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MODELLING OF TWO-PHASE SINGLE-LEG MATRIX CONVERTER USING LT SPICE CIRCUIT SIMULATOR

Abstract

The paper deals with two-phase one-leg matrix converter with minimum switching devices. Main emphasis is laid on modelling and simulation of a new type of single-phase supplied AC/AC converter with two phase outputs. It consists of one-leg half-bridge matrix converter loaded by the resistive-inductive load in series connection. As harmonic analysis of the voltage of both phases gives very high value of total harmonic distortion (roughly 86 %) the current waveforms should be improved by using of serial LC filter – which brings much more suitable value of THD (5 % - 8 %) acceptable for application. Real simulation results using LT Spice circuit simulator under RL loading are given in the paper.

INTRODUCTION

The matrix converter topology is well known for a longer time with intensive research going on for decades. Despite this, the industrial use in comparison to classical DC-link converters is still low but rising. In comparison to classical DC converters the matrix converter doesn't have intermediate circuitry with bulky filtering capacitors, which eliminates one step of the energy conversions and leads to smaller size and higher efficiency. This is one of the advantage of this type of converter. Other advantages are the unity power factor on input, sinusoidal current input and output harmonics quantity and bidirectional energy flow. The instant power on input must be same as the power on output due to the absence of intermediate energy storage element. But this doesn't apply for reactive power. One of the disadvantages of matrix converter is higher number of semiconductor switching devices. To reduce the number of switching devices it is possible to use one-leg connection for the converter.

1. TWO-PHASE SINGLE LEG LC MATRIX CONVERTER

From single leg VSI - voltage source inverter [4] was de-rived schematics for single leg matrix converter (Fig. 1), [10].

The matrix converter requires a bidirectional switch, capable of blocking voltage and conducting current in both directions |the energy flow. These bidirectional switches, consisting of a pair of devices with turn-off capability, can be reverse blocking RB_IGBTs or more usually IGBTs with anti-parallel diodes, connected in either a common collector or a common emitter back-to-back arrangement [7].

Similarly to single leg voltage source inverter [4], single leg matrix converter also works in to two operation modes: nominal frequency regime, and variable frequency regime.

A. Nominal (Fixed) Frequency Regime

In this case (Fig. 1) the auxiliary phase will be created by 90 degrees one against original supply voltage, Fig. 2.

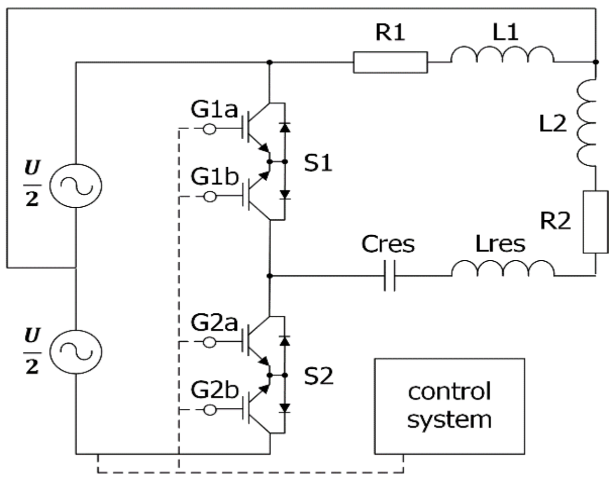

Fig. 1. *Single leg matrix converter – basic connection, nominal frequency, additional LC filter*

The resonant frequency of $L_{res}C_{res}$ should be the same as basic fundamental frequency of the converter and is governed by load requirements. Thus, based on the Thomson relation

$$\omega_{res} = \sqrt{\frac{1}{L_{res}C_{res}}} \qquad (1)$$

or, respectively

$$L_{res}\omega_{res} = \frac{1}{\omega_{res}C_{res}} \qquad (2)$$

where ω_{res} is equal 2π × fundamental frequency of the converter. Values of storage $L_{res}\omega_{res}$ components and their parameters are important for properties of $L_{res}\omega_{res}$ inverter, respectively. Theoretically, $\omega_{res}L_{res}$ and other values of (2) can be chosen from a wide range. For our first design approximation we suppose a simple resonant circuit (Fig. 1) with a resonant frequency equal to the switching input frequency ($\omega_{res} = \omega_{sw}$).

The LC design process can be considered from 3 different points of view or criteria:

1st: nominal voltage and current stresses at steady-states,
2nd: minimum voltage and current stresses during transients,
3rd: required value of total harmonic distortion of the output voltage.

