DETECTION OF REACTIVE POWER AND CONTROL OF STATIC CAPACITOR FOR REACTIVE POWER COMPENSATION

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ABSTRACT

The TRISTAN AR (accumulation ring) magnet power supply system generates the reactive power more than 4MVar, because of the thyrister rectifier. And the primary voltage decreases by about 6% as the reactive power increases.

In order to suppress the voltage fluctuation, the phase advance capacitors are used.

INTRODUCTION

When the magnet power supply system of the accelerator such as synchrotron is operated pulsatively, the primary voltage decreases due to the reactive power generated mainly from the phase control of SCR. The reactive power increases according to the acceleration to an extent to compensate the primary voltage variation. In such a case the facility for the phase modification must be equipped close to the source, otherwise the user on the same power line may be influenced.

In TRISTAN AR power supply system, the phase advance capacitors were installed to compensate the voltage fluctuation considerably. Their rapid switching can be possible owing to the improvement in the reactive power detection.

REACTIVE POWER AND ITS COMPENSATION

Normally, the power factor of the phase-controlled converter using SCR is given by[1)]

$$P.F. \fallingdotseq \frac{1}{2}[\ \cos(a) + \cos(a+u)\ ] \qquad (1)$$

where
P.F. : power factor
a : firing angle
u : commutation angle.

Eq.(1) shows that the amount of the reactive power is determined by the amount of active power, firing angle a, and commutation angle u.

Assuming that (a) a=10 deg., u=20 deg. and (b) the power utility factor is controlled in the range less than 90%, the following estimations are obtained.

$$Smax = Pdc/\cos(33.5 \text{ deg.})$$
$$Qmax = Smax \sin(33.5 \text{ deg.})$$

where
Pdc : dc power used by the load
Qmax : maximum reactive power
Smax : maximum apparent power.

In the AR magnet power supply system, Pdc =4.8 MW. The rough estimation of the reactive power is

$$Qmax = 3.2 \text{ MVar}.$$

Generally in the power transmission system the receiving end voltage Vr is expressed as follows,

$$Vr \fallingdotseq \frac{1}{2}\{\ Vs + \sqrt{Vs^2 - 4XQr}\ \} \qquad (2)$$

where
Vr :receiving end voltage (phase to phase)
Vs :sending end voltage (phase to phase)
Qr :reactive power
R+jX :impedance of the power transmission system (assuming R<<X).

Eq.(2) shows that the reactive power causes the fluctuation of the primary voltage. The line voltage drop is estimated to be

$$\delta V\ [\%] \simeq Q\ [MVar]$$

substituting

$$X = 9.7\% \quad (\ 10 \text{ MVA base }).$$

Therefore it is necessary to reduce the fluctuation of the voltage by compensating the reactive power.

There are two typical methods to compensate the reactive power. One is (a) to insert the capacitors stepwise, the other is (b) TQC.

In this case the former method is adopted from the following reasons,

(a) comparatively low cost
(b) reactive power changes so slowly that the controller works rapidly enough by improving the transducer to detect the reactive power.

TRANSDUCER OF REACTIVE POWER

The reactive power of one phase is defined as follows.

$$Q = Im\{\ \dot{E}\ \bar{\dot{I}}\ \} \qquad (3)$$

where
$\dot{E}$: voltage phasor
$\dot{I}$: current phasor.

$\bar{\dot{I}}$ expresses the complex conjugate of $\dot{I}$, Im means the imaginary part.

The reactive power which contains the harmonic voltage and current is not defined clearly. In this case the voltage and current are treated as only the fundamental wave.

There are some methods to detect the reactive power.[2)] Making conditions such as (a) simple structure (b) small ripple and (c) small error in the detection method, the following method is adopted.

$$Qm = \frac{1}{\sqrt{3}}\{\ Vcb\ Ia + Vac\ Ib + Vba\ Ic\ \} \qquad (4)$$

where
Vcb,Vac,Vba : phase to phase voltage
Ia ,Ib ,Ic : phase current

The transducer calculates eq.(4) in real time by the analog circuit. The error due to principle of this method is given by eq.(5).

$$q = -6E_2\ I_2\ \sin\phi_{22} \qquad (5)$$

where

q : error

E_2 : negative-phase-sequence voltage

I_2 : negative-phase-sequence current

ϕ_{22} : phase angle between E_2 and I_2

Assuming that the voltage unbalance is 3% and the loads are balanced, the amount of the error is obtained as follows,

$$\left|\frac{q}{Q}\right| = \left|\frac{-6E_2 I_2 \sin\phi_{22}}{3E_1 I_1 \sin\phi_{11} + 3E_2 I_2 \sin\phi_{22}}\right|$$

$$\leq 1.8 \times 10^{-3}$$

where

Q : reactive power

E_1 : positive-phase-sequence voltage

I_1 : positive-phase-sequence current

ϕ_{11} : phase angle between E_1 and I_1.

