

"AN ELECTRIC SYSTEM INCLUDING APPARATUS FOR COMPENSATING
REACTIVE POWER BY CURRENT-SOURCE TYPE CONVERTER"

The present invention generally relates to an
5 electric system including an apparatus for compensating an
instantaneous reactive power in a three-phase power supply
source by means of a circuit including a current-source type
converter connected in parallel with the three-phase load
without exerting influence to the output voltage of the
10 converter circuit.

A local electric system is extensively utilized in
which a converter load circuit including a current-source
type converter and a general purpose load circuit including
conventional three-phase loads are connected in parallel
15 with a three-phase power supply source. The converter load
circuit mentioned above includes DC loads connected thereto
through the current-source type converter or AC loads such
as AC motors connected by way of an inverter circuit. In
such electric systems, many of the general purpose load
20 circuits include various inductive loads which provide a
cause for lowering the power factor, giving rise to
generation of a

1 corresponding reactive power which necessary imposes a
burden on the three-phase power supply source. Under the
circumstances, it would be very desirable if the reactive
power could be compensated by the converter load circuit,
5 since the burden imposed on the three-phase load due to
the reactive power then could be mitigated, making it
possible to reduce the capacity of the power supply
equipment for a given effective power supply. In order
to allow the reactive power to be compensated by means of
10 the current-source type converter, it will be effective
to compensate the reactive current corresponding to the
reactive power through the current control by the
converter circuit. To this end, it is necessary to
detect the instantaneous reactive current in the general
15 purpose load circuit and compensate the instantaneous
reactive current by means of the converter circuit.

As the instantaneous reactive current detecting
apparatus known heretofore, there can be mentioned a
system disclosed in an article entitled "General Analysis
20 of Instantaneous Reactive Power and Application"
contained in "Periodical of the Institute of Electrical
Engineers of Japan", Vol. 103, No. 7, p.p. 483-490. This
known detecting apparatus is of a much complicated
circuit configuration including a three-phase/two-phase
25 conversion circuit. Certainly, this known detecting
apparatus is advantageous in that the instantaneous
reactive current can be detected even when the source
voltage suffers distortion in the wave form. In general,

- 1 however, the waveform of the source voltage is rarely susceptible to distortion, and any significant error would not be involved even on the assumption that the source voltage is of a three-phase sinusoidal wave form.
- 5 Accordingly, there exists a demand for the instantaneous reactive current detecting apparatus of much simplified circuit arrangement.

As another means for detecting and determining the instantaneous reactive power, there is known a method

10 according to which each phase current of the power supply source is multiplied with the value of the associated phase voltage shifted by 90° , wherein the products obtained for three phases, respectively, are added together. Reference may be made to Japanese Patent

15 Application Laid-Open No. 125035/1980 (JP-A-55-125035). However, no disclosure is contained in the above publication concerning the detection of the instantaneous reactive current.

As the reactive power compensating device,

20 capacitors have heretofore been employed in many applications. In recent years, there arises a tendency to use active filters.

With the capacitor, only the reactive power due to lag can be compensated, and the reactive current which

25 can be supplied is restricted only to the current of sinusoidal wave. On the other hand, with the active filter system in which GTO and/or transistors are employed, the reactive power due to the leading current can be

1 compensated and the reactive current of the waveform
other than the sinusoidal wave can also be supplied.

If the reactive current having the waveform
other than the sinusoidal wave and containing harmonic
5 components could be compensated, the harmonic current
components of the power supply source could also be
decreased, whereby the source waveform will be further
improved when compared with the case where the capacitor
is used as the reactive power compensating device. To
10 this end, the harmonic components of the reactive current
must be detected. Detection of the reactive current
without time delay has, however, encountered difficulty
with the hitherto known instantaneous reactive current
detecting apparatus because of much complicated circuit
15 configuration including a three-phase/two-phase conver-
sion circuit and the like.

