NEW CONFIGURATIONS DELIVERING VARIABLE ENERGY PORTIONS IN POWER ELECTRONICS

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Summary

A special technique has recently been developed in the field of communication engineering. In the frame of this new technique the resistance in integrated circuits is realized by switched condenser. The paper first presents the basic idea of the switched condenser. The objective of the paper is to describe the application possibilities of the switched-condenser concept in power electronics. It derives some new configurations, analyses their steady-state and transient-state behaviour and discusses their adaptation to some of the energy conversion job. One of the main features of the new configurations is that they operate periodically with high frequency and the energy portion delivered in one cycle towards the energy receiving end is proportional to the square of the voltage developed across the sending terminals.

Introduction

The analog IC technology widely applies the operational amplifier, the condenser and the resistance as principal components. The operational amplifiers and the condensers of excellent quality can be produced by MOS technology. The properties of the resistance are by far not so favourable.

The critical component deteriorating the performance of various circuits is the resistance. The switched condenser offers an attractive, ingenuous solution of this problem in IC technology and involves an inherent, additional advantageous feature. The resistance is substituted by the switched condenser consisting of an electronic switch and a condenser. A remarkably good electronic switch can be produced by MOS technology.

Basic concept

What is actually the switched condenser? A parallel and a series switched condenser circuit is shown in Fig. 1.a, and Fig. 1.b, respectively. The switch S is connecting terminal 0 to terminal 1 in the first half period $T/2$ and to terminal 2 in the second half period $T/2$. The switching frequency $f = 1/T$ can be either constant or it can be changed. Voltage u_i and u_0 are supposed to be constant within one period T.

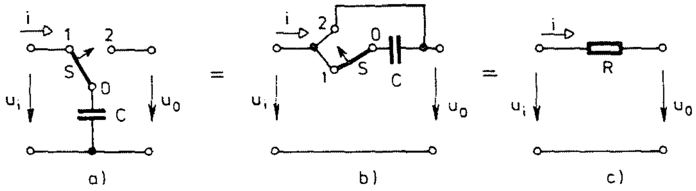

Fig. 1. Basic configuration of switched condenser. Parallel (Fig. a.) and series (Fig. b.) switched condenser

In the circuit of Fig. 1.a the charge of the condenser is $q_i = Cu_i$ in the first half period and $q_0 = Cu_0$ in the second one. The average current

$$i = \frac{q_i - q_0}{T} = C\frac{u_i - u_0}{T} = \frac{u_i - u_0}{R} \tag{1}$$

In the circuit of Fig. 1.b the charge of the condenser is $q = C(u_i - u_0)$ in the first half period and in the second one the condenser is short-circuited and the charge is zero. The average current

$$i = \frac{q}{T} = C\frac{u_i - u_0}{T} = \frac{u_i - u_0}{R} \tag{2}$$

From the viewpoint of average current i the switched condenser can be considered in both circuits as a resistance (Fig. 1.c)

$$R = \frac{T}{C} = \frac{1}{fC} \tag{3}$$

After every switching a transient process takes place in the circuit of Fig. 1.a and 1.b. It is supposed that the time of the transient process is much less than the period T and the whole phenomenon can be neglected.

R–C circuit with switched condenser

Let us assume that the charge of the condensers is zero in times $t < 0$ in the configuration shown in Fig. 2. Let u_i be varied by a sudden change at time $t = 0$ (Figs 2.c and 2.d). In the case of Fig. 2.a the output voltage u_0 is changing exponentially in time with time constant RC_0 ($i_0 = 0$). The instantaneous value of the input current $i = \dfrac{u_i - u_0}{R}$.

The situation is quite similar in the configuration of Fig. 2.b, for the average value of the input current flowing in a period T can also be expressed in

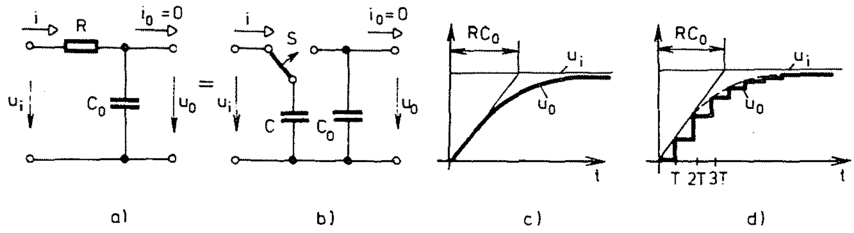

Fig. 2. R–C circuit with switched condenser

the form: $i=\frac{C}{T}(u_i-u_0)=\frac{1}{R}(u_i-u_0)$, that is, the value of the voltage u_0 developed at the end of the period T changes exponentially with the time constant RC_0 as well (dashed line in Fig. 2.d). The switch S starts oscillating with a delay of $T/2$ after time $t=0$. The time constant $\tau=RC_0=\frac{1}{f}\frac{C_0}{C}$ depends on the ratio C_0/C and on the frequency. The ratio of the capacitances can be manufactured by MOS technology with very high precision.

Integrator with switched condenser

After having switched a step function voltage u_i to the input of an operation amplifier integrator presented in Fig. 3.a, its input current $i=\frac{u_i}{R}$ will be constant. The output voltage $(-u_0)$ is a ramp function (Fig. 3.c).

