Polyphase Thyratron Amplifier

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Abstract

"Polyphase Thyratron Amplifier" is what the former thyratron amplifier, which is available for the amplification of the ultra low frequency signal, was developed into the polyphase system.

The present paper is devoted to the studies on the limitation of signal frequency to be amplified and the load current in the polyphase thyratron amplifier.

Under the assumption of a constant frequency of a.c. supply voltage, the limit of the signal frequency to be amplified is able to extend in proportion to the number of phase of the a.c. supply voltage.

Whereas, judging from a view-point of power amplification, the increase of the number of phase is not always efficient according to the waveform of a.c. supply voltage and the three-phase system is most efficient in a case of sinusoidal waveform being used extensively.

1. Introduction

In recent years, several papers[1-4] on the thyratron amplifier, being suitable for the power amplification of ultra low frequency signal, have been published.

As shown in the previous papers, it is able to amplify the ultra low frequency signal linearly by employing such circuit that thyratrons are connected in full-wave rectifier type with respect to the single phase a.c. source, of which grid circuits are composed of the specified bias voltage having an integrated waveform of a.c. source voltage and the amplitude modulated wave, which controls the firing angle of thyratrons, modulated by the ultra low frequency signal to be amplified.

The present paper deals with the thyratron amplifier developed into the polyphase system, which is named "Polyphase Thyratron Amplifier" and has the excellent characteristics for the current control and the amplification of the ultra low frequency signal.

2. Circuit

Fig. 1 shows the basic circuit of the polyphase thyratron amplifier employing W-phase a.c. source voltage. In Fig. 1, $e_1, e_2, \cdots$ and e_W represent the instantaneous a.c. plate voltages of thyratrons, T_1, $T_2, \cdots$ and T_W, respectively, which are supplied from W-phase a.c. source and their time functions are given by $f_1(\omega t)$, $f_2(\omega t)$, $\cdots$ and $f_W(\omega t)$. The

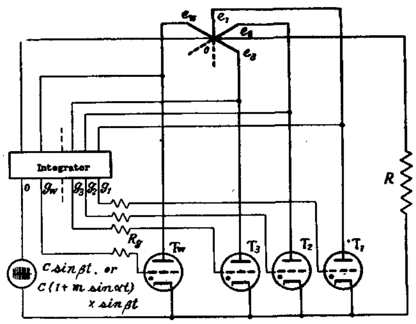

Fig. 1. Basic Circuit of Polyphase Thyratron Amplifier.

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plate voltage of the i-th phase is represented as

$$f_i(\omega t)=f\left\{\omega t-\frac{2\pi}{W}(i-1)\right\}. \tag{1}$$

Each grid circuit of the thyratron is composed of the specified bias voltage, which is generated in the integrator circuit with its a.c. plate voltage, given by

$$g_i(\omega t)=g\left\{\omega t-\frac{2\pi}{W}(i-1)\right\}$$

$$=\frac{-1}{k}\int_{\omega t}^{\frac{2\pi}{W}(i-1)+\pi} f\left\{\omega t-\frac{2\pi}{W}(i-1)\right\}\cdot d\omega t, \tag{2}$$

and the carrier wave voltage, $C_0 \sin \beta t$, that serves for controlling the firing angles of thyratrons. As reported in the previous papers, β, the angular frequency of carrier wave voltage, is very larger than ω, that of the a.c. source.

3. Load Current

Since the firing control of the thyratron under the positive half cycle of a.c. plate voltage is done in the same manner as the original thyratron amplifier reported in the previous papers, the firing angle, φ, of thyratron is given by

$$-g(\varphi)=C_0. \tag{3}$$

Eq. (3) is reasoned on the following hypotheses:

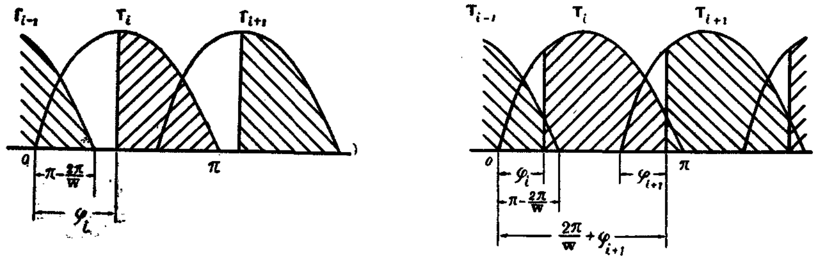
(1) The critical grid voltage is negligibly small in comparison with the specified bias voltage.