In order to not exceed nominal voltages of the storage elements, we used value of internal impedance of the storage element equal to the nominal load $|Z_N|$.

$$L_{res}\omega_{res} = \frac{1}{\omega_{res}C_{res}} = |Z_N| = \frac{U_1^2}{P_1} \quad (3)$$

where U_1, P_1 are nominal output voltage or power, respectively (fundamental harmonic).
From (18) and (19) one can obtain the design formulas for LC storage elements

$$L = \frac{U_1^2}{\omega_1 P_1} q_N \qquad C = \frac{P_1}{\omega_1 U_1^2}\frac{1}{q_N} \quad (4)$$

So, for parameters given by output power and frequency

$$P = 150\ \mathrm{W},\ U = 115\ V,\ \omega_{res} = 100\pi\ (f = 50\ \mathrm{Hz})$$

$$L = \frac{U_1^2}{\omega_1 P_1} = \frac{13\ 225}{100\pi 150} = 280\ \mathrm{mH}$$
$$C = \frac{P_1}{\omega_1 U_1^2} = \frac{150}{100\pi 13\ 225} = 36\ \mu\mathrm{F}$$

$$P = 2.2\ kW, U = 115\ V, \omega_{res} = 200\pi\ (f = 100\ \mathrm{Hz})$$

$$L = \frac{U_1^2}{\omega_1 P_1} = \frac{13\ 225}{200\pi 2200} = 9.57\ \mathrm{mH}$$
$$C = \frac{P_1}{\omega_1 U_1^2} = \frac{2200}{200\pi 13\ 225} = 264.8\ \mu\mathrm{F}$$

$$P = 2.2\ kW, U = 115\ V, \omega_{res} = 400\pi\ (f = 200\ \mathrm{Hz})$$

$$L = \frac{U_1^2}{\omega_1 P_1} = \frac{13\ 225}{400\pi 2200} = 4.79\ \mathrm{mH}$$
$$C = \frac{P_1}{\omega_1 U_1^2} = \frac{2200}{400\pi 13\ 225} = 132.4\ \mu\mathrm{F}$$

B. Variable frequency regime

In this regime both phases are frequency controlled by one leg matrix converter switching in the range from zero up to nominal frequency. Basic scheme is depicted in Fig. 2, [11].

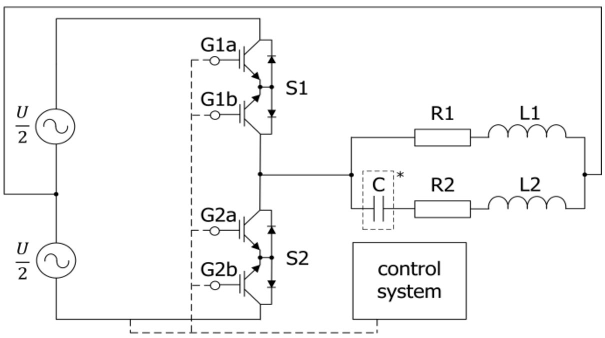

Fig. 2 *Single leg matrix converter – basic connection, variable frequency; C* - for motoric load.*

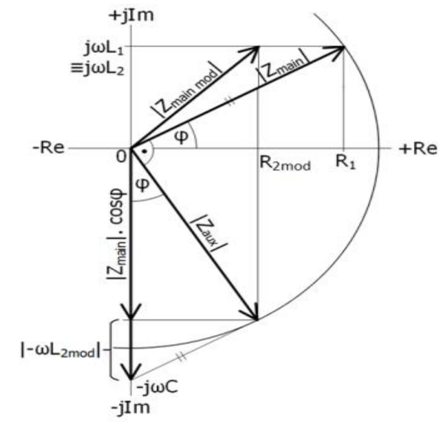

Fig. 3 *Phasor diagram for determination of capacitance and value of capacitor of auxiliary phase.*

Calculation C_{aux} for geometrical center of frequency band, i.e. 33.33 Hz at 50 Hz nominal frequency: from vector diagram the capacitor value for auxiliary phase can be determined.

$$|Z_{aux}| = |Z_{main}| \quad (5)$$

$$|\omega C_{aux}| = |Z_{aux}|\cos\varphi + |\omega L_2| \quad (6)$$

$$C_{aux} = \frac{|Z_{aux}|\cos\varphi + |\omega L_2|}{\omega} \quad (7)$$

There is equality of $|\omega L_2| = |\omega L_1|$ provide the same magnetic flux in both main and auxiliary phases.

