Control of Magnetizing Inrush Current in a Transformer by Means of Thyristors

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Synopsis

When a transformer is energized, the inrush of abnormally high magnetizing current may be noted for a short time until normal flux conditions are established. This may cause the failure of a protective relay, so many preventives are usually accepted for the purpose of normal relay performance. The authors, instead, now have tried to control the inrush current itself, by means of the soft-starting method using two reverse parallel thyristors. In this paper, the method to control the inrush current itself, is presented by the soft-starting method using thyristors. The experimental results of this method verifies the good controlability of the transient magnetic flux of a transformer and then the availability of the control of magnetizing inrush current in the cases of a single phase connection and a three phase one.

1. Introduction

When a transformer is energized, the inrush current may be abnormally high for a short time until the normal flux condition is established. This may cause the undesirable situation, such as the

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malfunction of a protective relay. So, various preventive measures are usually adopted for the purpose of normal relay performance, etc. The authors have tried to control the inrush current itself, by the soft-starting method using an inverse parallel thyristor pair, and have obtained good results. In this paper, the control method and its experimental results are described of the transient magnetic flux of a transformer and then the availability of the control of magnetizing inrush current in the cases of a single phase connection and a three phase one.

2. Mechanism

The equation of the flux in a transformer is given as follows[1]:

$$\phi = (\phi_R + \phi_{max}\cos\theta) - R\int_0^t i\,dt - \phi_{max}\cos(\omega t+\theta) \quad , \qquad (1)$$

where

ϕ = instantaneous value of the flux at any instant,

ϕ_P = residual flux at the instant immediately preceding energizing the transformer,

ϕ_{max} = maximum value of steady-state flux,

R = resistance of the circuit through which the magnetizing current flows,

θ = phase angle at which the transformer is energized, measured from the instant when the voltage is zero,

i = instantaneous current,

ωt = angular.

The inrush of the magnetizing current is caused by the flux saturation of the core due to the alternating component $\phi_{max}\cos(\omega t+\theta)$ superposed to the direct component $\phi_R+\phi_{max}\cos\theta$[1]. Therefore, to control the inrush, the alternating component is kept within a small value at switching-on.

The relation between the voltage e and the flux change $\Delta\phi$ is given as well-known in the following form:

$$\Delta\phi = (1/N)\int e\,dt \quad , \qquad (2)$$

where N designates the number of turns, the control of the flux change is achieved by that of the voltage-time integral. If the source voltage is controlled to apply a part of the voltage in each cycle to the transformer, the flux change of eq.(1) is made small not to saturate the core flux of the transformer. Then, the transformer is energized without flowing the inrush current, provided that the voltage-time integral of the core is gradually increased in proportion to the flux change corresponding to $R\int idt$ which moves the flux level, and the full voltage is finally applied to the transformer. This mechanism is realized by the soft-starting method based on the phase retard adjustment of the supply voltage by means of an inverse parallel thyristor pair.

3. Circuit and Experimental Results

3.1 Single phase[2)3)]

The experimental circuit of a single phase is shown in Fig.1, in which by operating the control circuit, the conduction angle of a thyristor pair, that is, the voltage-time integral of the transformer voltage, gradually increases at every one half cycles during the transient period.

Fig.2 shows oscillograms of the magnetizing inrush current;(a) is not controlled and, (b) and (c) are controlled, respectively. The effect of control of the inrush current is found evidently.