By connecting likewise a step function voltage u_i to an integrator realized by a switched condenser instead of resistance R (Fig. 3.b), the average value of the input current taken in a period T has now also constant value: $i=\frac{u_i}{R}$, that

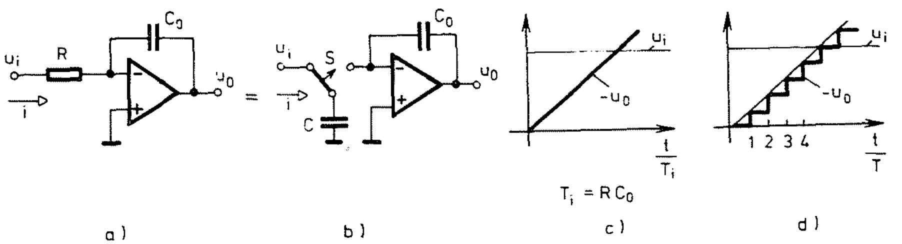

Fig. 3. Integrator with switched condenser

is, the value of the voltage $-u_0$ taken at the end of periods T is a ramp function as well (Fig. 3.d dashed line).

Active RC filters, for example, can be produced in a single IC chip with switched condensers, operational amplifiers and condensers in excellent quality. By changing the switching frequency, the virtual resistances and thereby the time constants of the filter can be jointly and continuously changed. The frequency response curves of the filter can be shifted parallel to themselves along the frequency axis.

The paper tries to explore some feasibility ideas of switched condensers in power electronics.

Energetical considerations

Obviously, in IC technique the energetics viewpoints play no decisive role. On the other hand, in power electronics efficiency is one of the most important factors.

One theoretically possible way to realize the parallel and series switched condenser by thyristor switch in power electronics is shown in Fig. 4.a and 4.b, respectively. Resistances R_l and R_{l1} are needed to limit the current. Unfortunately, the configurations shown in Fig. 4 cannot be applied due to the extremely high power loss. The energy dissipated in resistance R during the response time to a suddenly applied constant d.c. voltage u_i in a series R–C circuit is $\frac{Cu_i^2}{2}$, that is, it is the same as the stored energy in condenser C at the end of the transient process, provided, that the initial condition was zero.

In order to avoid the high power losses and the high di/dt value, chokes rather than resistors are inserted in the circuits of Fig. 4 (Fig. 5). The condenser voltage u_c is clamped at some maximum and minimum value by the free-

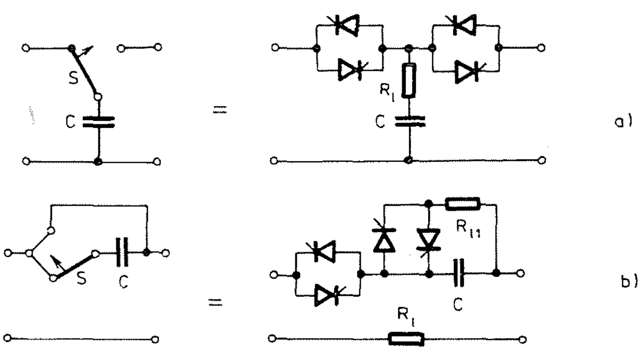

Fig. 4. Switched condenser with thyristors and resistances

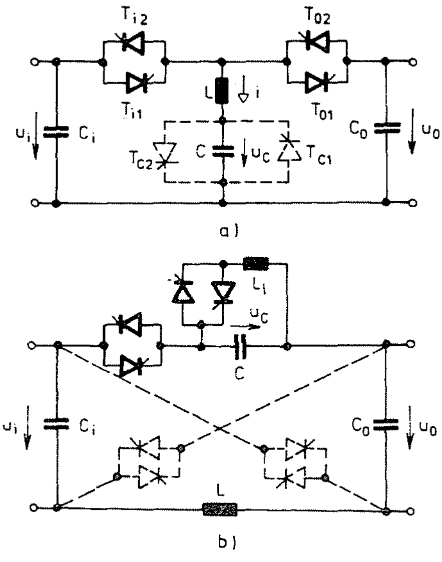

Fig. 5. Switched condenser with thyristors and inductances

wheeling thyristors indicated by a dashed line. The free-wheeling thyristors provide a path for the energy trapped in choke L towards the output or input condenser. Condenser C_i and C_0 are needed because of the high frequency operation. Energy can be transported by both configurations with good efficiency from the input to the output and vice versa.

Steady-state

The mode of action of the two circuits shown in Fig. 5 is described in the simplest case in steady-state with the assumptions as follows:

a) Voltage u_i and u_0 are constant and positive as well as $u_i > u_0$.

b) Energy is transported only from the input to the output.

c) Because of assumption a) and b) the circuits of Fig. 5 can be reduced to the ones shown in Fig. 6.

d) The losses in chokes, condensers, thyristors and diodes are neglected.

e) The capacitance of condenser C_i and C_0 is much higher than that of condenser C.

