PERIODICA POLYTECHNICA SER. EL. ENG. VOL. 34, NO. 2, PP. 137–152 (1990)

# THREE PHASE RECTIFICATION WITH HIGH FREQUENCY PULSES

I. NAGY

Department of Electrical Engineering
Technical University of Budapest

Received: May 5, 1988; Revised: February 1, 1989.

## Abstract

The three phase full bridge thyristor rectifier has drawbacks. The low power factor, the high harmonic content of the dc voltage at high firing angle and the inherent dead time are the main reasons for discomfort.

The configuration suggested here offers some remedy for all three disadvantages. High frequency sinusoidal current pulses are delivering the energy from the input to the output here. The paper describes the mode of action of the configuration. Symmetrical components are used for the mathematical analysis. Pulse distribution ensuring unit power factor in the whole operation range is suggested. Diodes are applied for clamping at the end of the paper. This is the simplest realization of the concept.

*Keywords:* power electronics, high frequency rectification, three phase rectifier.

## Introduction

Three phase full bridge thyristor rectifiers are widely used for supplying various motor loads and other power electronic units. It has three main drawbacks:

— the power factor can be low,
— the harmonic content of its output voltage is rather high in the low output voltage range,
— there is an inherent dead time.

The rectifier configuration discussed in the paper offers some remedy for all three disadvantages.

The main objective of the paper is the description of the so-called intelligent three phase rectifier suggested here. Its fundamental configuration is the same as that of the well-known full bridge rectifier but it is supplemented by two more switches as well as by several condensers and chokes. It is operated in two basically different ways, namely in normal and in pulse mode.

In *normal mode* it works in the same way as usual either as a rectifier or as an inverter. The configuration as a rectifier is intended to be operated in normal mode only in the high output power range when neither the power factor nor the harmonic contents are deteriorated up to a certain level and probably only in transient state.

In *pulse mode* the configuration is operated as a three phase switched condenser circuit in the middle and in the low output power range in rectifier operation. Only one switch is turned on out of the six rectifier switches at the same time, and current pulses deliver the energy from the input to the output. The pulse mode offers the following advantages:

— the power factor can be kept close to unity,
— due to the high frequency operation, the size of the filter components is relatively small,
— the dynamic behaviour is improved.

After the extinction of the output choke currents the switch-over from normal to pulse mode can be done. The steady state of the condenser voltage $u_c$ will be reached after a transient process that is beyond the scope of this paper.

In fact, the three phase diode rectifier, filter and chopper configuration offer more or less the same performance. However, the forced commutation can be avoided by applying the circuit discussed here. Furthermore, the circuit operated like an active filter does not transfer the input voltage variation of fundamental frequency ($f = 6\text{x}50\,\text{Hz}$) to the output terminals.

## Rectifier Configuration

The configuration investigated here stems from the three phase full bridge rectifier. In order to realize pulse mode operation some new components have to be added to it (*Fig. 1*). They are the three input $C_i$ and the two output $C_o$ condensers, the two L chokes, the clamping switches $T_{pl}$ and $T_{nl}$ and the switched condenser $C$. $C_i \gg C$ and $C_o \gg C$ are assumed. $u_{ia}, u_{ib}$ and $u_{ic}$ are phase voltages. The switches can be either thyristors (*Fig. 1a*) or some kind of transistors (*Fig. 1b*). The controlled switch between terminals $A$ and $B$ has to be connected in the places of thyristors. Mostly the application of thyristors will be supposed in the paper.

Positive current pulses are conducted by thyristor $T_{pa}$ from time $t_1$ till $t_3$ (*Fig. 2*). The current pulses flow via $T_{pa} - L - C_o - C - C_i$. After each positive current pulse a negative one is conducted by thyristor $T_{nb}$ from $t_1$ till $t_2$ in the lower part of the output circuit. Perfect symmetry is supposed, that is, the time functions will repeat themselves in each 60 degree interval with cyclically changing thyristor pairs. The investigation of one 60 degree interval, for instance, the interval from $t_1$ till $t_2$ is sufficient. Voltages $u_{PO}$ and $u_{NO}$ are dc voltages from segments of the phase voltages $u_{ia}, u_{ib}$ and$u_{ic}$.