Fig.3 shows waveforms

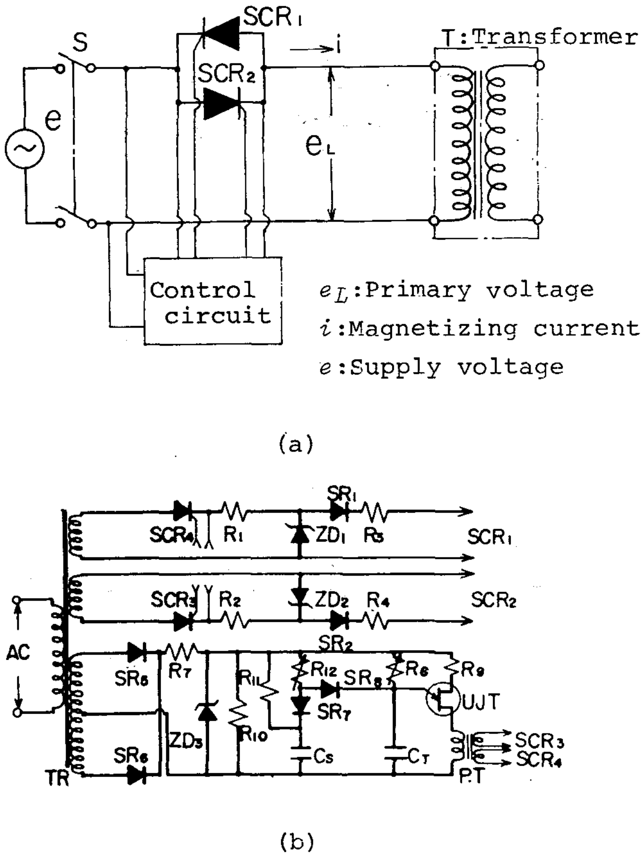
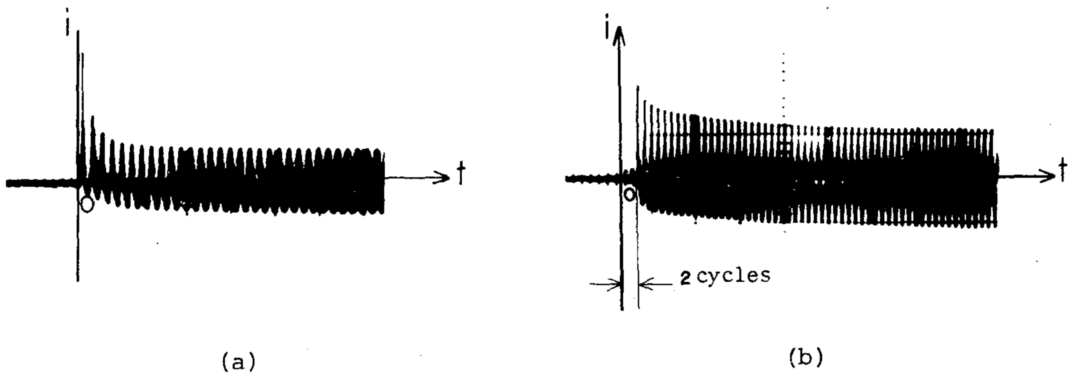


Fig.1. Soft-starting circuit of a single phase transformer by means of an inverse parallel thyristor pair. (a) Main circuit. (b) Auxiliary circuit.



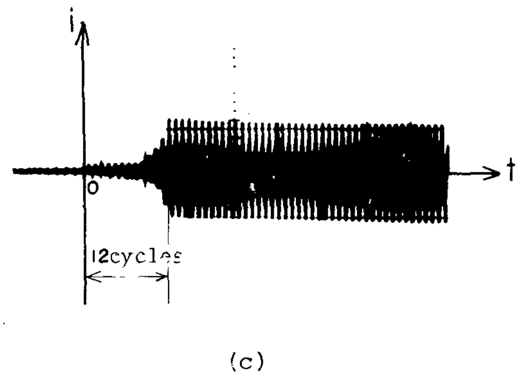


Fig.2. Oscillograms of magnetizing inrush current. (a) The inrush current is not controlled. (b) and (c) The inrush current are controlled,but the controlled periods are different.