The error of this method is small enough.

Table 1 shows the specifications of the transducer and Fig. 1 shows the block diagram of the transducer. In order to attain the responce time of 0.1 sec, the third order low pass filters are used. The quality of CT and PT is the first class of JIS.

Input current /	CT output 750A/5A
Input voltage /	PT output 6600V/110V
Range of measurement	-4.5MVar ∿ +4.5MVar
Output	4 ∿ 20mA
Accuracy	±0.5% F.S. (except for the error of CT and PT)
Output ripple	3%p-p F.S. in one phase
Response time	0.1sec

Table 1 Specifications of the transducer

THE SYSTEM OF REACTIVE POWER COMPENSATOR

Fig. 2 shows the primary line of the AR magnet power supply. The phase advance capacitors are composed of two base capacitors and six high-response capacitors. Each has 500 KVA capacity. The base capacitors are always inserted when the accelerator is operated. The high-response capacitors are controlled automatically by detecting the reactive power. Fig. 3 shows the block diagram of the control system and Fig. 4 gives the timing of switching the capacitors. The high-response capacitors are controlled so that each of them has the equal duty. The timing sequence of switching is adjusted to have 1.6 sec lag time, so more than one capacitor can not be switched at the same time.

OPERATION

The whole system comes into operation successfully. In 30 sec acceleration period all capacitors turn on and in 10 sec deceleration period turn off. The line voltage deterioration restores stepwise. Table 2 shows the measured fluctuation of the line voltage.

condition	magnet	voltage fluctuation
full capacitors	6.5 GeV operation	1.6%
	8 GeV operation	3.1%
base capacitors only	6.5 GeV operation	3.1%
	8 GeV operation	4.4%

Table 2 Fluctuation of the line voltage (experimental)

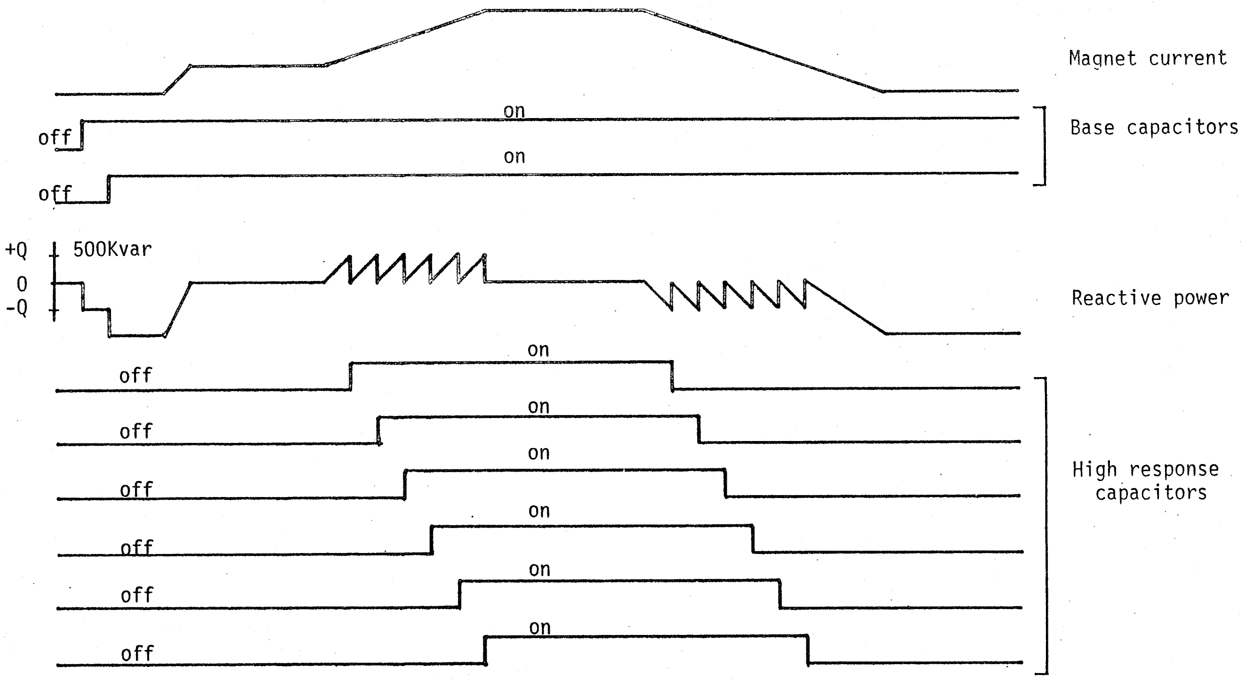
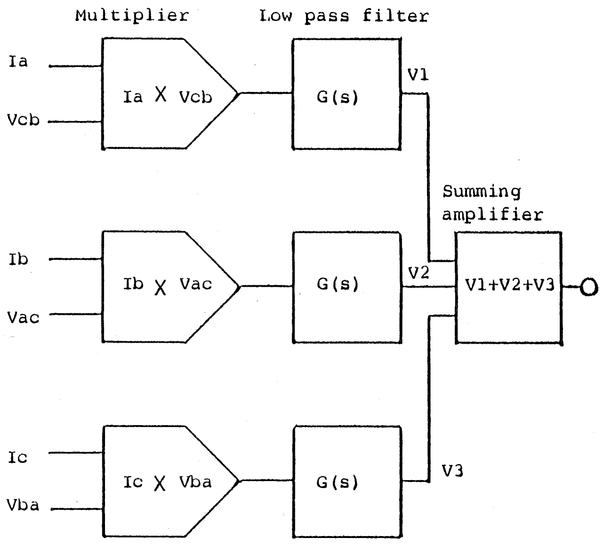