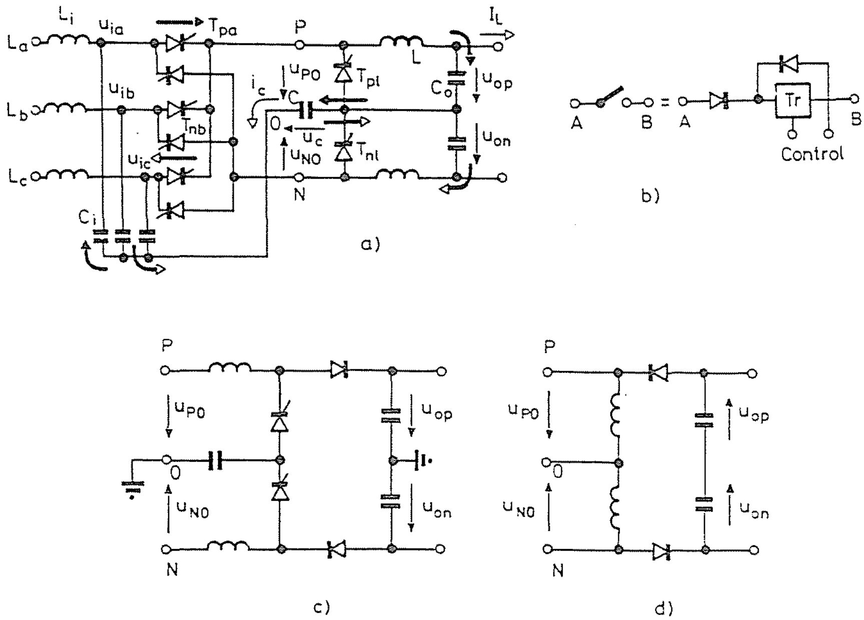


*Fig. 1. a)* Three phase configuration, $C_i \gg C$, $C_o \gg C$, *b)* The thyristor can be replaced by the transistor (Tr) connection, *c)* Boost configuration, *d)* Buck and Boost configuration.

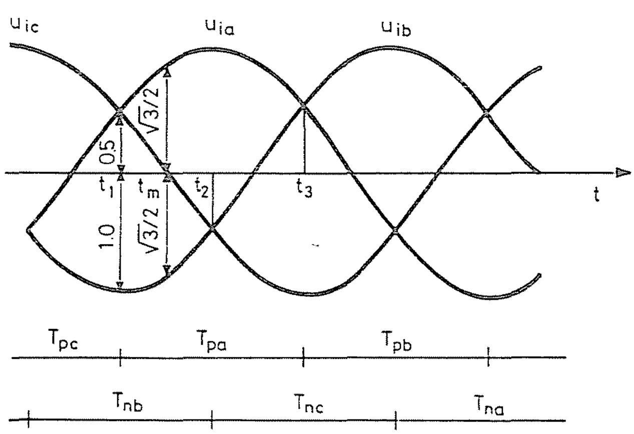


*Fig. 2.* Input phase voltages and firing sequence of the thyristors

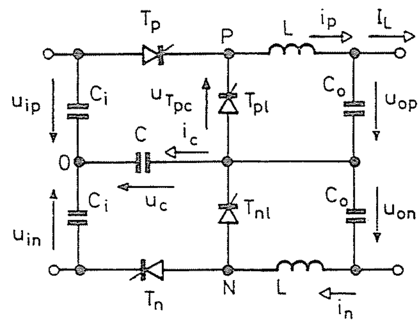


*Fig. 3.* DC-DC converter

The dc-dc converter circuit shown in *Fig. 3* is similar to the circuit in *Fig. 1*. The circuits to the right from terminals P-O-N in *Fig. 1* and *3* are the same. The basic difference in the rest of the circuit is that the main thyristors and supply voltages are cyclically changed in *Fig. 3*. During one sixth of the period of the three phase supply voltages only one positive and one negative, for instance, $T_{pa}$ and $T_{nb}$ thyristors are gated alternately. The dc-dc converter circuit has been described in detail in two previous papers (NAGY, 1986, 1988a). The operation of both circuits is based on the switched condenser concept (NAGY, 1985). The maximum value of the output voltage ($u_{op} + u_{on}$) is smaller than $(3/\pi)\sqrt{2}U_{im}$, where $U_{im}$ is the amplitude of the phase voltage $u_{ia}$ (NAGY, 1985, 1988a). Substituting the circuit right from terminals $P, O$ and $N$ by the circuit shown either in *Fig. 1c* or in *Fig. 1d*, the output voltage can be higher than $(3/\pi)\sqrt{2}U_{im}$ (NAGY, 1985). The paper deals only with the configuration shown in *Fig. 1a*.

## Pulse Mode

The maximum number of current pulses is $25 \sim 50$ within one 60 degree interval in thyristor configuration but it can be as high as several thousand using a suitable transistor. Positive and negative current pulse pairs are shown in *Fig. 4*. The input voltages $u_{ia}$ and $u_{ib}$ are almost constant during $\gamma$. Here $\omega_n = 2\pi f$ is the network angular frequency.

The positive current pulse increases the condenser voltage $u_c$, the negative one reverses it. The clamping thyristors are not fired. Negative voltage is developed across the previously conducting main thyristor, provided that the peak value of the condenser voltage $u_c$ is high enough.