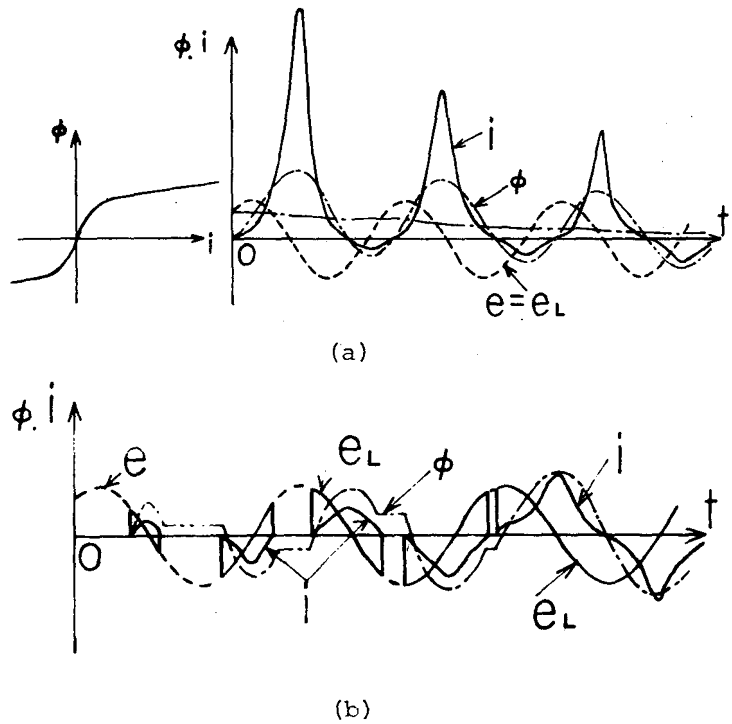
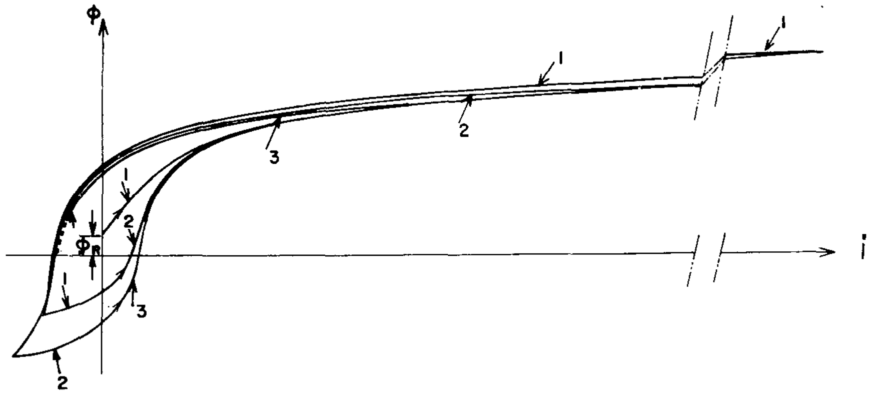
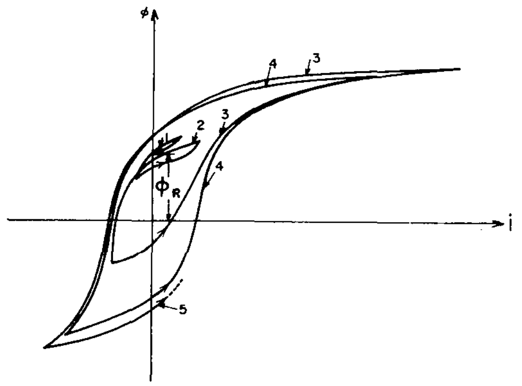


Fig.3. Waveforms of the voltage, current and magnetizing flux. (a) Not controlled. (b) Controlled. ϕ:flux, e:source voltage, e_L:voltage applied to the transformer, i: current.



(a)



(b)

Fig.4. Hysteresis loops in the transient period expressed by flux ϕ and current i. (a) The number in the figure designates a cycle number after the voltage is applied. (b) ϕ_R designates the residual flux.

of the voltage, current and magnetic flux which are not controlled and are controlled, to illustrate the effect of control, where is the magnetization curve of the core in Fig.3(a) assumed. Next, in Fig.4, the transient flux-current hysteresis loops are shown. By comparing Fig.4(a) with Fig.4(b), the mechanism of control of the core flux in a transformer can be understood.

3.2 Three phase[4)]

The soft-starting circuit of a three phase connection of transformers can be constructed of various types. In this paper, the experiments are carried out for tipical circuits. These circuits are shown in Fig.5. Fig.5(a) shows the open-delta control circuit that consists of inverse parallel thyristor pairs and transformers connected in delta shape. Fig.5(b) shows the line control circuit in which inverse parallel thyristor pairs are put into three lines. This circui controls three lines when a switch s is open or controls two lines when