(2) The angular frequency of controlling carrier wave voltage, β, is very larger than ω, as mentioned above.

Fig. 2 represents the state of firing of the thyratron T_i in a positive half cycle of the i-th phase plate supply voltage, in which the control voltage is not shown. As illustrated in Fig. 2(a), if the firing angle of the thyratron T_i is within the limitation of

$$\pi-\frac{2\pi}{W}\leqq\varphi_i\leqq\pi, \tag{4}$$

the thyratron in the preceding phase has already stoped to conduct by this time, and



(a) $\pi-\frac{2\pi}{W}\leq\varphi\leq\pi$ (b) $0\leq\varphi\leq\pi-\frac{2\pi}{W}$

Fig. 2. Firing of Thyratron in Ployphase Thyratron Amplifier.

therefore T_i starts to conduct at φ_i and stops at π, independently of the neighboring phases and the number of phases of the a.c. source.

Hence, the average value of the load current during this half cycle period of the plate source, I_m, is given by

$$I_m = \frac{W}{2\pi R}\int_{\frac{2\pi}{W}(i-1)+\varphi_i}^{\frac{2\omega}{W}(i-1)+\pi} f\left\{\omega t - \frac{2\pi}{W}(i-1)\right\}d\omega t$$

$$= -\frac{kW}{2\pi R}g(\varphi_i)\,. \qquad (5)$$

Referring to Eq. (3), I_m is proportional to the amplitude of the controlling carrier wave voltage. As illustrated in Fig. 2(b), if the firing angle, φ_i, is out of the limitation given in Eq. (4), namely the conduction of thyratron T_{i-1} in the preceding phase is still continued at that time when the thyratron T_i is to fire, I_m in this case is given by,

$$I_m = \frac{W}{2\pi R}\int_{\frac{2\pi}{W}(i-1)+\varphi_i}^{\frac{2\pi}{W}(i-1)+\varphi_{i+1}} f\left\{\omega t - \frac{2\pi}{W}(i-1)\right\}d\omega t$$

$$= -\frac{kW}{2\pi R}\left[g(\varphi_i) - g\left(\frac{2\pi}{W}+\varphi_{i+1}\right)\right]. \qquad (6)$$

It is readily seen from Eq. (6) that I_m is not proportional to the amplitude of controlling carrier wave voltage in a case that φ_i is out of the limitation of Eq. (4).

As mentioned above, the limitation of the firing angle for obtaining the linear amplification of the ultra low frequency signal is given by Eq. (4).

Now, we consider that the amplitude modulated wave voltage, $C(1+m\sin\alpha t)\sin\beta t$, modulated by the ultra low frequency voltage, is applied to the grid circuits of thyratrons in place of $C_0 \sin\beta t$.

For the purpose of putting each thyratron to work within the limitation given in Eq. (4), C should be subject to the next limitation.

$$C \leqq -\frac{1}{2}g\left(\pi - \frac{2\pi}{W}\right). \qquad (7)$$

Then, the firing angle, φ_p, of the p-th positive half cycle counted from $t=0$, is derived from

$$-g(\varphi_p) = C\left[1 + m\sin\frac{1}{S}\left\{\frac{2\pi}{W}(p-1) + \varphi_p\right\}\right], \qquad (8)$$

where

$$S = \frac{\omega}{\alpha} = \frac{N}{M} \qquad (M,\ N\text{: relatively prime integers})$$