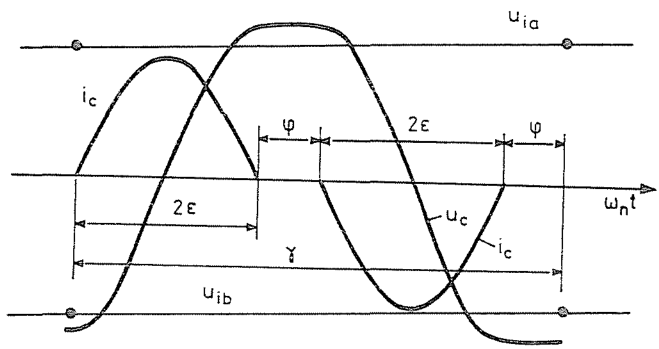


*Fig. 4.* Time functions during two current pulses

Constant and smooth dc output voltages $U_{\mathrm{op}}$ and $U_{\mathrm{on}}$ will be assumed in steady state corresponding to the choice $C_{\mathrm{o}} \gg C$. The circuit is capable of changing the output voltages only with the help of the clamping thyristors. Without them the output voltage $(U_{\mathrm{op}}+U_{\mathrm{on}})$ would be equal to the average value of the input voltage $(u_{\mathrm{ip}} - u_{\mathrm{in}})$. This statement can be proved for asymmetrical input and output voltages (NAGY, 1986, 1988a). For the sake of simplicity let us suppose here complete symmetry and constant input and output voltages, that is, $U_{\mathrm{op}} = U_{\mathrm{on}} = U_{\mathrm{o}}$ and $u_{\mathrm{ip}} = -u_{\mathrm{in}} = U_{\mathrm{i}}$. After turning on the main thyristor on the positive side, a positive current pulse $i_{\mathrm{c}}$ flows and it makes the condenser voltage $u_{\mathrm{c}}$ change at the end of the pulse from $U_{\mathrm{cn}} < 0$ to

$$U_{\mathrm{cp}} = -U_{\mathrm{cn}} + 2(U_{\mathrm{i}} - U_{\mathrm{o}}). \tag{1a}$$

In the same way:

$$U_{\mathrm{cn}} = -U_{\mathrm{cp}} - 2(U_{\mathrm{i}} - U_{\mathrm{o}}). \tag{1b}$$

The first term on the right side corresponds to the initial condition of the condenser voltage. $u_{\mathrm{c}} = U_{\mathrm{cn}}$ would be reversed by the current pulse without the voltage component $(U_{\mathrm{i}} - U_{\mathrm{o}})$. The second term is the result of the resultant "input" voltage $(U_{\mathrm{i}} - U_{\mathrm{o}})$ of the L-C ringing circuit. Its double develops across the condenser at the end of the current pulse. Steady-state condition is met only if $U_{\mathrm{i}}-U_{\mathrm{o}} = 0$, otherwise the peak value of the condenser voltage would always be increasing $(U_{\mathrm{i}} > U_{\mathrm{o}})$ after each current pulse, that is,

$$U_{\mathrm{o}} = U_{\mathrm{i}} \tag{2}$$

must be met in steady state.

On the other hand, *Eq.* (2) is not a precondition if the clamping thyristors are fired at the right time. Now $U_o$ can be smaller than $U_i$. At the beginning of a positive current pulse $i_c$ the voltage across the clamping thyristor $T_{pl}$ is negative. After a certain time the instantaneous value of the condenser voltage reaches the value $U_i$. The clamping thyristor voltage turns to positive value at that instant ($u_{\mathrm{Tpl}} > 0$) and it can be turned on any time later *(Fig. 5)*.

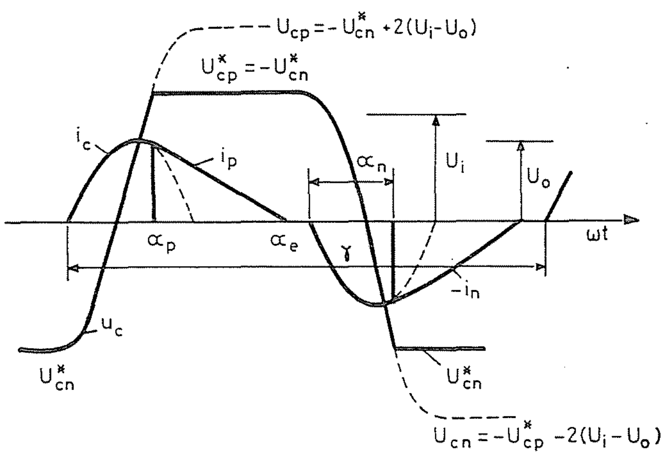


*Fig. 5.* Clamping thyristors are fired

The clamping thyristor $T_{pl}$ is fired at angle $\alpha = \alpha_p = \alpha_n$ when $u_c = U^*_{cp} = -U^*_{cn}$. The $*$ denotes the clamped peak value. Without firing $T_{pl}$, the condenser voltage would reach the peak value $U_{cp} = -U_{cn} + 2(U_i - U_o)$ *(Fig. 5)*. Here $\omega = 1/\sqrt{LC}$ and the losses are neglected. The condenser voltage is clamped by $T_{nl}$ at the value $U_{cn}$ during the negative current pulse. Constant peak value in the condenser voltage swing is ensured though $U_o < U_i$.