As another instantaneous reactive power
compensating apparatus known heretofore, there can be
mentioned a reactive power control in which a voltage-
20 source type converter is employed, as disclosed in an
article entitled "Operation Analysis and Designing of
Instantaneous Reactive Power Compensating Apparatus Using
Voltage-Source Type PWM Converter" contained in "Periodi-
cal of the Institute of Electrical Engineers of Japan",
25 Vol. B106, No. 4, p.p. 323-330. However, neither teach-
ings nor suggestion has ever been made as to the use of
the current-source type converter and the control of the
output current thereof for the purpose of compensating the

instantaneous reactive power up to the possible maximum capacity of the current converter.

It is an object of the present invention to provide electric system including an apparatus for
5 compensating a reactive power supplied to a general purpose
load circuit which includes conventional three-phase loads
and is connected in parallel to a three-phase power supply
source together with a converter load circuit including a
current-source type converter which cooperates with the
10 general purpose load circuit to constitute the electric
system, wherein the compensation of the reactive power is
accomplished by detecting the instantaneous reactive
current and controlling the switching elements of the
current-source type converter on the basis of the detected
15 instantaneous reactive current.

According to the present invention there is provided an electric system in which a converter load circuit including a current-source type three-phase converter and a load circuit including a three-phase load
20 are connected in parallel to a three-phase power supply source, said system further including an apparatus for compensating a reactive power supplied to said load circuit by means of said converter, said apparatus comprising:
first means for determining a first value to be
25 assumed by a control factor selected in conjunction with

output current control of said converter so that said converter produces a desired output current;

5 second means for generating a signal related to the instantaneous reactive power supplied to said ~~general~~ purpose load circuit;

third means for determining a second value to be assumed by said control factor for compensating said instantaneous reactive power on the basis of said signal
10 related to said instantaneous reactive power; and

fourth means for controlling switching elements of said current-source type converter on the basis of said first and second values.

The present invention will now be described in
15 greater detail by way of example with reference to the accompanying drawings, wherein:

Fig. 1 is a view showing in a form of block diagram a circuit arrangement of the instantaneous reactive current detecting apparatus not forming part of the present
20 invention;

Fig. 2 is a view showing in a form of block diagram an electric system including apparatus for compensating a reactive power in a three-phase load circuit by means of a current-source type converter according to an
25 embodiment of the present invention;

Fig. 3 is a view showing a load circuit including a current-source type converter connected to a three-phase

power supply source;

Figs. 4A and 4B are views for illustrating
operation of switching elements constituting major parts of
the current-source type converter shown in Fig. 3;

1 Fig. 5 is a view showing a circuit arrangement
of the instantaneous reactive current detecting apparatus
shown schematically in Fig. 2; and

Fig. 6 is a view for illustrating in a flow
5 chart operation of an arithmetic unit shown in Fig. 2.

Now, the instantaneous reactive current detect-
ing apparatus for a three-phase load ~~according to an~~
~~exemplary embodiment of the present invention~~ will be
10 described. In this conjunction, it is assumed that
individual phase currents in the three-phase load are
balanced with one another and no zero-phase-sequence
current flows. In view of the fact that such situation
is prevailing ordinarily in the conventional three-phase
15 load, the above assumption will involve no problems as to
the validity of the present invention.

Referring to Fig. 1, three phase voltages are
represented by e_u , e_v and e_w , respectively, the effective
value of line voltage is represented by E_a , and the
20 electrical angle of u-phase is represented by which
is given by $2 \cdot \pi \cdot f \cdot t$ (where f represents a source
frequency). Then, the following relations apply valid
among the three phase voltages e_u , e_v and e_w .

$$\left. \begin{aligned} e_u &= \sqrt{2/3} \cdot E_a \cdot \sin \theta \\ e_v &= \sqrt{2/3} \cdot E_a \cdot \sin(\theta - 2/3 \cdot \pi) \\ e_w &= \sqrt{2/3} \cdot E_a \cdot \sin(\theta - 4/3 \cdot \pi) \end{aligned} \right\} \dots\dots (1)$$