The average value of the load current during the p-th half cycle period is represented by

$$I_{mp} = \frac{kW}{2\pi R}C(1+m\sin\alpha t_p)\,, \qquad (9)$$

where

$$\alpha t_p = \frac{2\pi}{W}(p-1) + \varphi_p\,. \qquad (10)$$

Eq. (9) shows clearly that the average value of load current during a positive half cycle period is proportional to the instantaneous value of the ultra low frequency signal to be amplified at the instant that the thyratron starts to conduct if the circuit illustrated in Fig. 1 is employed under such conditions as given in Eq. (4) and Eq. (7). Fig. 3 illustrates the relation of the load current and the ultra low frequency signal to be amplified, over its one period. As will be seen from Fig. 3, where three-phase a.c. voltage is shown, W positive half cycles in number are included in one period of W-phase a.c. voltage and it becomes SW in total number during one period of the ultra low frequency signal.

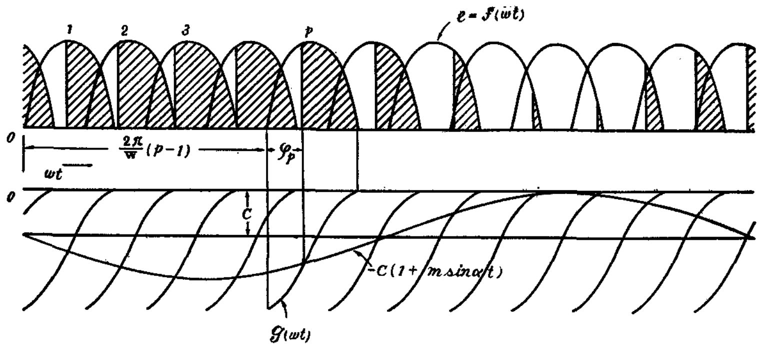


Fig. 3. Firing of Polyphase Thyratron Amplifier over one cycle period of Ultra Low Frequency Signal.

In such a case that thyratron works within the limitation given by Eq. (4), it has the very same characteristic, so far as it concerns the limitation of the ultra low frequency to be amplified, that the former thyratron amplifier shows under the single phase a.c. source voltage having an arbitrary waveform and the angular frequency of $\omega W/2$.

Since the linear amplification of the ultra low frequency signal of which angular frequency is subject to the limitation of $\alpha \leqq \omega/6$, is obtainable in the former thyratron amplifiiers, in which thyratrons are connected in full-wave rectifier type and the plate power source is the single phase a.c. voltage, the signal within the limitation of

$$\alpha \leqq \frac{\omega W}{12}, \tag{11}$$

is amplified linearly in this polyphase system.

It is evident from Eq. (11) that the more number of phase of a.c. source is, the higher frequency signal can be amplified if the frequency of a.c. source is constant.

Now, we consider the Fourier series representation of the instantaneous load current in this polyphase thyratron amplifier, which is shown as

$$i = a_0 + \sum_{n=1}^{\infty} a_{\frac{n}{M}} \cos \frac{n}{M} \alpha t + \sum_{n=1}^{\infty} b_{\frac{n}{M}} \sin \frac{n}{M} \alpha t . \tag{12}$$

If a.c. plate voltage of the thyratron in each phase, e, of which the angular frequency is ω, is such that

$$e = f(\omega t) , \tag{13}$$

then the Fourier coefficients are shown as follows:

$$a_0=\frac{1}{2N\pi R}\sum_{p=1}^{NW}\int_{\varphi_p}^{\pi} f(\omega t)\cdot d\omega t\,, \tag{14}$$

$$a_{\frac{n}{M}}=\frac{1}{N\pi R}\sum_{p=1}^{NW}\int_{\varphi_p}^{\pi} f(\omega t)\cdot\cos\frac{n}{M}\left\{\frac{2\pi}{W}(p-1)+\omega t\right\}\cdot d\omega t\,, \tag{15}$$

$$b_{\frac{n}{M}}=\frac{1}{N\pi R}\sum_{p=1}^{NW}\int_{\varphi_p}^{\pi} f(\omega t)\cdot\sin\frac{n}{M}\left\{\frac{2\pi}{W}(p-1)+\omega t\right\}\cdot d\omega t\,. \tag{16}$$