The time functions of the so called parallel switched condenser circuit given in Fig. 6.a are presented in Fig. 7. By turning on thyristor T_i at time $t=0$, a sinusoidal current pulse is flowing in the ringing circuit L–C till time t_1 (Fig. 7.b). The condenser voltage u_c is changing from zero up to $2u_i$ (Fig. 7.c). Thyristor T_0 is off during interval $0 \leqq t \leqq t_2$ (Fig. 7.d).

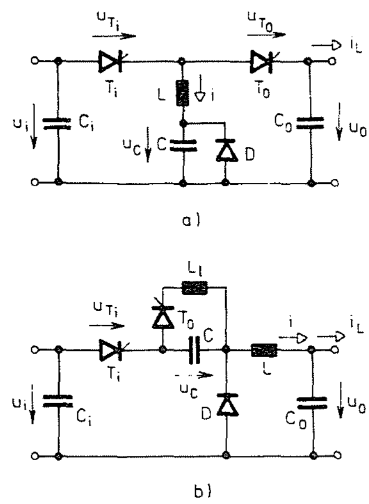

Fig. 6. Configuration of transporting energy in one direction

By gating thyristor T_0 at time t_2, a negative current pulse starts flowing due to the voltage $(2u_i - u_0)$ (Fig. 7.b). The condenser voltage u_c is decreasing from $2u_i$ towards $2u_i - 2(2u_i - u_0) = -2(u_i - u_0)$. At time t_3 the condenser voltage is $u_c = 0$. From time t_3 on, diode D is conducting the choke current i which is diminishing towards zero at constant speed: $di/dt = -u_0/L$. The energy stored in choke L at time t_3 is supplied to the output circuit. From time t_4 on, the conditions in the circuit are the same as they were at time $t = 0$. The next period may be started. Had not the free-wheeling diode been inserted, the

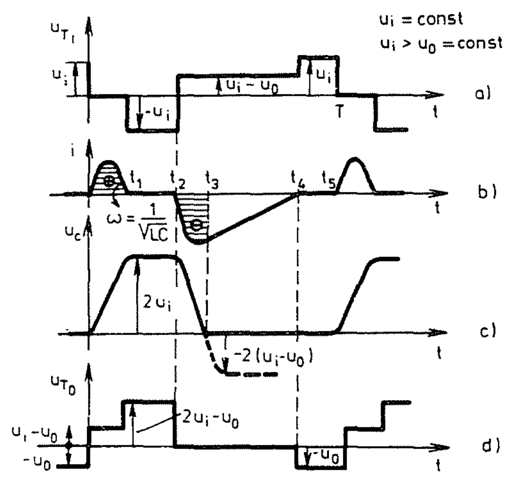

Fig. 7. Time functions of configuration shown in Fig. 6.a

condenser voltage u_c would have been $-2(u_i-u_0)$ at the end of the negative current pulse, that is, the original initial condition would not have been restored.

The energy W taken from the input side and stored in condenser C from time t_1 till time t_2 as well as forwarded to the output circuit in every period is

$$W=\frac{(2u_i)^2C}{2} \qquad (4/a)$$

The time functions of the so called series switched condenser circuit in Fig. 6.b are shown in Fig. 8. By turning on thyristor T_i, a sinusoidal current pulse is flowing in the series ringing circuit L–C (Fig. 8.b).

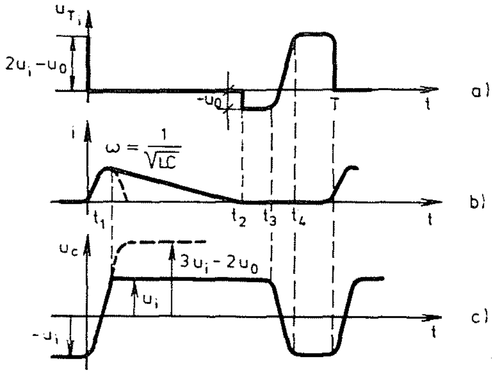

Fig. 8. Time functions of configuration shown in Fig. 6.b

The condenser voltage u_c is increasxing from $-u_i$ towards $-u_i+2(2u_i-$ $-u_0)=3u_i-2u_0$ and reaches the value u_1 at time t_1 (Fig. 8.c). From time $t=t_1$ on, diode D starts conducting the choke current i which is diminishing as a negative ramp function with speed $di/dt=-u_0/L$ (Fig. 8.b).

The condenser voltage remains unchanged until thyristor T_0 is not gated. After gating T_0, voltage u_c is reversed and from time t_4 on, the conditions are the same as they were at time $t=0$.

The energy transported from the input to the load in one period is

$$W=u_iI_iT=u_i\left(\frac{1}{T}\int_0^{t_1} i\,dt\right)T=u_iq$$

where charge $q=\int_0^{t_1} i\,dt$. According to Fig. 8 charge $q=2u_i\,C$ and

$$W=\frac{(2u_i)^2C}{2} \qquad (4/b)$$

that is, the energy delivered by the circuit to the load in one period is the same as in the parallel switched condenser circuit.

The average value of the input and output curıent for both configurations

$$I_i = \frac{W}{u_i T} = \frac{u_i}{T/2C} = \frac{u_i}{R} \tag{5}$$

and

$$I_0 = \frac{W}{u_0 T} = \frac{u_i}{u_0} I_i \tag{6}$$

respectively, that is, the average input resistance R can be changed by period T. The constant load current $I_L = I_0$.