After turning on $T_{pl}$, the main thyristor $T_p$ turns off and the current $i_c(\alpha)$ starts circulating in the circuit $T_{pl} - L - C_o$ and decreasing at the rate $di_{ip}/dt = -U_o/L$. The commutation process is neglected here and later. Furthermore, discontinuous current conduction will be supposed, that is, the extinction angle $\alpha_e < \gamma/2$.

## Pulse Energies

Turning back to the more general case, let us suppose that $U_{ip} = -U_{in}$ and $U_{cp} = -U_{cn}$ although all four voltages are constant. Here and later the $*$ is omitted for the sake of simplicity unless it is stated otherwise. Of course, $U_{\mathrm{cp}}$ can differ from $-U_{\mathrm{cn}}$ in steady state. Shifting the firing angle $\alpha$ forward or backward accomplishes $U_{\mathrm{cp}} = -U_{\mathrm{cn}}$ *(Fig. 5)*.

The relations of the pulse energies taken out of the supply and delivered to the output by the current pulse will be determined.

The energy taken by one positive and one negative current pulse out of the input source in steady state is ($\alpha_{\mathrm{p}} = \alpha$):

$$W_{\mathrm{ip}} = U_{\mathrm{ip}} \int_0^{\alpha/\omega} i_{\mathrm{c}} \mathrm{d}t = C U_{\mathrm{ip}} (U_{\mathrm{cp}} - U_{\mathrm{cn}}). \tag{3}$$

and

$$W_{\mathrm{in}} = -U_{\mathrm{in}} \int_0^{\alpha/\omega} i_{\mathrm{c}} \mathrm{d}t = -C U_{\mathrm{in}} (U_{\mathrm{cp}} - U_{\mathrm{cn}}). \tag{4}$$

respectively. The input energy is proportional to the product of the input voltage and the condenser voltage change or in other words, it is proportional to the product of the input voltage and the sum of the charges stored in the condenser at the start and end of the current pulse.

The corresponding change in the energy stored in the switched condenser is:

$$\Delta W_{\mathrm{cp}} = C(U_{\mathrm{cp}}^2 - U_{\mathrm{cn}}^2)/2. \tag{5}$$

and

$$\Delta W_{\mathrm{cn}} = C(U_{\mathrm{cn}}^2 - U_{\mathrm{cp}}^2)/2. \tag{6}$$

respectively. The output energies are:

$$W_{\mathrm{op}} = W_{\mathrm{ip}} - \Delta W_{\mathrm{cp}} = C(U_{\mathrm{cp}} - U_{\mathrm{cn}})[U_{\mathrm{ip}} - (U_{\mathrm{cp}} + U_{\mathrm{cn}})/2], \tag{7}$$

$$W_{\mathrm{on}} = W_{\mathrm{in}} - \Delta W_{\mathrm{cn}} = C(U_{\mathrm{cp}} - U_{\mathrm{cn}})[-U_{\mathrm{in}} + (U_{\mathrm{cp}} + U_{\mathrm{cn}})/2]. \tag{8}$$

The sum of the output energies is supplied to the load:

$$W_{op} + W_{on} = C(U_{cp} - U_{cn})(U_{ip} - U_{in}). \tag{9}$$

It is proportional to the product of the sum of the input voltages and to the condenser voltage change. The variation of the condenser peak voltages by clamping modifies the output energy.

## Symmetrical Components

The introduction of the two phase symmetrical components can be rewarding. Their definitions are:

$$U_{\mathrm{i1}} = (U_{\mathrm{ip}} - U_{\mathrm{in}})/2, \qquad U_{\mathrm{i2}} = (U_{\mathrm{ip}} + U_{\mathrm{in}})/2, \tag{10}$$

$$U_{\mathrm{c1}} = (U_{\mathrm{cp}} - U_{\mathrm{cn}})/2, \qquad U_{\mathrm{c2}} = (U_{\mathrm{cp}} + U_{\mathrm{cn}})/2, \tag{11}$$

$$W_{\mathrm{o1}} = (W_{\mathrm{op}} + W_{\mathrm{on}})/2, \qquad W_{\mathrm{o2}} = (W_{\mathrm{op}} - W_{\mathrm{on}})/2, \tag{12}$$

where suffixes 1 and 2 denotes the positive and the negative sequence components, respectively. The positive and the negative sequence components are proportional to the sum and the difference of the variables, respectively.

Substituting *Eq.* (11) into *Eqs.* (7) and (8)

$$W_{\mathrm{op}} = 2CU_{\mathrm{c1}}(U_{\mathrm{ip}} - U_{\mathrm{c2}}), \tag{13}$$

$$W_{\mathrm{on}} = 2CU_{\mathrm{c1}}(-U_{\mathrm{in}} + U_{\mathrm{c2}}) \tag{14}$$

are obtained.