In the case of $\alpha\leqq\omega W/12$, the coefficients of harmonics and subharmonics except the fundamental of α and the $nW/2$-th component of ω, are negligibly small and Eq. (12) can be transformed into

$$i\simeq\frac{kWC}{2\pi R}(1+m\sin\alpha t)+\sum_{n=1}^{\infty}a_{ns\frac{W}{2}}\cos\frac{nW}{2}\omega t+\sum_{n=1}^{\infty}b_{nsW}\sin nW\omega t\,. \tag{17}$$

Accordingly, it is interpreted by the first term of Eq. (17) that the linear amplification of the ultra low frequency signal is obtainable.

Now, we consider the amplitude of the term which is varied according to the ultra low frequency signal to be amplified. Assuming that this magnitude is represented by I_α, it is given by the next equation from Eq. (17).

$$I_\alpha=\frac{kWCm}{2\pi R}\,. \tag{18}$$

Referring to Eq. (7), if $m=1$, I_α represents the maximum value shown as

$$I_{\alpha\,\max}=-\frac{kW}{4\pi R}g\left(\pi-\frac{2\pi}{W}\right). \tag{19}$$

Eq. (19) gives the various values for the different waveforms of a.c. plate supply voltage. If the rectangular wave voltage, of which amplitude is E, is applied, $I_{\alpha\,\max}$ is given by

$$I_{\alpha\,\max}=\frac{E}{2R}\,, \tag{20}$$

and if the sinusoidal wave voltage, $E_{\max}\sin\omega t$, is applied,

$$I_{\alpha\,\max}=\frac{WE_{\max}}{4\pi R}\left(1-\cos\frac{2\pi}{W}\right). \tag{21}$$

As represented by Eq. (20) and Eq. (21), the maximum value of I_α is constant for the a.c. plate supply voltage having a rectangular waveform, but varies as to the number of phase of a.c. plate supply voltage in the case that the sinusoidal voltage is employed for the a.c. plate supply voltage.

Table 1. shows corresponding values of $I_{\alpha\,\max}$ and the number of phase of a.c.

Table 1. Amplitude of amplified u.l.f. signal component with respect to the number of phase of a.c. sinusoidal source

W (Number of Phase)	2	3	4	6	8	∞
$I_{\alpha\,\max}$ (Relative Value)	4	4.5	4	3	2.34	0

sinusoidal supply voltage, in which $I_{\alpha\ max}$ given as a relative value, represents the maximum value for three-phase voltage and decreases as to the increase of number of phase.

Consequently, the output power for use is rather decreased in contrast with the fact that the higher frequency signal can be amplified by increasing the number of phase of a.c. plate supply voltage.

3. Conclusions

The principles and the characteristics of the polyphase thyratron amplifier were described above in outline.

It may be concluded that the polyphase thyratron amplifier has the merits that the amplified signal component in the output current is easily selected from the harmonic components of a.c. source frequency if the ultra low frequency to be amplified is fixed and the limitation of the ultra low frequency can be extended as the increase of the number of phase under the constant a.c. source frequency. Increasing the number of phase of the a.c. plate source is not always efficient for the amplification, that is the three-phase is most efficient if the sinusoidal supply voltage is employed. It goes without saying that the rectangular waveform voltage is most efficient compared with other waveform voltages.

The development into the polyphase system of the thyratron amplifier may suggest that of the magnetic amplifier and its wide application.

References

1) K. Miyakoshi, S. Hata, and S. Minamoto: Bull. of Namiwa Univ. A **2**, 25 (1954).
2) K. Miyakoshi, S. Minamoto, and K. Nohara: Bull. of Univ. of Osaka Pref. A **4**, 59 (1956).
3) K. Miyakoshi, S. Hata and Y. Kojima: J.I.E.E. of Japan. **75**, 783 (1955).
4) K. Miyakoshi, K. Nagami and Y. Kojima: J.I.E.E. of Japan **76**, 134 (1956).