The most important feature of both configurations in Fig. 6 is that constant energy portions can be transported by them to the load in every period if $u_i > u_0$ and both u_i and u_0 are constant. On the other hand, it can easily be shown that energy cannot be transported from the input to the output in steady-state when $u_i \leqq u_0$.

Output power

The average output power in both cases is

$$P = \frac{W}{T} = \frac{(2u_i)^2 C}{2T} = 2fCu_i^2 \tag{7}$$

By introducing $X_C = \dfrac{1}{2\pi f C} = \dfrac{1}{\omega_T C}$

$$P = \frac{1}{\pi} \frac{u_i^2}{X_C} \tag{8}$$

The output power can be changed by the input voltage and by frequency $f = 1/T$.

Transient-state

The transient behaviour of the circuits in Fig. 6 will be discussed. To simplify the analysis the following assumptions hold:

a) Energy is delivered only from the input to the output: $u_i > u_0$.

b) All losses are neglegted.

c) The capacitance of condenser C_i and C_0 is much higher than that of condenser C.

d) All initial conditions are zero, but $u_c = -u_i$ in Fig. 6.b.

A voltage step function with a magnitude u_i is applied across the input terminals at time $t = 0$.

The variation in time of output voltage u_0 at the end of each period is to be determined. The energy balance equation at the end of the $(k+1)$-th period is

$$\frac{C_0 u_{0k+1}^2}{2} = \frac{C_0 u_{0k}^2}{2} + W - \frac{u_{0k}^2}{R_L} T \tag{9/a}$$

where u_{0k} is the output voltage at the end of the k-th period, R_L is the load resistance. The output voltage at the start of the $(k+1)$-th period u_{0k} was assumed being constant in the whole $(k+1)$-th period when calculating the energy delivered to the load. The second possible approximation could be the other extreme assumption that the voltage developed across the output terminals at the end of the $(k+1)$-th period u_{0k+1} is presumed being constant in the whole $(k+1)$-th period when calculating the energy delivered to the load. Now the energy balance equation takes the form as follows:

$$\frac{C_0 u_{0k+1}^2}{2} = \frac{C_0 u_{0k}^2}{2} + W - \frac{u_{0k+1}^2}{R_L} T \tag{9/b}$$

By rearranging eq. (9/a) and (9/b), difference equation

$$x_{k+1} - a_1 x_k = b_1 \tag{10/a}$$

and

$$x_{k+1} - a_2 x_k = b_2 \tag{10/b}$$

are obtained, respectively, where

$$x_k = u_{0k}^2$$

$$a_1 = 1 - \frac{2T}{C_0 R_L}; \qquad a_2 = \frac{1}{1 + \dfrac{2T}{C_0 R_L}} \tag{11}$$

$$b_1 = \frac{2}{C_0} W; \qquad b_2 = \frac{2}{C_0} W \frac{1}{1 + \dfrac{2T}{C_0 R_L}} \tag{12}$$

W and therefore b is changing as a step function. The Z transform of the difference equation (10) is

$$x(z) = b \frac{z}{z-1} \frac{1}{z-a} = \frac{b}{1-b} \left(\frac{z}{z-1} - \frac{z}{z-a} \right) \tag{13}$$

The inverse Z transform of eq. (13) is

$$x_k = \frac{b}{1-a} (1 - a^k)$$

and the output voltage at the end of the k-th period is

$$u_0 = \sqrt{\frac{b}{1-a}}\sqrt{1-a^k}\,. \tag{14}$$

The steady-state value of voltage u_0 is

$$u_0 = \sqrt{\frac{b}{1-a}} = \sqrt{\frac{R_L W}{T}} \tag{15/a}$$

or introducing eq. (4/b)

$$u_0 = u_i \sqrt{\frac{T_L}{T}}\sqrt{\frac{2}{n}} \tag{15/b}$$

where $T_L = R_L C_0$ and $n = C_0/C$.

In order to obtain a sense of the speed of change in voltage u_{0k}, time T_0 needed to reach 63% of the final value of voltage u_{0k} will be determined from equation

$$\sqrt{1-a^{T_0/T}} = 0.63$$

or

$$\frac{T_0}{T} = -\frac{0.51}{\ln a}\,.$$

As $\ln a = \ln(1-q)$ where $q = \frac{2T}{C_0 R_L} \ll 1$,

$$\ln(1-q) = -\left(q + \frac{q^2}{2} + \frac{q^3}{3} + \ldots\right) \cong -q.$$

Therefore

$$T_0 \cong 0.255 C_0 R_L\,. \tag{16}$$

In no load $R_L = \infty$ and $a = 1$. The Z transform of difference equation (10) is

$$x(z) = b\frac{z}{(z-1)^2}\,.$$

The inverse Z transform is

$$x_k = bk$$

$$u_{0k} = \sqrt{b}\sqrt{k} = \sqrt{\frac{2}{C_0}W}\sqrt{k} \tag{17/a}$$

or introducing eq. (4)

$$u_{0k}=\frac{2u_i}{\sqrt{n}}\sqrt{k}=u_{01}\sqrt{k}. \tag{17/b}$$

The time function of u_{0k}/u_i is shown in Fig. 9.