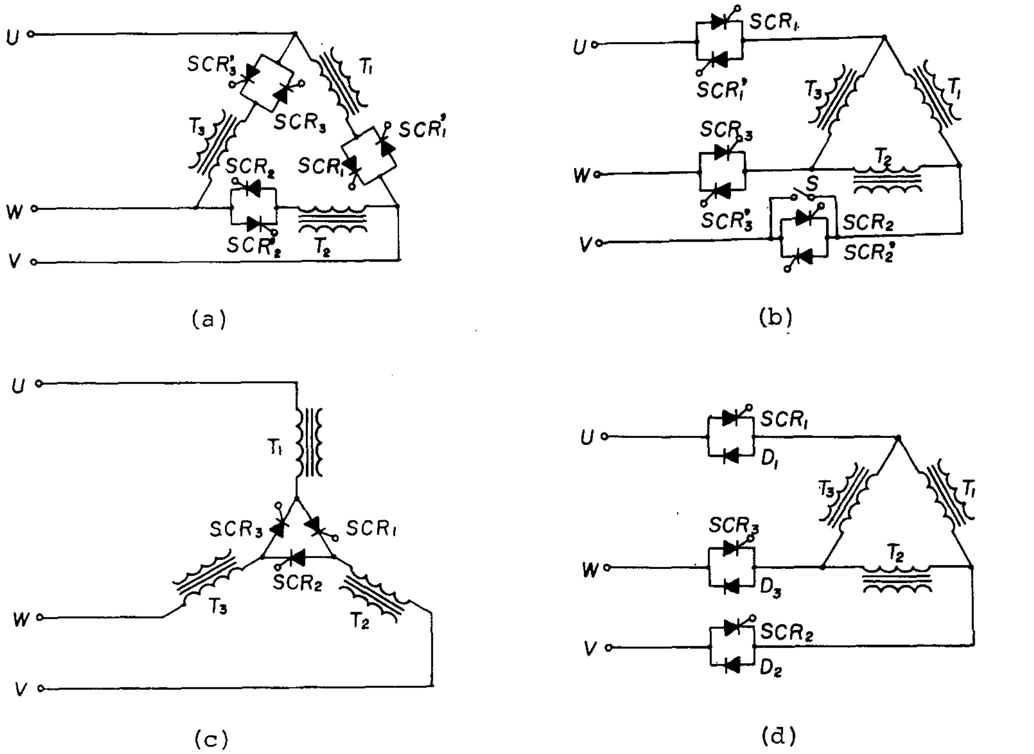


Fig.5. Control circuit of three phase. (a) Open delta control circuit. (b) Line control circuit. (c) Circulative delta control circuit. (d) Hybrid inverse parallel thyristor pair control circuit.

the switch *s* is closed. Fig.5(c) shows the circulative delta control circuit which consists of the three thyristors connected in delta shape. Fig.5(d) shows hybrid inverse parallel thyristor pair control circuit, in which one thyristor of each inverse parallel thyristor pair is replaced with a rectifier. The transformers in Fig.5(a),(b),(d) are connected in delta, and in Fig.5(c) the transformer is connected in star at primary winding, and in delta at secondary winding.

Fig.6 shows the controlled waveforms of current when the three phase load is resistive with the phase control angle as a parameter. The behavior of the soft-starting control applied to each circuit can be understood well from these figures.

The observed inrush current in the three phase connection of transformers is shown in Fig.7. This is the typical inrush current that reaches thirteen times value compared with the steady state value of current at the half cycle after the circuit operation is started.