First adding and in the second step subtracting the last two equations and substituting the results into *Eqs.* (10) and (12), we end up with:

$$W_{\mathrm{o1}} = 2CU_{\mathrm{c1}}U_{\mathrm{i1}}, \tag{15}$$

$$W_{\mathrm{o2}} = 2CU_{\mathrm{c1}}(U_{\mathrm{i2}} - U_{\mathrm{c2}}). \tag{16}$$

Knowing the input voltages and prescribing the energies $W_{\mathrm{op}}$ and $W_{\mathrm{on}}$, the positive and the negative sequence components of the condenser voltage can be calculated from the last two equations. The peak values of the clamped condenser voltage are:

$$U_{\mathrm{cp}} = U_{\mathrm{c1}} + U_{\mathrm{c2}}, \tag{17}$$

$$U_{\mathrm{cn}} = -U_{\mathrm{c1}} + U_{\mathrm{c2}}. \tag{18}$$

The positive and the negative sequence components of the input energies are

$$W_{i1} = W_{o1} = 2CU_{i1}U_{c1}, \tag{19}$$

$$W_{i2} = 2CU_{i2}U_{c1} \tag{20}$$

and those of the energy changes in the switched condenser are

$$\Delta W_{c1} = 0, \tag{21}$$

$$\Delta W_{c2} = 2CU_{c1}U_{c2}. \tag{22}$$

The ratio of the output energies are

$$W_{op}/W_{on} = \beta$$

and

$$W_{o2}/W_{o1} = \delta.$$

On the other hand

$$W_{o2}/W_{o1} = (W_{op} - W_{on})/(W_{op} + W_{on}) = (\beta - 1)/(\beta + 1) = \delta \tag{22a}$$

and from *Eqs.* (15) and (16)

$$U_{c2} = U_{i2} - U_{i1}. \tag{23}$$

Three states belonging to different $\delta$ values can be distinguished. Selecting the values $U_{cp}$ and $U_{cn}$ by controlling the firing angles $\alpha_p$ and $\alpha_n$, the value $\delta$ is set.

*Symmetrical Energy Supply (SES)*

Now $\delta = 0$ and

$$U_{c2} = U_{i2}. \tag{24}$$

The input voltages $U_{ip}$ and $(-U_{in})$ can be equal or different. Even in the second case (see *Eq.* (16)):

$$W_{o2} = 0, \text{ that is}$$

$$W_{\text{op}} = W_{\text{on}} = W_{\text{o}} \tag{25}$$

and

$$\Delta W_{\text{c2}} = W_{\text{i2}}, \tag{26}$$

that is, SES is maintained in the output circuit.

The ratio of the input energies see *Eqs.* (3) and (4)):

$$W_{\text{ip}}/W_{\text{in}} = U_{\text{ip}}/(-U_{\text{in}}). \tag{27}$$

The equal output energy pulses in the two branches of the circuit are covered by the positive sequence component of the input energy pulses (*Eq.* (19)). The negative sequence components of the input energies cover the energy unbalance in the condenser (*Eq.* (26)). In other words, the energy being equal to the condenser energy decrease ($\Delta W_{\text{cp}}$ or $\Delta W_{\text{cn}}$) is supplied to the output in the branch of the circuit where the input energy is smaller than the output one while the energy being equal to the condenser energy increase is supplied from the input source in the other branch where the input energy is bigger than the output one (see *Eqs.* (7) and (8)). The condenser as a buffer ensures equal output energies though the input energies differ from each other.

SES can be maintained even at $U_{\text{ip}} > 0$ and $U_{\text{in}} = 0$ or $U_{\text{in}} < 0$ and $U_{\text{ip}} = 0$.

## *Asymmetrical Energy Supply (AES)*

Now $\delta = U_{i2}/U_{i1}$ and from *Eq.* (23):

$$U_{\text{c2}} = 0, \tag{28}$$

as well as from *Eq.* (22) $\Delta W_{\text{c2}} = 0$. The condenser voltage swing is symmetrical to the time axis. There is no condenser energy unbalance, $\Delta W_{\text{cp}} = \Delta W_{\text{cn}} = 0$.

On the basis of *Eqs.* (16) and (20) $W_{\text{o2}} = W_{\text{i2}}$ and taking into account *Eq.* (19)

$$W_{\text{op}} = W_{\text{ip}} \text{ and } W_{\text{on}} = W_{\text{in}} \tag{29}$$

as well, as from *Eqs.* (13) and (14):

$$W_{\text{op}}/W_{\text{on}} = W_{\text{ip}}/W_{\text{in}} = U_{\text{ip}}/(-U_{\text{in}}). \tag{30}$$

The input energies are transferred directly to the outputs.