Output voltage is increasing without limit. Because of our original assumption (*a*), that is, $u_i > u_0$ the gating of the thyristors will be stopped after u_{0k} reaches the value u_i. It can be seen from eq. (17/b) that $u_{0k}=u_i$ after the $(k=4n)$-th period.

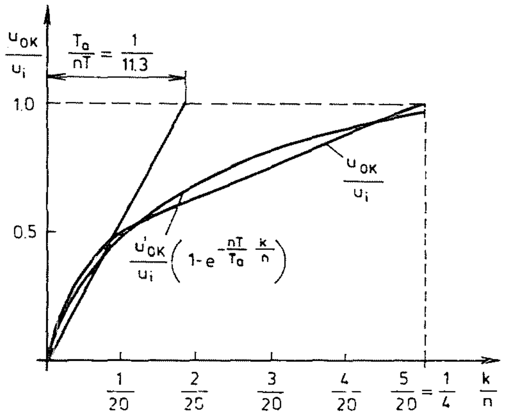

Fig. 9. Time function of output voltage

Time function u_{0k}/u_i can be approximated by the exponential function

$$\frac{u'_{0k}}{u_i}=1-e^{-\frac{nT}{T_a}\frac{k}{n}}. \tag{18}$$

Time constant T_a is determined from equation

$$\int_0^{1/4}(u_{0k}-u'_{0k})d(k/n)=0. \tag{19}$$

It means that the voltage-time area under both functions is the same from $\frac{k}{n}=0$ till $\frac{k}{n}=\frac{1}{4}$. The result is

$$T_a=0.0886nT. \tag{20}$$

When the switching frequency $f=1/T=1$ kHz and $n=C_0/C=100$, the time constant $T_a=8.86$ ms.

Computer results

The time function of current i and that of output voltage u_0 is shown in Fig. 10 in transient state in the case of series switched condenser circuit (see Fig. 5.b). The curves are the responses to a step change in the input voltage from $u_i = 0V$ to $u_i = 400$ V. The data of the circuit are as follows: $C = 4$ µF, $C_i = C_0 = 400$ µF, $L = L_l = 2.56$ µH, $R_L = 5$ Ω and $T = 40$ µs. Each thyristor is fired 10 µs after the current conduction stopped in the other one. The average value of the output voltage is 400 V as well and that of the output power is 32 kW in steady-state. The thyristor 700 PBQ from International Rectifier, for example, can handle the duty.

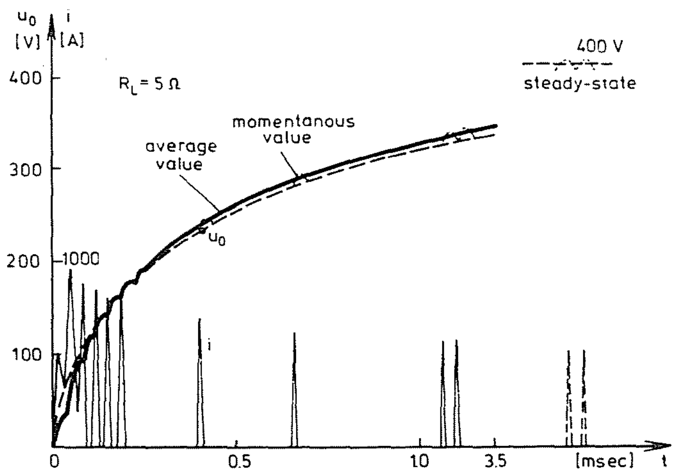

Fig. 10. Computer results

The curve drawn with a dotted line shows the results for the output voltage obtained by the approximate relation (14). The two kinds of approximation provide almost the same result. The accurate and the approximate results are close to each other.

Configurations

One quadrant operation: The circuits drawn in Fig. 6 operate only with positive input and output voltage and only one direction for the average value of the input and output current is possible in steady-state. It means that energy can be transported only from the input to the output. A further condition for energy transport is: $u_i > u_0$.

Two quadrant operation: The circuits shown in Fig. 11 can operate only with positive input and output voltage but the average value of the input current can be bidirectional due to the back to back thyristor pairs in steady-state. Energy can be delivered from the input towards the output by alternately gating thyristor T_{i1} and T_{01} provided that $u_i > u_0$ and from the output to the input by alternately firing thyristor T_{02} and T_{i2} provided that $u_0 > u_i$. In this second case the average value of current i_i will be negative.