- 1 Under these conditions, relation given by the following expression (2) applies valid among the three phase currents i_u , i_v and i_w on the assumption that the zero-phase-sequence current is zero.

$$i_u + i_v + i_w = 0 \quad \dots\dots\dots (2)$$

- 5 When the effective value of the phase currents i_u , i_v and i_w are represented by I with the phase difference relative to the respective phase voltages being represented by α , the following relations apply valid.

$$\left. \begin{aligned} i_u &= \sqrt{2} \cdot I \cdot \sin(\theta + \alpha) \\ i_v &= \sqrt{2} \cdot I \cdot \sin(\theta + \alpha - 2/3 \cdot \pi) \\ i_w &= -(i_u + i_v) \\ &= \sqrt{2} \cdot I \cdot \sin(\theta + \alpha - 4/3 \cdot \pi) \end{aligned} \right\} \dots\dots (3)$$

- 10 More specifically, the phase currents i_u , i_v and i_w are given by the following expressions.

$$\left. \begin{aligned} i_u &= \sqrt{2} \cdot I \cdot \cos\alpha \cdot \sin\theta + \sqrt{2} \cdot I \cdot \sin\alpha \cdot \cos\theta \\ i_v &= \sqrt{2} \cdot I \cdot \cos\alpha \cdot \sin(\theta - 2/3 \cdot \pi) \\ &\quad + \sqrt{2} \cdot I \cdot \sin\alpha \cdot \cos(\theta - 2/3 \cdot \pi) \\ i_w &= \sqrt{2} \cdot I \cdot \cos\alpha \cdot \sin(\theta - 4/3 \cdot \pi) \\ &\quad + \sqrt{2} \cdot I \cdot \sin\alpha \cdot \cos(\theta - 4/3 \cdot \pi) \end{aligned} \right\} \dots (4)$$

From the expressions (1) and (4), electric power P can be determined as follows:

$$\begin{aligned}
 P &= e_u \cdot i_u + e_v \cdot i_v + e_w \cdot i_w \\
 &= 2/\sqrt{3} \cdot E_a \cdot I [\cos \alpha \{ \sin^2 \theta + \sin^2 (\theta - 2/3 \cdot \pi) \\
 &\quad + \sin^2 (\theta - 4/3 \cdot \pi) \} + \sin \alpha \{ \sin \theta \cdot \cos \theta \\
 &\quad + \sin (\theta - 2/3 \cdot \pi) \cos (\theta - 2/3 \cdot \pi) \\
 &\quad + \sin (\theta - 4/3 \cdot \pi) \cdot \cos (\theta - 4/3 \cdot \pi) \}] \\
 &= \sqrt{3} \cdot E_a \cdot I \cdot \cos \alpha + 0 \quad \dots\dots\dots (5)
 \end{aligned}$$

1 As will be seen from the above expressions,
phase current components i_{up} , i_{vp} and i_{wp} given by the
first terms of the expressions (4), respectively, are
active components contributing to generation of the
5 electric power, while the phase current components i_{uq} ,
 i_{vq} and i_{wq} given by the second terms of the expressions
(4) are out of phase relative to the respective phase
voltages by 90° and thus represent the reactive current
components, respectively.

10 In the case of the single-phase system, the
reactive power becomes zero after integration over one
period. Thus, when the electric power undergoes change
within a time span shorter than one period, the concept
"reactive power" can not have positive or explicit mean-
15 ing. In contrast, in the case of the three-phase power
supply system, there exist the reactive currents in terms
of the instantaneous values.

By connecting to the power supply source a
circuit for detecting and absorbing the reactive
20 currents, only the instantaneous effective phase currents
 i_{up} , i_{vp} and i_{wp} can flow to the power supply source.

The phase currents flowing to the power supply source are in phase with the respective source voltages. Accordingly, the power supply source may be only of a capacity that is enough to be capable of supplying the current corresponding to the effective power.