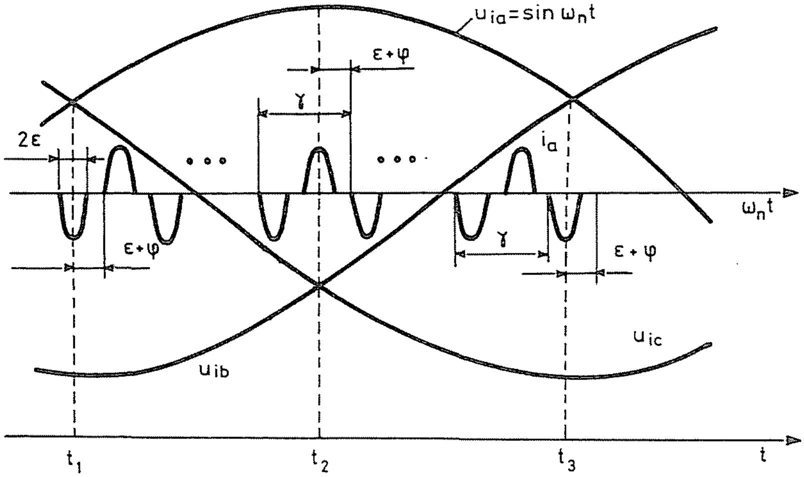


*Fig. 6.* Current pulse distribution

*General Energy Supply (GES)*

Now $\delta = 0$ and $\delta = U_{i2}/U_{i1}$ . The ratio of the output energies is:

$$W_{op}/W_{on} = \beta, \tag{31}$$

where

$$\beta = (1+\delta)/(1-\delta). \tag{32}$$

The ratio of the input energies remains unchanged:

$$W_{ip}/W_{in} = U_{ip}/(-U_{in}).$$

It means that there are certain energy exchanges between the condenser on the one hand, and between the input and output circuits on the other hand.

## Pulse Distribution

The three phase configuration (*Fig. 1*) has been abandoned in section Pulse Mode and for the sake of simplicity constant dc input voltages were assumed (*Fig. 3*).

Now turning back to the three phase configuration shown in *Fig. 1*, its investigation may be confined to the interval $(t_2 - t_1)$ (*Fig. 2*).

It is supposed that the number of full $\gamma$ cycles during the time span $t_2 - t_1$ is $N$ where the suggested maximum value for $N$ is $25 \sim 50$ and it is much higher for transistor switches. In order to ensure *complete symmetry,* only the $\pi/3 - 2(\varepsilon + \varphi)$ interval is divided into $N$ equal sections (*Fig. 6*). Being $\omega_n(t_2 - t_1) = \pi/3$ and

$$\gamma = 2(2\varepsilon + \varphi) \tag{33}$$

it means that

$$\gamma = (\pi/3)/(N + 1/2). \tag{34}$$

Furthermore,

$$4\varepsilon = 2\pi\omega_n/\omega_n, \tag{35}$$

where $\omega = 1/\sqrt{LC}$ and $\omega_n$ is the angular frequency of the supply network. Choosing $N$, the values $\gamma$ and $\varphi$ can be calculated when $\omega$ is given. *Fig. 6* assumes full current pulses. In fact, the pulses are shortened because of clamping.

By maintaining this pulse distribution the power factor is kept close to unity. Now the input voltages change sinusoidally (*Fig. 2*). The amplitude of the phase voltages is chosen as voltage unit. The sine waves are approximated by step functions. The approximate value for the input voltage $u_{ia}$ during the positive current pulse in the interval $k\gamma$ is

$$u_{ia} \cong u_{ip}(k) = \sin[\alpha_\varepsilon + (k-1)\gamma + \varepsilon] \tag{36}$$

and the same for $u_{ib}$ is

$$u_{ib} \cong u_{in}(k) = \sin[\alpha_\varepsilon - 120^\circ + (k-1)\gamma + 3\varepsilon + \varphi], \tag{37}$$

where $\alpha_\varepsilon = 30^\circ + \varepsilon + \varphi$ (*Figs. 6* and *7*) and $k = 1, 2, \ldots N$. The conditions $u_{cp}(k)|1 \geq u_{ip}(k)$ and $-u_{cn}(k) \geq -u_{in}(k)$, that is

$$u_{c1}(k) \geq u_{i1}(k) \tag{38}$$

for turning on the clamping thyristors and turning off the conducting thyristors must be met after each current pulse and in each state as well.

Before investigating the three states set by the appropriate firing of the clamping thyristors, first the simplest case, namely, the diode clamping is discussed.