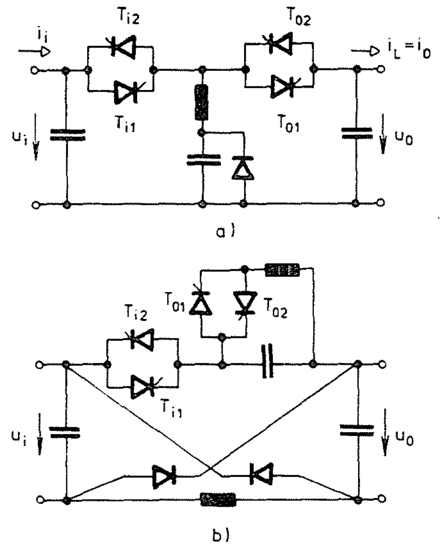

Fig. 11. Switched condenser circuits for two quadrant operation

Four quadrant operation: Both the input and the output voltage and the average value of the input and output current can be bidirectional in the configurations presented in Fig. 5 in steady-state. The following remarks are referring to the connection shown in Fig. 5.a. *By positive input and output voltage* energy can be delivered towards the output ($u_i > u_0$ and T_{i1}, T_{01} are gated) or towards the input ($u_0 > u_i$ and T_{02}, T_{i2} are gated). In both cases only thyristor T_{c1} has to be fired in order to shorten condenser C. *By negative input and output voltage* energy can be transported towards the output ($u_i < u_0$ and T_{i2}, T_{02} are gated) or towards the input ($u_0 < u_i$ and T_{i1}, T_{01} are gated). In both cases only thyristor T_{c2} has to be fired when voltage u_c tends to take a positive value. *By positive input and negative output voltage* the sign of the output voltage will be reversed within one switching cycle. First thyristor T_{i1} has to be fired and later T_{01}. Neglecting the damping effect of the load, the ringing current i flowing in thyristor T_{01} is first varying sinusoidally with angular frequency $\frac{1}{\sqrt{LC}}$ till voltage u_c is reduced to zero and thyristor T_{c1} gets fired. From that time on, current i is changing sinusoidally with angular frequency $\frac{1}{\sqrt{LC_0}}$. As long as $u_0 < 0$, first the negative current i is increasing in negative direction. When current i reaches its zero value and thyristor T_{01} and T_{c1} turn off the output voltage u_0 has been positive. It means that the sign of the output voltage will always be identical with the sign of the input voltage after one switching cycle.

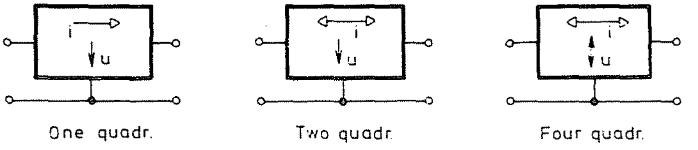

Fig. 12. Denotations of parallel switched condenser circuits

On the one hand the parallel switched condenser circuit seems to be more favourable for two reasons:

a) The input and output circuit has always a common terminal.

b) The circuit is simpler in two and four quadrant versions.

On the other hand, the series switched condenser circuit has two very important advantages over the parallel one

a) A single current pulse delivers the energy from the sending side to the receiving end.

b) The condenser voltage reversing circuit consisting of thyristor T_0 and choke L_t (Fig. 6.b) is unnecessery in some configurations (see later Figs 18 and Fig. 21).

The denotation of the parallel switched condenser configurations operating in one, two and four quadrants is given in Fig. 12. The denotations do not include condensers C_i and C_0.

Applications

The firing control of the thyristors has to take into consideration some restrictions or viewpoints as follows:

a) The gating of the thyristors has to be stopped when the voltage at the energy receiving side is equal to or higher than the voltage at the energy sending side.

b) The circuit turn-off time must be higher than the thyristor one.

c) By changing the switching frequency $f=1/T$ and by selecting the thyristors to be fired, a wide variety of time functions of the output voltage can be realized.

Concerning the application of the switched condenser concept some possible configurations will be shown.

One of the most natural applications of the circuitry operating in one quadrant is a fast responsee chopper (Fig. 13).

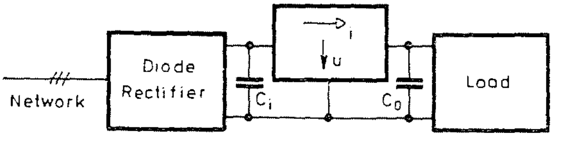

Fig. 13. Switched condenser as chopper

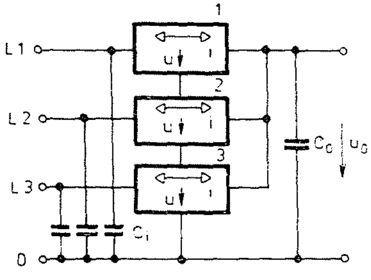

Fig. 14. Three phase switched condenser rectifier

The configuration shown in Fig. 14 realizes a rectifying and filtering function. The three phase rectifier incorporates two quadrant switching condenser circuits given in Fig. 11.a. The mode of action of the circuit in a rectifier state is as follows. The time functions of the input and output voltages are shown in Fig. 15. The approximately constant output voltage is small in Fig. 15.a and high in Fig. 15.b. Thyristor T_{i1} and T_{01} (see Fig. 11) are alternately fired in subcircuit 1 from time 1 till 2. The corresponding thyristors are alternately gated in subcircuit 2 from time 3 till 4, while thyristor T_{i1} and T_{01} in subcircuit 3 are alternately turned on from time 5 till 6. In the case of small output voltage one subcircuit can transport energy from the network to the load during one third of the line period while at high output voltage the operation range in time is smaller.

Energy can be supplied back to the network from the d.c. side in an inverter state. This mode of operation can be implemented in intervals where the line voltages are positive and smaller than the output voltage. Thyristor T_{02} and T_{i2} have to be gated in an inverter state.