The principle of the present invention thus resides in detection of the instantaneous reactive currents given by the second terms of the expressions (4). To this end, it is necessary to determine the common component $\sqrt{2}.I.\sin\alpha$, which can be accomplished by determining the reactive power Q . In this connection, it is noted that the following expression holds true.

$$\begin{aligned}
 Q/(\sqrt{2/3}.E_s) &= i_u \cos\theta + i_v \cos(\theta/3.\pi) + i_w \cos(\theta/3.\pi) \\
 &= \sqrt{2}.I[\cos\alpha\{\sin\theta.\cos\theta + \sin(\theta-2/3.\pi).\cos(\theta-2/3.\pi) \\
 &\quad + \sin(\theta-4/3.\pi).\cos(\theta-4/3.\pi)\} \\
 &\quad + \{\sin\alpha(\cos^2\theta + \cos^2(-\theta/3.\pi) + \cos^2(\theta-4/3.\pi))\}] \\
 &= 0 + 3\sqrt{2}/2.I.\sin\alpha \dots\dots\dots (6)
 \end{aligned}$$

In other words, $Q/(\sqrt{2/3}.E_s)$ is first determined and multiplied by 2/3 thereby obtaining $\sqrt{2}.I.\sin\alpha$, which is multiplied by $\cos\theta$, $\cos(\theta-2/3.\pi)$, and $\cos(\theta-4/3.\pi)$, respectively, thereby determining the three-phase instantaneous reactive currents i_{uq} , i_{vq} and i_{wq} , respectively.

Now referring to Fig. 1, a reference character L represents a three-phase load which demands the three-phase currents containing instantaneous reactive current

1 components. This load is supplied with three phase currents i_u , i_v and i_w , of which the currents i_u and i_v are detected by means of current transformers CT_u and CT_v , respectively. Reference character SP designates a
5 synchronizing pulse generator which produces a pulse on the basis of the $u - v$ interphase voltage at every zero crossing point of the u -phase voltage, the pulse signal thus produced being then applied to a sinusoidal wave generator SG, which in turn produces three phase sinusoidal waves represented by $\cos\theta$, $\cos(\theta - 2/3 \cdot \pi)$ and
10 $\cos(\theta - 4/3 \cdot \pi)$, respectively, with θ being set to zero at the time point at which the zero-cross pulse makes appearance. As will be seen by considering comparatively the expression (1), these sinusoidal waves are out of phase
15 with the source voltage by a phase difference of 90° .

An adder A_1 serves for an additional function to determine the phase current i_w in accordance with $i_w = -(i_u + i_v)$. By multiplying the instantaneous values of the three phase currents determined in this manner with
20 the instantaneous values of the corresponding phases of the three phase sinusoidal wave forms appearing at the same time point as the instantaneous three phase current values by means of multipliers M_1 , M_2 and M_3 , respectively, and subsequently adding together the products thus
25 obtained by means of an adder A_2 , the value given by the term $3\sqrt{2}/2 \cdot I \cdot \sin\alpha$ in the expression (6) can be determined. Then, by multiplying the value thus determined with a factor of $2/3$, there can be obtained a value of $\sqrt{2} \cdot I \cdot \sin\alpha$,

1 which is then multiplied with $\cos\theta$ and $\cos(\theta - 2/3\cdot\pi)$ by
multipliers M_4 and M_5 , respectively, to thereby determine
the two phase instantaneous reactive currents i_{uq} and i_{vq}
by means of an adder A_3 . By inverting the polarity of
5 the sum output of the adder A_3 , the instantaneous
reactive current i_{wq} of the other phase can be deter-
mined.

When the current transformers CT_u and CT_v are
each of the type in which an A/D converter is incorpo-
10 rated, the circuit portion indicated as enclosed by a
broken line block in Fig. 1 can be implemented in the
form of digital circuit DS which may be preferably
constituted by a microcomputer.

