Four-quadrant Switch-mode Gyrator

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***Abstract*—A gyrator design based on an inductor coupled double bridge converter is presented. It is shown that this gyrator can operate in four-quadrant mode by using bi-directional MOS switches without the necessity of any feedback control circuit. There are different usage areas of such a gyrator. Some of which can be used for conversions of voltage to current, current to voltage, capacitor to inductor and Resistance to Resistance. In this paper, the dynamic and static gyrator behavior is first simulated and some of above conversions are also tested.**

I. Gyrator Behavior of the Inductor Coupled Double Bridge Converter

In literature, the gyrator concept is firstly proposed by Tellegen [1]. An ideal gyrator which is shown in Fig.1 is a two port network element and it can be defined by following admittance matrice where

$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} 0 & g \\ -g & 0 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \tag{1}$$

"g" is gyration conductance.

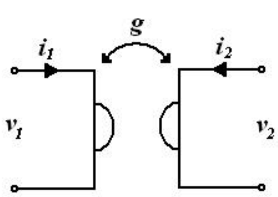

Figure 1. Symbolic Representation of a Gyrator

The V-I, I-V, L-C, C-L and R-R conversions can be easily done with a gyrator and the values of the converted components can also be easily adjusted by controlling gyration conductance (g).

Gyrators can be realized either by analog [2-8] or switch-mode circuits [9-18]. Analog gyrators can be realized by transistors or operational amplifiers but they are not efficient. Most of the switch-mode gyrators are realized by using feedback control circuits [9-10, 14-18]. This type of gyrators with feedback control works only one or two quadrant modes. The first loss-free gyrator which was designed with switch mode power converters is presented by Singer [9-10]. A double bridge converter with inductive or capacitive energy transfer is proved to be work as a power gyrator [11-12]. These two circuits have control-free structure. In [13] it is shown that a transmission line between two switching networks exhibits gyrator-like behavior. More recently, however it is reported that a new gyrator structure is disclosed with an equivalence sliding mode and PWM control [14-18], it has still a control circuit and work under steady state conditions.

The gyrator presented in this paper is constructed by double-bridge converter [11-12] which works by means of inductive energy transfer. It has a control-free structure and power conservative because of switch mode operation. By using such a gyrator, a voltage source type load is transferred to the input as a current source type. This means that the duality applies. Voltage-to-current source and capacitance-to-inductance conversion can easily be done with this gyrator. The component value seen at the input port can be adjusted by changing the gyration conductance with switching frequency or phase difference between two bridges. The design steps and simulation results are also presented in the paper.

To the authors' knowledge four-quadrant gyrator realization has not been presented yet. In this paper a four quadrant gyrator realization by using bidirectional switches is reported.

II. Gyrator Behavior of the Inductor Coupled Double Bridge Converter

The double bridge converters are constructed by an input bridge and an output bridge for power conversion. The double bridge topology, shown in Fig. 2 uses an inductor link for the temporary storage of energy. It represents a power converter that inherently satisfies the gyrator equations when state-space averaging is considered without being forced by closed-loop control. Considering the ideal converter circuit in fig. 2, V_1 and V_2 are normally changing. Due to the high

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frequency switching, V_1 and V_2 are assumed to be constant in a switching period.

Then it can be considered a dc-dc switching power converter in a short time interval. It operates as follows: On the source-side (left) bridge, the switching sequence is Sll-S14, S12-S13, Sll-S14,... . The load-side (right) converter follows the same switching sequence. However, the corresponding switching events between the source and load bridges are phase shifted. The voltages v_A and v_B are square waves. The average power can be calculated over one switching cycle. The voltage and current waveforms are shown in fig. 4.

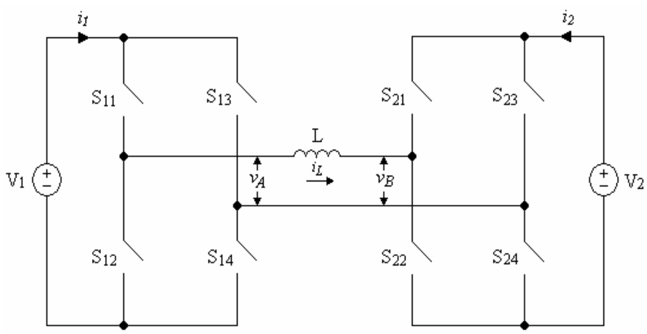

Figure 2. Double bridge topology with inductive energy transfer

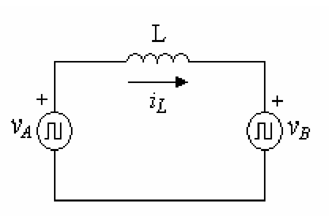

Figure 3. Simplified double-bridge toplogy and inductor link.