## Diode Clamping

In the simplest case the clamping thyristors are replaced by clamping diodes. The switched condenser voltage amplitudes are limited by the instantaneous values of the input voltages, that is,

$$u_{\mathrm{cp}}(k) = u_{\mathrm{ip}}(k), \tag{39a}$$

$$u_{\mathrm{cn}}(k) = u_{\mathrm{in}}(k). \tag{39b}$$

The minimum value of the condenser voltage change is approximately 1.5 at time $t_1$ and its maximum value is $\sqrt{3}$ at time $t_{\mathrm{m}}$ (*Fig. 2*). In case of constant input voltages the sum of the output energies is proportional to the product of $U_{\mathrm{c1}}$ and $U_{\mathrm{i1}}$ (see *Eq.* (15)). Their value at time $t_1$ is $U_{\mathrm{c1}} = U_{\mathrm{i1}} = (1 + 0.5)/2$ and at time $t_{\mathrm{m}}$ is $U_{\mathrm{c1}} = U_{\mathrm{i1}} = \sqrt{3/2}$ (*Fig. 2*). The ratio of the maximum and minimum energy portions

$$w_{\mathrm{o1}}(t_{\mathrm{m}})/w_{\mathrm{o1}}(t_1) = (\sqrt{3})^2/(1.5)^2 = 1.333. \tag{40}$$

The function of $w_{\mathrm{o1}}(k)/C$ is shown for a 60° interval in *Fig. 8* in the case $N = 12$. It was calculated on the basis of *Eqs.* (7) and (8) in the $k$'th interval as follows (see *Fig. 7*).

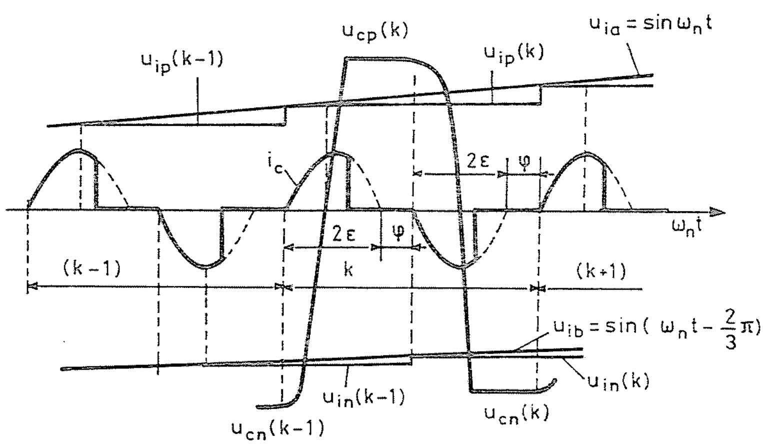


*Fig. 7.* Calculation of $u_{cp}(k)$ and $u_{cn}(k)$

The output energy portion carried by the positive and negative current pulses is:

$$W_{op} = C[u_{cp}(k) - u_{cn}(k-1)]\{u_{ip}(k) - [u_{cp}(k) + u_{cn}(k-1)]/2\} \tag{41}$$

and

$$W_{on} = C[u_{cp}(k) - u_{cn}(k)]\{-u_{in}(k) + [u_{cp}(k) + u_{cn}(k)]/2\}, \tag{42}$$

respectively.

Now $u_{cn}(k-1) = u_{in}(k-1)$, $u_{cp}(k) = u_{ip}(k)$ and $u_{cn}(k) = u_{in}(k)$ (see *Fig. 7)*. Function $w_{o1}(k)/C$ justifies the estimation given in *Eq.* (40) since the output energy ratio taken from *Fig. 8* is 1.365.

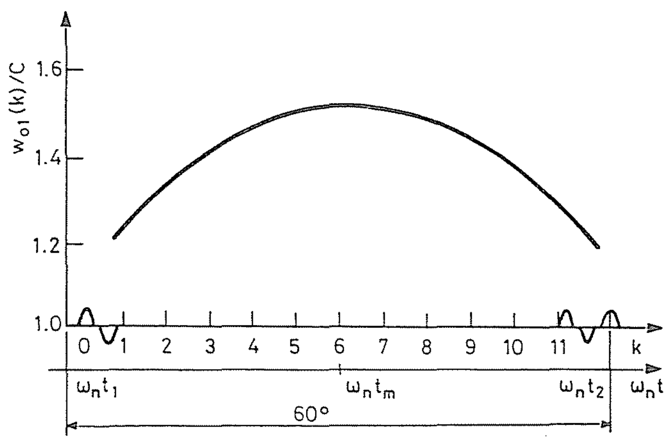


*Fig. 8.* Output energy variation at diode clamping. $N$=12

A harmonic having a frequency six times higher than the supply frequency appears in the output voltages. It can be eliminated by applying the clamping thyristors rather than diodes and by gating them to ensure constant output energy portions. It can be expected that the energy portions will not change if the condenser voltage change is proportional to

$$1/(u_{ia} - u_{ib}) = 1/\big(\sin\omega t - \sin(\omega t - 120°)\big)$$

in the interval investigated (see *Eq.* (9)), that is, the ratio of the maximum to minimum condenser voltage change is:

$$\frac{(u_{cp} - u_{cn})_{\text{ nearest to } t_1}}{(u_{cp} - u_{cn})_{\text{ nearest to } t_m}} = 1.15.$$

By using controlled switches in place of clamping diodes the output energy $W_{o1}(k)$ can be kept constant in each $\gamma$ cycle.

