse generating circuit PS for the thyristors includes three phase-shifters PU, PV, and PW. The three phase voltage of an
20 ac power source E_a is Δ -Y transformed by a transformer T_r into line voltages UW, VU and WV having a neutral point which are then supplied to the phase-shifters PU, PV and PW. A phase command signal S_α is also applied to each of the phase-shifters PU, PV and PW. The phase
25 command signal S_α is produced by a function generator F_α having such an output which causes the control lag angle α to be zero in the range where a voltage command signal S_v and hence the output voltage take large

1 values, as shown in Fig. 3. Thus, the phase-shifters
PU, PV and PW produce wide-width pulses GU_1 and GU_2 ;
 GV_1 and GV_2 ; and GW_1 and GW_2 , respectively, as shown in
Fig. 6, which are then applied to the respective gates
5 of the thyristors U_1 to W_2 . At a point of each of the
phase-shifters PU, PV and PW, a gate pulse for controll-
ing a positive half-wave of the source E_a is produced,
while at a pin 2 of the same, another gate pulse for
controlling a negative half-wave is generated.

10 A GTO gate pulse generating circuit PP is
supplied with a pulse-width command signal S_p . This GTO
pulse-width command signal S_p is obtained by a second
function generator F_p which produces such an output
signal the pulse-width of which is a small fixed value
15 in the range where the voltage command signal S_v and
hence the output voltage take smaller values, while the
pulse-width of which becomes large in the range where
the voltage command signal S_v and hence the output
voltage take larger values, as seen in Fig. 3.

20 Thus, corresponding to the pulse width
command signal S_p , the GTO gate pulse generating circuit
produces pulses GT_1 and GT_2 , as illustrated in Fig. 6,
which are then applied to the thyristors GTO_1 and GOT_2 ,
respectively.

25 In response to these pulses GT_1 and GT_2 , the
thyristors GTO_1 and GTO_2 are conductive and non-
conductive, respectively, during the period P, while
they are non-conductive and conductive, respectively

1 during the period (T-P).

Fig. 7 illustrates an application of an embodiment of the power converting system according to the invention into the speed control of a dc motor.

5 In Fig. 7, M designates an armature of a dc motor, F a field system of the motor, TH is a push-pull thyristor amplifier for controlling a field current of the motor, and FPS a phase-shifter for the amplifier.

Further, PS designates a gate control circuit
10 for the thyristors U_1 to W_2 which is similar to that shown in Fig. 5, and PA a comparator which compares an actual armature current detected by a dc current transformer CT with an armature current command S_C .

The armature current is controlled to a given
15 value in accordance with the armature current command S_C . An actual speed detected by a tachometer generator PG is compared in the phase-shifter FPS with a speed command S_S so that the actual speed is caused to follow the speed command S_S by controlling the field current
20 over positive and negative ranges.

Such a control system has a feature that by controlling the armature current only in one direction, the motor may be controlled to operate in any one of four running modes, i.e. a forward running mode, a
25 backward running one, a powering running one, and a regenerative running one.

In case where a service interruption occurs in the regenerative running mode, there is a possibility

1 of damage of the thyristors because the output voltage
of the thyristor circuit becomes zero so as to allow the
armature current to abruptly increase. For this,
ordinarily, a dc contactor is inserted in the armature
5 circuit. In the present embodiment, however, since a
chopper circuit constituted by the thyristors GTO_1 and
 GTO_2 is connected between the dc terminal of the full-
wave bridge circuit and the motor, it is possible to cut
off the armature current by applying an off-pulse gate
10 signal to the thyristors GTO_1 and GTO_2 to turn off them
when the armature current exceeds a given level. Thus,
there is no requirement of any dc contactor, resulting
in reduction in size of the system as well as in cost
of the same.

15 According to the present embodiment, a remark-
able industrial effect may be shown in such a way that
the power factor in the three-phase power converter or
inverter system can be improved, the capacity of the
electric power source can be reduced, the dc contactor
20 so far required becomes unnecessary, etc.

Fig. 8 illustrates another embodiment of the
present invention and Fig. 9 shows wave-forms for
explaining the operation of the embodiment.

In the embodiments as so far described, the
25 full-wave bridge is constituted only by thyristors in
order to enable the system to convert the electric
power not only in the converter mode from ac into dc
but reversely in the inverter mode from dc to ac.

1 In the case where the system is not required
to operate in such an inverter mode, it will do that
thyristors U_1 , V_1 and W_1 are connected at the positive
side of the full-wave bridge, diodes D_1 , D_2 and D_3 are
5 connected to the negative side of the same, a GTO is
connected between the dc terminal of the full-wave bridge
and a load L of the same, and a diode D_4 for circulating
a load current is connected in parallel with the load L ,
as shown in Fig. 8.

10 In this case, if the control lag angle α of
the thyristors U_1 , V_1 and W_1 is controlled to vary, the
voltage E_o across the dc terminals takes a value between
the solid lines as shown in Fig. 9(a). Further, Fig.
9(b) shows the wave-form of the output voltage E_o when
15 the pulse-width P for the on-off control of the GTO is
controlled with the control lag angle maintained un-
changed. In particular, Fig. 9(b) illustrates the case
where the chopping operation is repeated five times.
Thus, the present invention is also effective in the
20 case where the system operates only in the converter
mode, so that power conversion may be made in a wide
range with a high power factor by controlling the phase
angle α as well as the pulse-width P .

Although only the power conversion between a
25 three-phase ac side and a dc side has so far been
described, the present invention will be of course
applicable to the power conversion between a single-
phase or poly-phase, other than three-phase, ac side

1 and a dc side.