~~In the case of the illustrative embodiment~~
15 ~~shown in Fig. 1~~ the instantaneous reactive current i_w of
one phase is arithmetically determined from the instan-
taneous reactive currents i_u and i_v of the other two
phases. However, it goes without saying that the
reactive current i_w may be determined by another current
20 transformer provided in addition to the transformers CT_u
and CT_v . It should further be added that the instantane-
ous reactive current i_{wq} may also be determined through
multiplication of $\cos(\theta - 4/3\cdot\pi)$, since $\sqrt{2}\cdot I\cdot\sin\alpha$ has
been already known.

25 Referring to Fig. 2 of an electric system including
Next, description will be made ~~on~~ an apparatus
for compensating the reactive power of a three-phase load
by a converter load circuit including a three-phase

1 current-source type converter connected in parallel with
the three-phase load, wherein the instantaneous reactive
current detector for a three-phase load described above
by reference to Fig. 1 is made use of.

5 Fig. 3 is a circuit diagram showing an arrange-
ment of a three-phase full-wave current converter of
transistorized type. Reference symbols $U_1, U_2; V_1, V_2;$
 W_1 and W_2 designate switching elements, respectively,
each of which may be constituted, for example, by a
10 reverse blocking transistor module composed of a
transistor and a diode connected in series to each other.
In the figure, only transistors are shown for simplifica-
tion of the illustration and those transistors attached
with suffix "1" are located on the positive polarity side
15 while those attached with suffix "2" are disposed on the
negative polarity side. A DC current I flows through a
DC output circuit of the converter to which a load L_d is
connected by way of a DC reactor L . The load L_d may be a
simple DC load such as a DC motor or an AC load such as a
20 three-phase induction motor connected by way of an
inverter.

A power supply source generates three phase
sinusoidal wave voltages e_u, e_v and e_w which are balanced
with one another. When the phase angle of the u-phase
25 voltage is represented by θ , these phase voltages e_u, e_v
and e_w are given by the aforementioned expression (1).

Now, the control of the switching elements
which constitute major parts of the current-source type

1 converter will be elucidated by referring to Figs. 4A and
4B. Fig. 4A illustrates individually the phase voltage
waveforms e_u , e_v and e_w of the three-phase voltage supply
source. For convenience's sake of description, an
5 interval T_1 (corresponding to an electrical angle range
of $0^\circ - 60^\circ$) will be considered in which only the v-phase
voltage is negative with the u- and w-phase voltages
being positive. During this interval T_1 , the switching
element V_2 is conducting. On the other hand, conduction
10 of the switching elements U_1 , V_1 and W_1 are so controlled
that when the abovementioned interval T_1 is divided into
a plurality of sub-intervals ΔT , the conduction time of
the switching elements in each sub-interval ΔT is deter-
mined by the instantaneous values of the respective phase
15 voltages making appearance during the sub-interval ΔT .
More specifically, it is assumed that the zero-cross
point of the phase angle θ is such as illustrated in Fig.
4A. Then, from the expression (1), the instantaneous
values of the phase voltages in the sub-interval ΔT can
20 be expressed as follows:

$$e_u = K \cdot \sin \theta_1$$

$$e_v = K \cdot \sin(\theta_1 - \frac{2}{3}\pi)$$

$$e_w = K \cdot \sin(\theta_1 - \frac{4}{3}\pi)$$

where K represents a constant determined by the effective
value of the interphase voltage. Accordingly, the time

- 1 intervals t_u , t_v and t_w during which the switching elements U_1 , V_1 and W_1 become conductive as illustrated in Fig. 4B are, respectively, given by

$$t_u = K' \cdot \sin \theta_1$$

$$t_v = K' \cdot \sin(\theta_1 - \frac{2}{3}\pi)$$

$$t_w = K' \cdot \sin(\theta_1 - \frac{4}{3}\pi)$$

- where K' represents a coefficient which can be selectively
5 ly determined in consideration of the desired value of the output current of the current-source type converter.