The average source current $< i_1 >$ can be calculated from fig. 4 as follows. In this calculation 90 degrees phase shift is assumed between the switching times of the left and the right bridges.

The current increases "ia" and "ib" given in the fig. 4 can be found by using $V = L\frac{\Delta i}{\Delta t}$ as follows

$$i_a = \frac{(V_1 + V_2)}{L}\frac{T}{4} \tag{2}$$

$$i_b = \frac{(V_1 - V_2)}{L}\frac{T}{4} \tag{3}$$

Geometrically from the areas of A_1, A_2, A_3 and A_4 we obtain

$$< i_1 >= \frac{A_1 + A_2 - A_3 - A_4}{T} \tag{4}$$

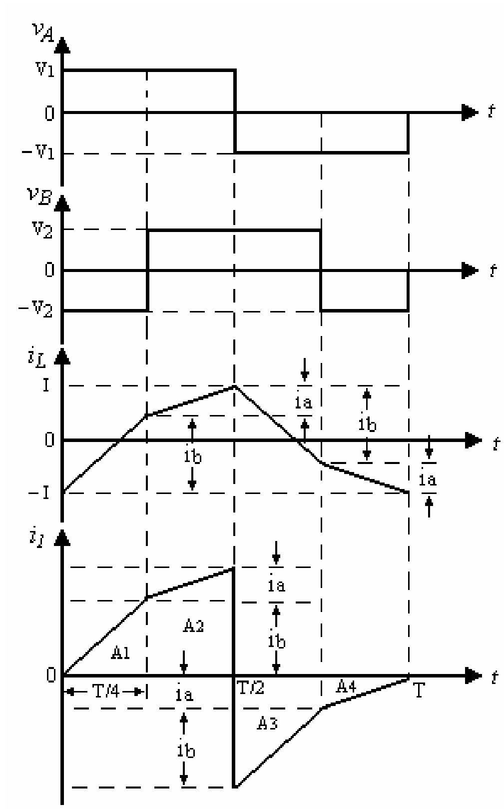

Figure 4. Waveforms of the double-bridge converter given in fig 2.

Then it results

$$< i_1 >= \left(\frac{T}{8.L}\right)V_2 \tag{5}$$

And the net power becomes

$$P = V_1 < i_1 >= gV_1V_2 \tag{6}$$

As the gyrator is a loss-free circuit with ideal elements

$$P = V_1 < i_1 >= V_2 < i_2 > \tag{7}$$

So the gyration conductance (g) is found

$$g = \frac{T_s}{8.L} = \frac{1}{8.L.f_s} \tag{8}$$

where L is the link inductor and f_s is the switching frequency. This result is the special case of the general "g" equation (9) given in [12].

$$g_L = \frac{\phi - \phi^2 / \pi}{\omega L} \tag{9}$$

Substituting $\phi = \pi / 2$, $\omega = 2\pi f_s$ in eq. (9) gives the same "g" with (8) which is the maximum obtainable value for ϕ.

III. Simulation Results

The four-quadrant operation of the gyrator is simulated by using PSpice. From the input of the gyrator an inductor will be seen when a capacitive load is used.

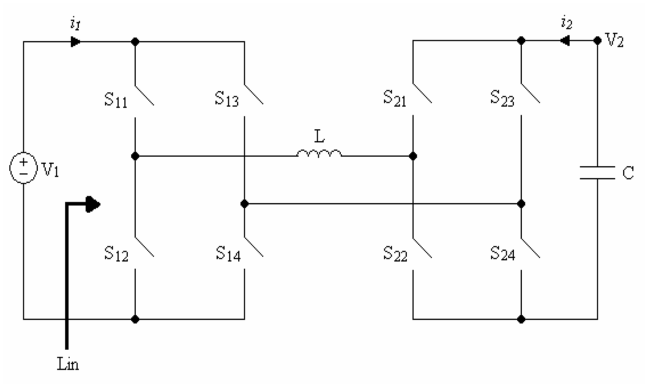

Figure 5. Gyrator circuit with capacitive load.

The value of the inductor seen at the input port is

$$L_{in} = \frac{C}{g^2} \tag{10}$$

$$L_{in} = 64L^2 f_s^2 C \tag{11}$$

It is interesting that "g" can also be controlled by switching frequency.

When the link inductance (L) is 2mH, switching frequency f_s is 10Khz and the phase shift between input and output bridge is 90° the inductance L_{in} is calculated as follows.

$$g = \frac{1}{8.2.10^{-3}10.10^{3}} = \frac{1}{160}\Omega^{-1} \tag{12}$$

$$L_{in} = \frac{1.10^{-6}}{\left(\frac{1}{160}\right)^2} = 25.6\text{mH} \tag{13}$$

The capacitor loaded four–quadrant gyrator structure used in simulation is given in fig 6. There are eight switches in the circuit. Four of them are at the input bridge and the others are at the output. The link inductance L and the load capacitor C are taken 2mH and 1uF.