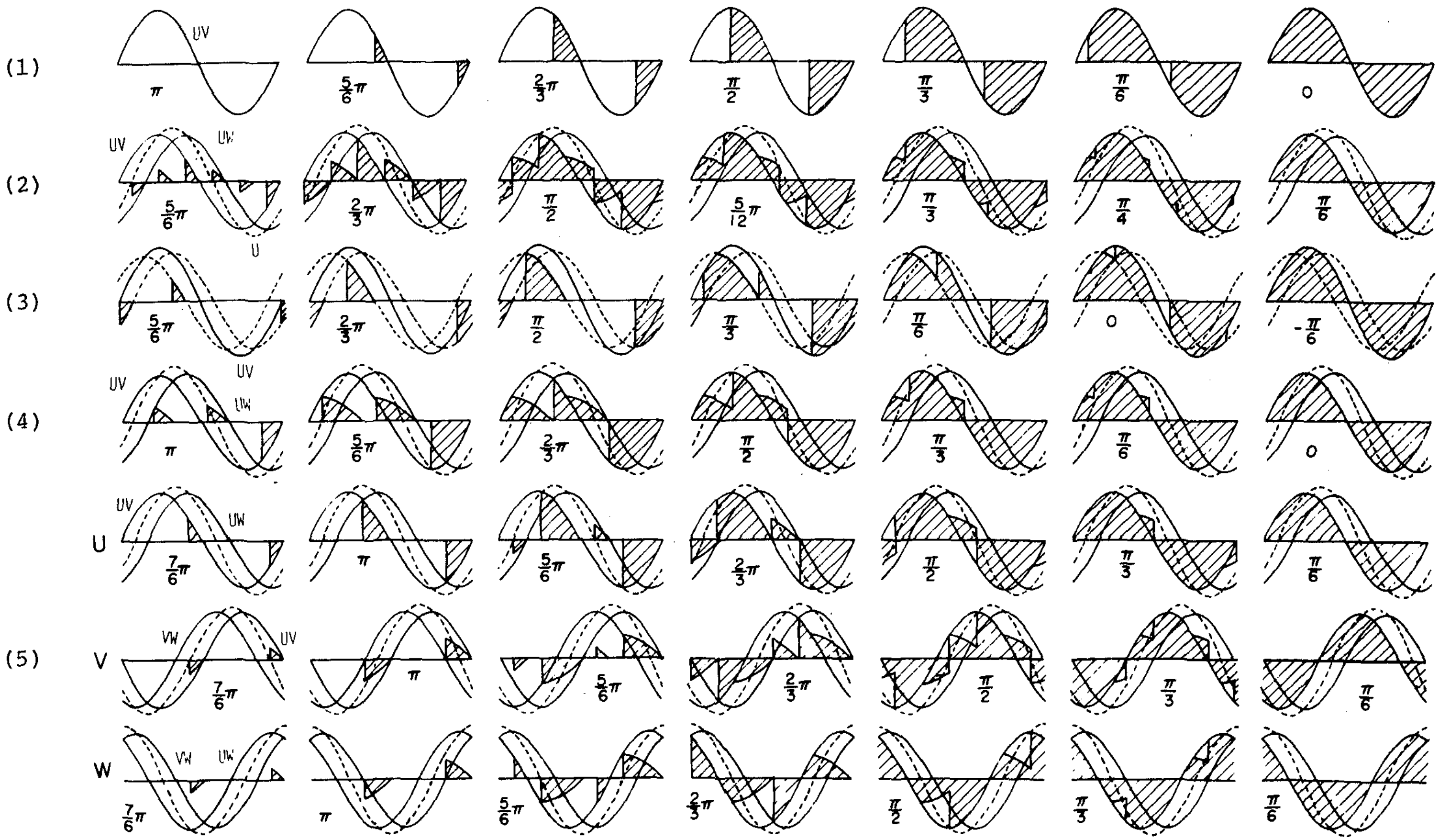


Fig.6. Controlled waveforms of current with the phase retard adjustment as a parameter when the three phase load is resistive. (1) Open delta control. (2) Three lines control of the delta. (3) Circulative delta control. (4) Hybrid inverse parallel thyristor pair control. (5) Two lines control of the delta. (6) Three lines control of the star. (7) Hybrid inverse parallel thyristor pair control of star. (8) Two lines control of the star.