Fig. 4 Switching of the capacitors



$$G(s)=\frac{\omega a\cdot\omega o^{2}}{(s+\omega a)\,(s^{2}+\frac{\omega o}{Q}s+\omega o^{2})}$$

$\omega a=60.6$ $\omega o=58.1$ $Q=1.581$

FIG.1 BLOCK DIAGRAM OF THE TRANSDUCER

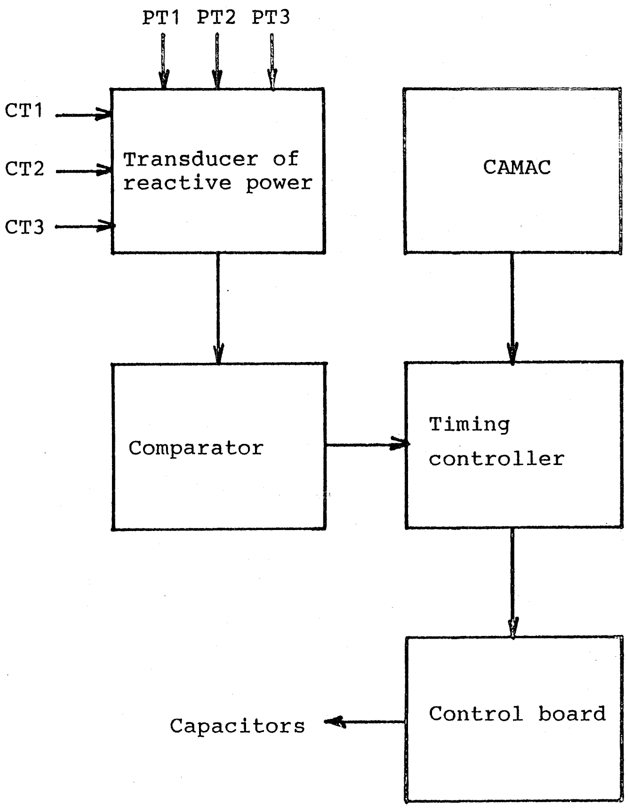


FIG. 3 CONTROL SYSTEM

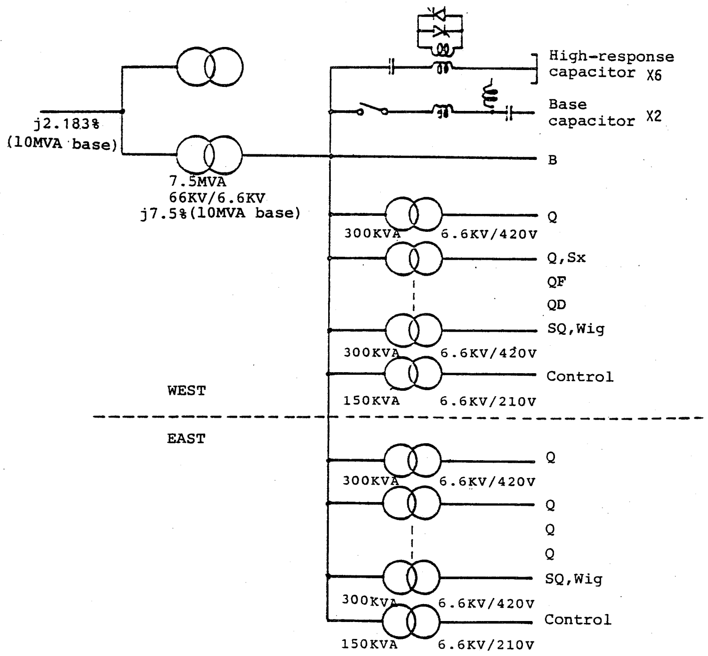


FIG. 2 PLIMARY LINE OF THE AR MAGNET POWER SUPPLY SYSTEM

REFERENCES

1) K.Heumann, Grundlagen der Leistungselektronik, B.G.Teubner, Stuttgart, 1975.
2) JIS C 1263-1979.