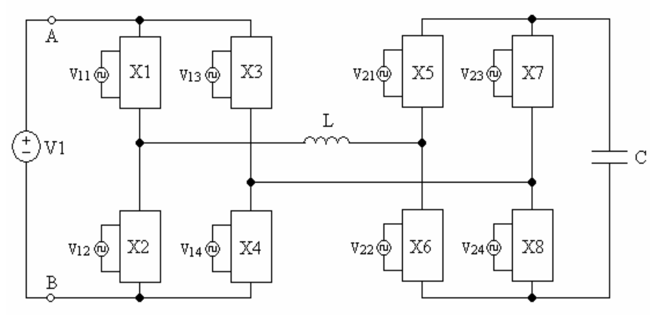

Figure 6. Gyrator with four-quadrant switches

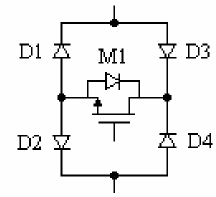

Figure 7. Four quadrant switch topology

One of the switches used in fig 6 is shown in fig. 7.

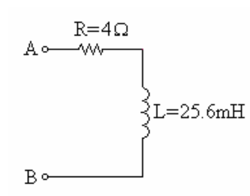

Figure 8. Test circuit

In these figures, the test circuit results can also be seen together. The switch mode gyrator is compared with a simple test circuit given in fig. 8. The 4Ω resistor is found by trial and error. It represents the equivalent series resistor of the inductor seen from the input. Simulation results for a step, pulse and sinusoidal inputs are given in fig. 9, 10 and 11.

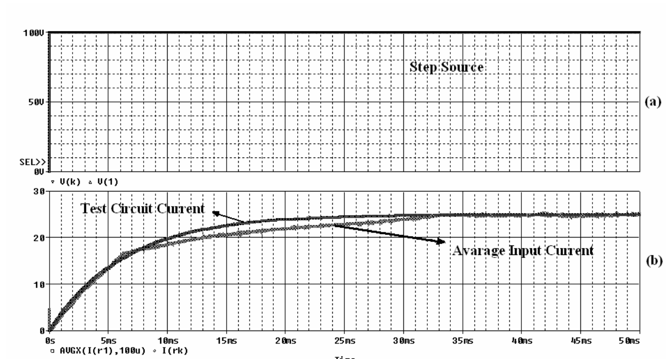

Figure 9. (a) 100V step source (b) Avarage gyrator current and test circuit current

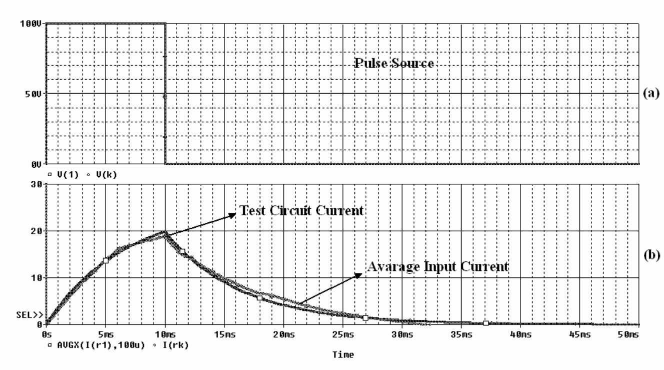

Figure 10. (a) 10ms pulse source (b) Avarage input current and test circuit current

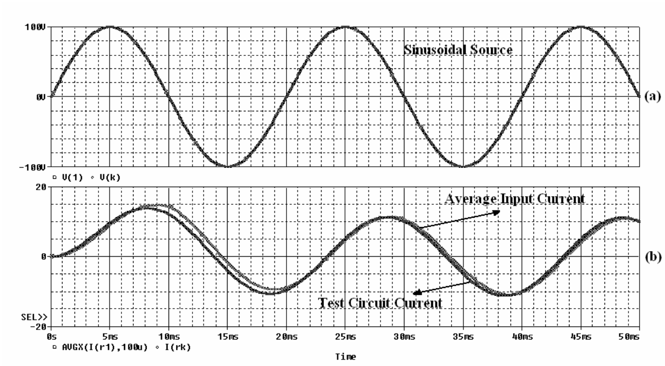

Figure 11. (a) Sinusoidal source (b) Avarage input current and test circuit current

IV. CONCLUSION

As a result, the proposed double bridge power gyrator with inductive energy transfer brings control-free gyration ability. It can be seen from the simulation results that the gyrator can work under both transient and steady-state conditions. These features separate the gyrator given in this paper from the previously presented ones.

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