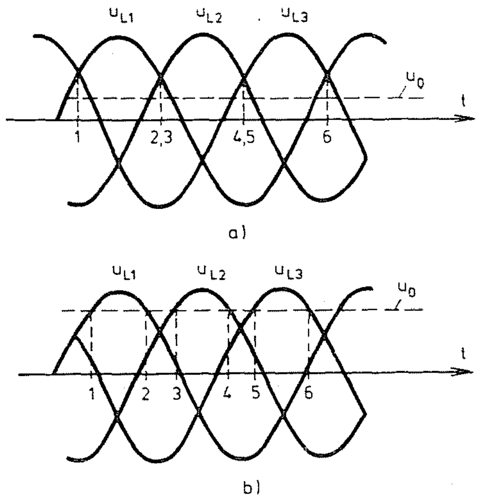

Fig. 15. Mode of action of circuit shown in Fig. 14

Filtering of the output voltage is achieved by the proper design of condenser C_0 and the right timing of firing. The advantageous feature of this circuit is that filtered d.c. voltage is obtained without bulky filtering choke.

By reversing the direction of the free-wheeling diode (Fig. 11.a) in the parallel switched condenser configurations in Fig. 14, a negative output voltage is obtained. The firing circuit has to make subcircuit 1, 2 and 3 operate in the negative half period of the phase voltages.

By inserting the four quadrant version into the configuration of Fig. 14 into the place of subcircuit 1, 2 and 3, a four quadrant rectifier is obtained. It can provide both positive and negative output voltage and current and it can operate either in a rectifier or an inverter mode.

Cycloconverter operation can be realized by changing the output voltage sinusoidally with lower frequency than that of the supply one.

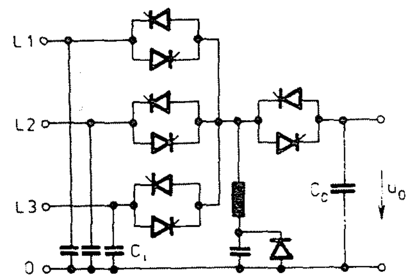

Fig. 16. Simplified version of configuration shown in Fig. 14

A simpler realization of the configuration shown in Fig. 14 is given in Fig. 16. The mode of action of the circuit is the same but there is only one switched condenser and one back-to-back thyristor pair in the output circuit.

The current drawn from the network by the configuration shown in Fig. 14 and in Fig. 16 has a d.c. component. Configuration presented in Fig. 17 draws only a.c. current from the network. Here the current is simultaneously conducted by two thyristors.

A three phase rectifying and filtering function can be realized by series switched condenser circuits as well (Fig. 18). There are only six thyristors and

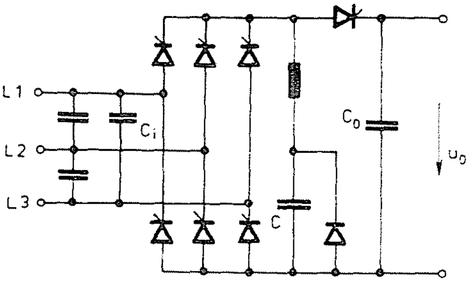

Fig. 17. Three phase rectifier drawing only a.c. current from the line

one switched condenser here. In one sixth of the mains period one thyristor is gated periodically. The restriction mentioned in connection with Fig. 15 has to be taken into consideration. Only one current pulse delivers the energy from the input to the output. No condenser voltage reversing circuit $T_0 - L_l$ (see Fig. 6.b) is needed since the positive and negative current pulses in condenser C are the same in average.

The circuit with switched condenser can be an *adaptive filter* provided, that the smooth output d.c. voltage is always smaller than the smallest instantaneous value of the fluctuating d.c. input voltage.

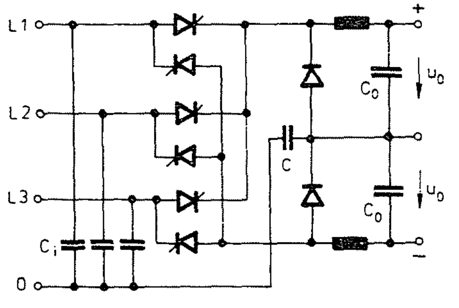

Fig. 18. Three phase rectifier with series switched condenser

A high frequency inverter configuration is shown in Fig. 19 using the principle of switched condensers. There is a parallel ringing circuit across the output terminals. The aim of the inverter is to produce a sinusoidal voltage u_0 oscillating with the natural frequency of the load. In the positive half cycle of the output voltage the energy is drawn from the phase with a most positive voltage while in the negative half cycle of the output voltage the phase with the

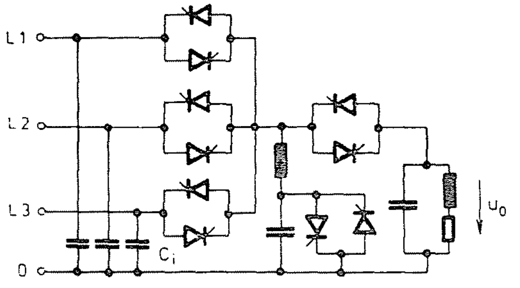

Fig. 19 High frequency inverter supplied by three phase voltages

most negative voltage supplies the energy. The peak value of the output voltage must be smaller than or equal to the half of the peak value of the phase voltages. Twelve energy portions can be supplied to the load in each half cycle of the output voltage provided that the output frequency is 1 kHz and the switching frequency is $f=\frac{1}{T}=\frac{1}{40\,10^{-6}\,\mathrm{s}}=25$ kHz.