Fig. 10 illustrates an embodiment in which power conversion is made between a single-phase ac side and a dc side, and Fig. 11 shows wave-forms for explaining the operation of this embodiment.

Referring to Fig. 10, a chopper circuit constituted by gate-turn-off thyristors GTO_1 and GTO_2 is connected between a dc terminal and a load L of a full-wave bridge circuit constituted by thyristors R_1 , R_2 , S_1 and S_2 .

Fig. 11(a) shows the output voltage E_o in the case where only the phase angle α of the thyristors R_1 to S_2 is controlled, and Fig. 11(b) shows the output voltage E_o in the case where the thyristors GTO_1 and GTO_2 are on-off controlled by the pulse-width P in addition to the control of the phase angle α . In particular, these figures show wave-forms under the condition that the control lag angle α is 90° and the output voltage E_o is zero. Similarly to the previous embodiment, the power factor may be remarkably improved when the output voltage E_o is zero if the pulse width P is caused to be minimum. Further, also similarly to the previous embodiment, if the control lag angle α is controlled from 0° to 180° and the pulse-width P is also controlled from its maximum value to its minimum one, control can be made over a whole range in the converter mode and in the inverter mode.

In the afore-mentioned embodiments, although

1 the fundamental wave power factor may be improved,
higher harmonics may be produced since an intermittent
current may flow in the ac power source as shown in
Fig. 2. Such higher harmonics may be reduced by insert-
5 ing a filter circuit between the full-wave bridge
circuit and the chopper circuit. Fig. 12 illustrates an
embodiment of such a technique and Fig. 13 shows wave-
forms for explaining the operation of the embodiment.

In the drawings, a filter circuit includes a
10 reactor L_D and a capacitor C_D . If a current I_{LD} flowing
through the reactor L_D is maintained at a continuous
constant value when the GTO_1 is at OFF state, the output
voltage E_o of the full-wave bridge circuit has a wave-
form as shown in Fig. 13(b) under the condition that
15 the control lag angle α of the thyristors U_1 to W_2 is
maintained to be zero.

In Fig. 13, diagrams (c) to (f) respectively
show the terminal voltage E_{CD} across the capacitor C_D ,
the terminal voltage EL across the load L , the current
20 I_{LD} flowing through the reactor L_D and the U-phase
current I_U , when the thyristors GTO_1 and GTO_2 are one-off
controlled with the pulse widths P and $(T-P)$ respectively
as shown in figure (g), while maintaining the control
lag angle α to be zero.

25 In this manner, there are meritorious effects
that not only the source wave-form may be improved but
also the gate pulse generating circuit may be simplified
because the output current I_{LD} of the full-wave bridge

1 circuit is continuous so that the thyristors U_1 to W_2 can be fired even by a narrow-width gate pulse.

5 In the embodiments as mentioned above, although descriptions have been made, by way of example, about the cases where GTOs are used as switching means capable of cutting off a current, these GTOs may be replaced by conventional transistors Q_1 and Q_2 as shown in Fig. 14, with quite the same effects as those obtained in the previous embodiments.

10 As discussed above, according to the embodiments of the invention, power conversion may be made over a wide range with an improved power factor.



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CLAIMS:

1. An electric power converting system in which electric power is converted between ac and dc by using a controlled rectifier circuit including phase-controllable controlled rectifier means, said system comprising switching means for chopping a dc output of said controlled rectifier circuit, means for controlling a phase angle of said rectifier means in accordance with a desired output voltage, and means for controlling a pulse-width for chopping said switching means in accordance with said desired output voltage.
2. An electric power converting system according to Claim 1, in which it is so arranged that said phase angle is caused to be variable when said desired output voltage is lower than a predetermined value, while said pulse-width is caused to be variable when said desired output voltage is higher than said predetermined value.
3. An electric power converting system according to Claim 2, in which said phase angle controlling means is so arranged that when said desired output voltage is lower than said predetermined value, said phase angle is caused to be variable in accordance with said desired output voltage, while when said desired output voltage is higher than said predetermined value, said phase angle is maintained at its minimum value if said phase angle is represented by a control lag angle.
4. An electric power converting system according to Claim 2, in which said pulse-width controlling means



is so arranged that when said desired output voltage is lower than said predetermined value, said pulse-width is maintained at its minimum value, while when said desired output voltage is higher than said predetermined value, said pulse-width is caused to be variable in accordance with said desired output voltage.

5. An electric power converting system according to Claim 1, in which a filter circuit is connected between said controlled rectifier circuit and said switching means.

6. An electric power converting system according to Claim 1, in which said switching means includes first and second switching means each having current interrupting ability, said first switching means being connected between said controlled rectifier circuit and a load, said second switching means being connected across said load in an inverse-parallel relation.

7. An electric power converting system according to Claim 6, in which said second switching means is maintained non-conductive during a conduction period of said first switching means, while said second switching means is rendered conductive during a non-conduction period of said first switching means.

8. An electric power converting system according to Claim 1, in which a load is connected to an output terminal of said switching means and a half-wave rectifier element is connected across said load in an inverse-parallel relation.



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9. An electric power converting system according to Claim 1, in which said controlled rectifier circuit comprises a full-wave rectifier bridge circuit.

10. An electric power converting system according
5 to Claim 1, in which said desired output voltage is an output voltage command for said electric power converting system.

11. An electric power converting system substantially as
hereinbefore described with reference to, and as illustrated in,
10 Figures 4 to 7; or Figures 8 and 9, or Figures 10 and 11; or Figures
12 and 13 or Figures 14 of the accompanying drawings.