## Conclusion

In the present paper a new configuration for three phase rectification by high frequency pulses has been suggested. It was devised to maintain the power factor close to unity, to improve the dynamic performance and to reduce the filter components.

The paper describes the symmetrical (SES), the asymmetrical (AES) and general (GES) energy supply in the case of dc input voltages. In SES the output energy $W_{\mathrm{op}}$ delivered by the positive current pulse $i_{\mathrm{p}}$ equals the output energy $W_{\mathrm{on}}$ delivered by the negative current pulse $i_{\mathrm{n}}$. In AES the ratio

$$W_{\mathrm{op}}/W_{\mathrm{on}} = W_{\mathrm{ip}}/W_{\mathrm{in}} = U_{\mathrm{ip}}/U_{\mathrm{in}}\,.$$

A pulse distribution ensuring complete symmetry and unit power factor has been presented.

Assuming clamping diodes the switches are turned on and off when either their voltage or their current or both of them are zero reducing the switching power losses. Now the only way to change the output voltage is to vary the number of pulses.

A next paper to be published (NAGY, 1991) will describe another way for changing the output voltage and for maintaining constant output energy $W_{\mathrm{o1}}(k)$ in each $\gamma$ cycle by using controlled switches for clamping the voltage of the switched condenser.

## References


DE CARLI, A. (1983): Steady-State Behaviour of Converter Fed Systems. Proceedings of the Third IFAC Symposium on Control in Power Electronics and Electrical Drives, Lausanne, Switzerland, Sept. 12-14, 1983. Published by Pergamon Press, 1983, pp. 735–755.

DE CARLI, A.– MICHELETTI, R. (1987): On Line Measurement of Highly Distorted Three-Phase Supply. Second European Conference on Power Electronics and Applications. Grenoble, France, Sept. 22-24, 1987. Proc. Vol. *2.* pp. 1221–1226.

DE HAAN, S.W.H. – LODDER, J.D. (1987): A Formalistic Approach to Series-Resonant Power Conversion. Second European Conference on Power Electronics and Applications. Grenoble, France, Sept. 22-24, 1987. Proc. Vol. *1.* pp. 231–238.

HENZE, C.P. – MOHAN, N. (1985): Modeling and Implementation of a Digitally Controlled Power Converter Using Duty Ratio Quantization. Proc. ESA Sessions at 16th Annual IEEE PESC, Univ. Paul Sabatier, Toulouse, June 24-28, 1985. (ESA SP-230, May 1985), pp. 245–255.

HENZE, C.P. – MOHAN, N. (1986): A Digitally Controlled AC to DC Power Conditioner that Draws Sinusoidal Input Current. PESC 86 Record 17th Annual IEEE Power Electronics Specialists Conference. Cat. No.86CH2310-1, Vancouver, June 23-27, 1986. (N.Y. USA IEEE 1986, pp. 531–40).

NAGY, I. (1985): The Application of Switched-Condenser Concept in Power Electronics. First European Conference on Power Electronics and Application, Oct. 16-18, 1985, Brussels. Proceedings Vol. *1*. pp. 2.251–2.255

NAGY, I. (1986): New Configurations Delivering Variable Energy Portions in Power Electronics. Periodica Polytechnica Ser. Mech. Eng, Vol. *30*, No. 1. pp. 1–23.

NAGY, I. (1988a): DC-DC Converter. Periodica Polytechnica Ser. Mechanical Engineering. Vol. *32*, No. 1. pp. 3–36.

NAGY, I. (1988b): DC-DC Converters with Series Commutation. Proc. International Conference for Power Electronics. Munich, June 6-8, 1988. pp. 360–378.

NAGY, I. (1991): Evaluation of a Three Phase Rectification of High Dynamic Performance. Paper submitted for publication to Periodica Polytechnica Ser. Electrical Engineering.

OMORI, H. – IWAI, T. – NAKAOKA, M. – MARUHASHI, T. (1987): Circuit Topology of Self-Controlled Single-Ended High Frequency Resonant Inverter. Second European Conference on Power Electronics and Applications. Grenoble, France, Sept. 22-24, 1987. Proc. Vol. *1*, pp. 205–211.

SEGER, T. – WACHTER, M. (1987): Direct Digital Control of Four Quadrant Power Converter. Second European Conference on Power Electronics and Applications. Grenoble, France, Sept. 22-24, 1987 Proc. Vol. *1*, pp. 123–128.

SZÉKELY, I. – SZENTGYÖRGYI, V. (1987): Circular Current Analysis in a Medium Frequency Parallel Operating Converter. Second European Conference on Power Electronics and Application. Grenoble, France, Sept. 22-24, 1987. Proc. Vol. *1*, pp. 497–502.

*Address:*

Dr. István NAGY
Department of Electrical Engineering, Technical University of Budapest
H-1521 Budapest, Hungary