The known high frequency time sharing inverter configuration shown in Fig. 20 is built up in fact by six parallel switched condenser subcircuits. One of them, that is, subcircuit 1 is encircled by a dotted line. The output voltage is changing sinusoidally. It should be stressed that only one energy portion is supplied to the load by the inverter in one half cycle of the output voltage. The main difference between the parallel switched condenser circuit and one of the subcircuits drawn in Fig. 20 is that there is no free-wheeling diode parallel with the switched condenser. The lack of the free-wheeling diode creates no problem here, since in a steady-state, the average value of the output voltage calculated in the current conduction time of an output thyristor T_0 equals the average value of the input voltage determined in the current conduction interval of an input thyristor T_i since the average value of the voltage across the chokes during one current conduction interval is zero. This mode of operation corresponds to the case when the input and output voltage in the switched condenser circuits are d.c. one. they are smooth and $u_i=u_0$. (See Fig. 7.c and Fig. 8.c.) The mode of action of the inverter can be read in literature [7], [8].

An other known version of the high frequency inverter configurations is shown in Fig. 21 [9]. It is built up by six series switched condenser subcircuits of

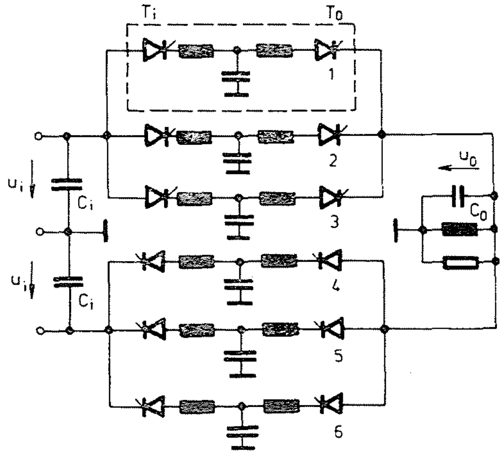

Fig. 20. High frequency time sharing inverter with parallel switched condenser

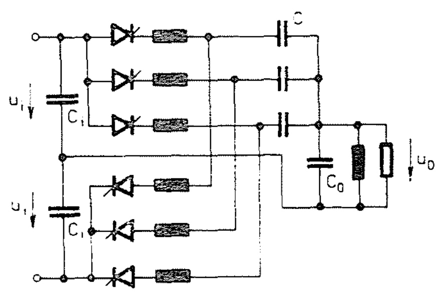

Fig. 21. High frequency time sharing inverter with series switched condenser

which two have the same condenser, C. The output voltage is alternating sinusoidally by the resonancc frequency of the load. Here again only one energy portion is supplied to the load by the inverter during the half cycle of the output voltage. There is no need for condenser voltage reversing thyristor T_0 and choke L_l (Fig. 5.b) since the same size of positive and negative current pulse is flowing in condenser C in a steady-state, because of the symmetry. The free-wheeling diode is omitted for the same reason as was stated in connection with the previous circuit.

A stand-by power supply configuration is shown in Fig. 22. It provides a single phase alternating voltage u_0 from d.c. voltage u_i. In the positive half cycle of the output voltage, subcircuit 1 provides the energy to the load and in the negative half cycle subcircuit 2 does that. It is assumed here that the system built up from the load and parallel condenser C_0 would reduce its voltage u_0 much faster without power supply than desired from the viewpoint of

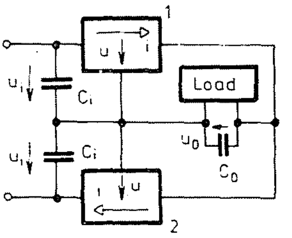

Fig. 22. Stand-by power supply

sinusoidal change even at the lowest load consumption. It means that the load—condenser C_0 system needs power supply in the second half of the half-cycle of the output voltage to ensure a more or less sinusoidal output voltage.

The configuration carries out the inverting and filtering function together without any special filter circuit.

Conclusions

The switched condenser used in integrated circuits replaces the resistor in communication engineering. A number of simple and sophisticated integrated circuits can be realized by it, such as R–C circuits, integrators and filters.

The switched condenser circuits introduced here operate periodically with variable high frequency and deliver under certain restrictions constant energy portions from the input to the output or vice versa within one period in steady-state at constant input or output voltage. The energy delivered by the circuits is proportional to the square of the voltage developed across the sending terminals.

Their dynamic behaviour can be changed with switching frequency f. By increasing f, the response time is reduced.

By using the same basic concept one, two and four quadrant configurations can be built.

Special advantageous features of the switched condenser circuits are that on the one hand, the application of expensive, bulky chokes can be avoided and on the other, a number of different energy conversion tasks can be solved basically by the same configurations and finally there are no force-commutated thyristors in them.

It should be stressed that further theoretical and experimental work has to be done to acquire deeper insight into the behaviour of the configurations.

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