- As will be seen from the foregoing, during the periods t_u and t_w in the sub-interval ΔT , currents of positive polarity flow from the power supply source
10 toward the load in the phases u and w, while a corresponding current of the negative polarity will flow toward the power supply source from the load in the phase v. During the period t_v , only the circulating current can flow through a closed loop formed by the load L_d and
15 the switching elements V_1 and V_2 under the effect of energy stored in a reactance L , and no current flows from the power supply source to the load L_d . In other words, when the only current flow between the power supply source and the load is considered, it is safe to say that
20 currents of positive polarity flow from the power supply source toward the load during the periods t_u and t_w in the phases u and w, respectively, while the current flow

1 with negative polarity takes place in the phase v during
the same periods.

Here, definition will be made concerning the terminology. The ratio to the sub-interval ΔT of the
5 period during which the current of positive polarity flows from the power supply source toward the load in each phase will be referred to as the positive duty factor, while the ratio to the sub-interval ΔT of
period during which the negative current flow takes place
10 is referred to as the negative duty factor. The duty factors γ_u , γ_v and γ_w in the phases u, v and w (which may be considered to be equivalent to the duty factors of the switching elements U_1 , V_1 and W_1 in the case of the illustrated embodiment) can be expressed as follows:

$$\left. \begin{aligned} \gamma_u &= \frac{K'}{\Delta T} \cdot \sin \theta_1 \\ \gamma_v &= -(\gamma_u + \gamma_w) = -\frac{K'}{\Delta T} \cdot \left\{ \sin \theta_1 + \sin \left(\theta_1 - \frac{4}{3}\pi \right) \right\} \\ &= \frac{K'}{\Delta T} \cdot \sin \left(\theta_1 - \frac{2}{3}\pi \right) \\ \gamma_w &= \frac{K'}{\Delta T} \cdot \sin \left(\theta_1 - \frac{4}{3}\pi \right) \end{aligned} \right\} \dots (7)$$

15 and

$$\gamma_u + \gamma_v + \gamma_w = 0 \dots \dots \dots (8)$$

The foregoing elucidation is based on the assumption that the conduction time of each switching element in the sub-interval ΔT is proportional to the

1 instantaneous value of the associated phase voltage in
the sub-interval ΔT . However, in practice, the conduc-
tion time interval of each switching element can be so
determined as to be proportional to the instantaneous
5 value of the corresponding phase voltage at the time
point corresponding to the phase shift α relative to θ_1
by ΔT , i.e. proportional to the instantaneous value of
the corresponding phase voltage at the phase angle of
($\theta + \alpha$) as illustrated in Fig. 4A in the case of the
10 illustrated embodiment. Similar relations apply valid to
the intervals $T_2, T_3, \dots$ and so forth following the
interval T_1 . When $K'/\Delta T$ occurring in the expressions (7)
is represented by γ , the duty factors of the switching
elements can be generally expressed as follows:

$$\left. \begin{aligned} \gamma_u &= \gamma \cdot \sin(\theta + \alpha) \\ \gamma_v &= \gamma \cdot \sin(\theta + \alpha - \frac{2}{3}\pi) \\ \gamma_w &= \gamma \cdot \sin(\theta + \alpha - \frac{4}{3}\pi) \end{aligned} \right\} \dots\dots\dots (9)$$

15 It will be noted that the value of γ can not
exceed "1" as is apparent from the aforementioned expres-
sion (7) which defines the duty factor. Further, it
should be mentioned that the value resulting from
multiplication of the duty factor given by the above
20 expression (9) with the amplitude I of the corresponding
phase current at the time when $\gamma = 1$ indicates the source
current in the corresponding phase. Accordingly, when
the effective value of the interphase voltage is

1 represented by E_a , the electric power P at that time can
be given by the following expression (10) independently
of the electrical angle in the u-phase voltage.

$$P = \sqrt{\frac{3}{2}} \cdot E_a \cdot I \cdot \gamma \cdot \cos \alpha \quad \dots\dots\dots (10)$$

Since this AC power must coincide with the DC
5 power, the DC output voltage E_d can be determined in
accordance with

$$E_d = \sqrt{\frac{3}{2}} \cdot E_a \cdot \gamma \cdot \cos \alpha \quad \dots\dots\dots (11)$$

On the other hand, the reactive power q can be
determined in accordance with

$$q = \sqrt{\frac{3}{2}} \cdot E_a \cdot I \cdot \gamma \cdot \sin \alpha \quad \dots\dots\dots (12)$$

The above expressions show that the output
10 voltage can be controlled by controlling the duty factor
 γ with the phase angle α being set equal to 0 (zero),
while the reactive power can be controlled by controlling
the factor γ with α being set to $\pi/2$.