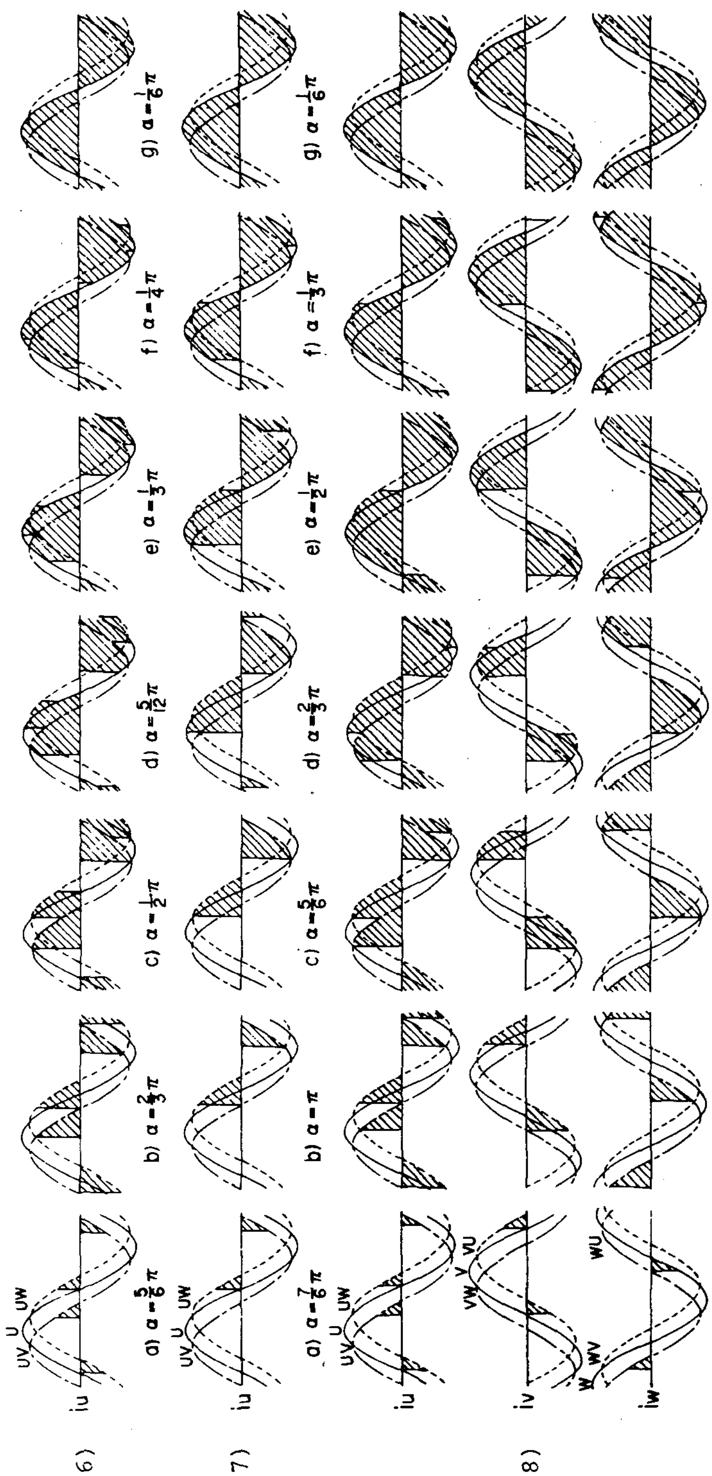


Fig.6. (continued)

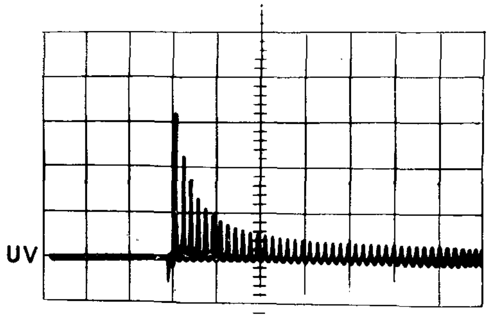


Fig.7. Line current when the circuit is not controlled.

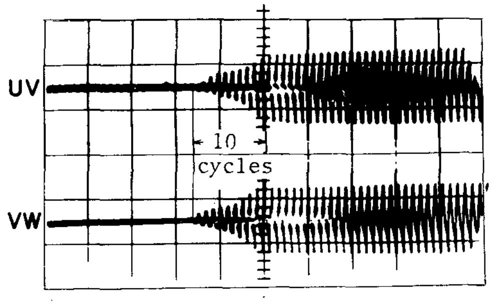


Fig.8. Phase current when the open delta connection is controlled by the soft-starting method.

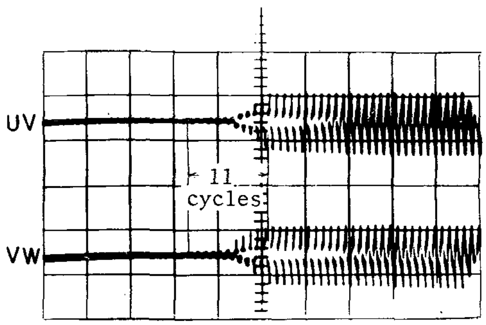


Fig.9. Phase current when the three line is controlled.

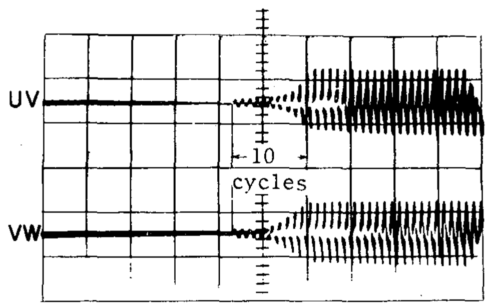


Fig.10. Phase current when the two line is controlled of the three phase.

Figs.8,9 and 10 show the current for the open delta control circui the three line control circuit and the two line control circuit of three phase, respectively. In these figures, the soft-starting control keeps the current within the steady state value in the transient period and is demonstrated effective to depress the inrush current. The soft-starting period is set about 10 cycles at the experiment.

4. Conclusions

It has been demonstrated that the magnetizing inrush current in a transformer can be appropriately controlled by means of thyristors. This method will be very available to solve various problems originated from the inrush current, such as the malfunction of protective relays, etc.

References

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[4] T.Himei, S.Nakanishi, H.Komatubara, S.Kawata and T.Tabuchi " Control of magnetizing inrush current of a transformer by means of thyristors (2) " *Annual Meeting of I.E.E. of Japan. Chugoku District*, Nov.(1972) 40504.