When the duty factor for controlling the DC
15 output voltage E_d is represented by γ_d with the factor
for controlling the reactive power being represented by
 γ_q , the duty factor γ and the phase angle α at which both
of the DC output voltage and the reactive power take

- 1 desired values are given by the following expressions
(13) and (14), respectively.

$$\gamma = \sqrt{\gamma_d^2 + \gamma_q^2} \dots\dots\dots (13)$$

$$\alpha = \tan^{-1} \frac{\gamma_q}{\gamma_d} \dots\dots\dots (14)$$

It should be however be understood that α is not in the
range of $\pi/2$ to $-\pi/2$ as adopted generally but assumes a
5 value in the range of π to $-\pi$ in dependence on the
polarity of the duty factors γ_q and γ_d .

In the case of the current-source type
converter, the duty factor γ_d for controlling the output
voltage can be arithmetically derived from the difference
10 between the current command value and the output current
value.

The duty factor γ_q for controlling the reactive
power can be determined as the value of γ at which the
reactive power Q to be compensated for is equal to the
15 value q determined in accordance with the expression (12)
on the assumption that $\sin\alpha = 1$. That is,

$$\gamma = \frac{Q}{\sqrt{3/2} \cdot E_a \cdot I} \dots\dots\dots (15)$$

An apparatus for detecting the reactive power
in a three-phase load circuit is shown in Fig. 5. In the
figure, reference character q_d denotes a reactive current
20 detecting circuit which is substantially same as the one
shown in Fig. 1 except for insignificant difference in

1 the output circuit arrangement. Accordingly, it will be appreciated from the description made hereinbefore in conjunction with Fig. 1 that the output value appearing at a circuit OUT in Fig. 5 can be expressed as follows:

$$\frac{Q}{\sqrt{3/2} \cdot E_a}$$

5 Thus, by dividing the above output value at the circuit point OUT by the output current I of the converter by means of a divider D, there can be obtained the duty factor γ_q defined by the aforementioned expression (15).

On the basis of the principle taught above, it is possible to implement an apparatus for compensating the reactive power of a three-phase load by means of a converter circuit including a current-source type three-phase converter connected in parallel to the load. An exemplary embodiment of such apparatus is shown in Fig. 2. In the figure, reference character I_n designates a converter main circuit composed of six transistor switching elements $U_1, \dots, W_2$. A current control circuit I_c serves to compare a DC current I detected by a current transformer CT_d with a current command I_s to arithmetically determine the duty factor γ_d which is then supplied to an arithmetic unit C. The duty factor γ_q is detected by a reactive power detector q_d shown in Fig. 5 and applied to the arithmetic unit C, which in turn determines the duty factor γ and the phase angle α from the duty factors γ_d and γ_q in accordance with the

1 equations (13) and (14), respectively.

In Fig. 2, a symbol P_C designates a circuit for generating a pulse signal to control the converter main circuit, which circuit P_C is constituted by a micro-
5 computer and has the inputs supplied with the factor γ , phase angle α and the synchronizing pulse signal produced by the synchronizing pulse generator SP.

The electrical angle θ of the u-phase voltage is determined with reference to the synchronizing pulse
10 signal and added with α to obtain " $\theta + \alpha$ ", being followed by determination of the terms " $\sin(\theta + \alpha)$ " and " $\sin(\theta + \alpha - 2/3 \cdot \pi)$ " to determine subsequently the duty factors defined by the expressions (9) through multiplication with γ .

15 By multiplying the duty factor thus determined with a carrier period (corresponding to the sub-interval ΔT shown in Fig. 4A), a corresponding pulse duration can be determined. When the pulse durations are determined for two phases, the pulse duration for the remaining
20 phase can be readily derived from the two pulse durations in accordance with the aforementioned expression (8). For the conducting period in which the input current is zero, the switching transistor elements belonging to the same phase and disposed on the negative and positive
25 sides, respectively, may be fired with the number of chopping times being decreased as small as possible.

The functions mentioned above can be easily accomplished with the aid of a one-chip microcomputer.

1 As mentioned hereinbefore, the factor γ is not
allowed to exceed "1" (one). Accordingly, when the value
of γ calculated in accordance with the expression (6)
should go beyond "1", it is necessary to limit the value
5 of γ to "1". The arithmetic operation performed by the
arithmetic unit C in this conjunction is illustrated in a
flow chart in Fig. 6. More specifically, when the value
of γ determined from γ_d and γ_q in accordance with the
expression (13) exceeds "1", either of the duty factor
10 components γ_d or γ_q must be reduced. In this connection,
it is noted that when the duty factor γ_d is reduced,
there can no more be obtained the requisite DC output
voltage, resulting in that the DC current I can not
follow the current command I_s . Under the circumstances,
15 the reactive power component γ_q is reduced to prevent the
value γ from going beyond "1". In other word, γ is
limited to "1" by setting the value of γ_q equal to
 $\sqrt{1 - \gamma_d^2}$ while the corresponding value of α is determined
in accordance with

$$\alpha = \tan^{-1} \frac{\sqrt{1 - \gamma_d^2}}{\gamma_d} \cdot \frac{\gamma_q}{|\gamma_q|} \dots\dots\dots (16)$$

20 In the above expression, multiplication with $(\gamma_q/|\gamma_q|)$ is
for the purpose of determining accurately the quadrant of
 α .

The present invention can be advantageously
adopted in such application where the load L_d is
25 constituted by a lift car system in a building and the

instantaneous reactive power of the other loads L_c present within that building are to be compensated, whereby the power supply demand for all the loads in the building are to be managed satisfactorily in a coordinated manner.

CLAIMS:

1. An electric system in which a converter load circuit including a current-source type three-phase converter and a load circuit including a three-phase load are connected in parallel to a three-phase power supply source, said system further including an apparatus for compensating a reactive power supplied to said load circuit by means of said converter, said apparatus comprising:
- first means for determining a first value to be assumed by a control factor selected in conjunction with output current control of said converter so that said converter produces a desired output current;
- second means for generating a signal related to the instantaneous reactive power supplied to said load circuit;
- third means for determining a second value to be assumed by said control factor for compensating said instantaneous reactive power on the basis of said signal related to said instantaneous reactive power; and
- fourth means for controlling switching elements of said current-source type converter on the basis of said first and second values.
2. A system according to claim 1, wherein said control factor is a duty factor indicative of the ratio of time for which the switching element in each phase of said



converter is made conductive.

3. A system according to claim 2, wherein said fourth means includes an arithmetic unit for arithmetically
 5 determining a control value $\gamma = \sqrt{\gamma_d^2 + \gamma_q^2}$ for said duty factor and a control value $\alpha = \tan^{-1}(\gamma_q/\gamma_d)$ for phase angle from said first value γ_d and said second value γ_q of said duty factor, and a control circuit for controlling electric
 10 conduction of the switching elements of said converter on the basis of said control value for said duty factor and said control value for said phase angle.

4. A system according to claim 3, wherein when the arithmetically determined value of said control value
 15 for said duty factor exceeds "1" (unity), said control value is set equal to "1", while the control value α for the phase angle is determined such that

$$\alpha = \tan^{-1}(\sqrt{1 - \gamma_d^2}/\gamma_d) \cdot (\gamma_q/|\gamma_q|).$$

20 5. An electric system constructed and arranged to operate substantially as herein described with reference to and as illustrated in Figs. 2 to 5 of the accompanying drawings.