Completing scheme in Fig. 2 by LC resonant circuit we get a new schematic, Fig. 4

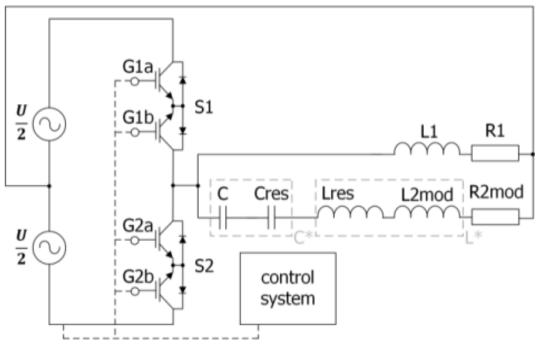

Fig. 4 *Completed schematic with LC resonant circuit at 50 Hz as nominal frequency*

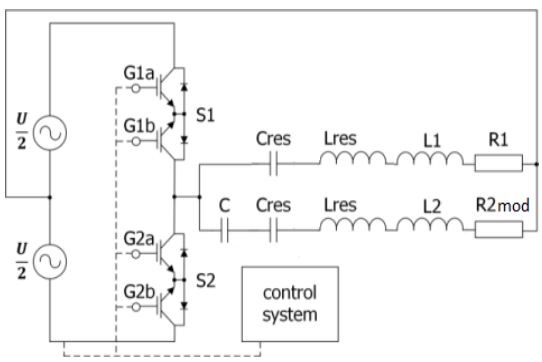

Fig. 5 *Completed schematic with LC resonant circuit at 100 Hz as nominal frequency*

2. SIMULATIONS USING LT SPICE

All simulations were provided using the LT Spice package under source voltage 2 x 115 VRMS, 50 Hz.

Parameters of the system:

R-L load: R_1=1 Ω; L_1=2.8e-3 H; cos φ1=0.82 (was changed)
Operating frequency: 50 – 40 – 33.33 – 25 – 16.66 - 10 Hz
Simulation step: 1e-5 sec.
Then

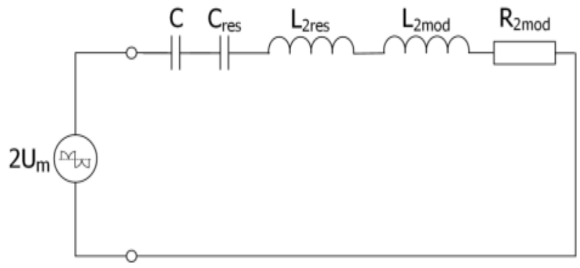

Fig. 6 Equivalent scheme of auxiliary phase for calculation

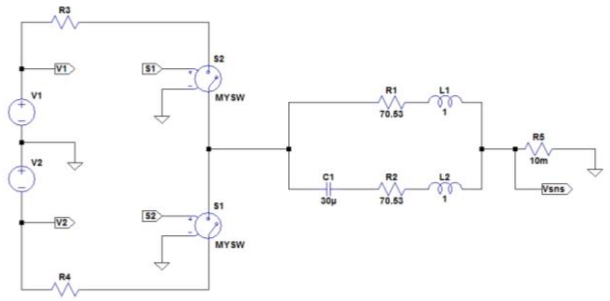

Fig. 7 LT Spice scheme of one-leg MxC circuitry (it can be change for relating operation state)

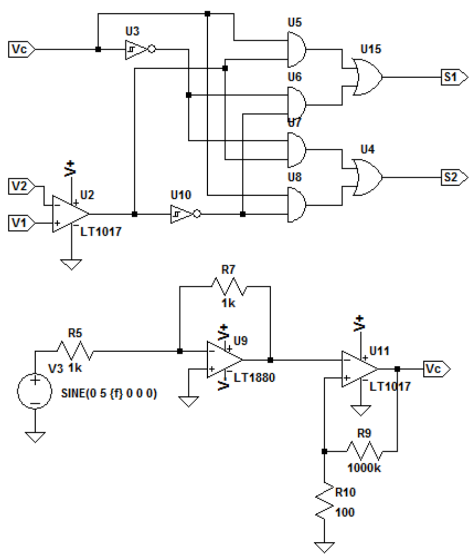

Fig. 8 LTSpice scheme of control and logic circuitry

Simulation results of voltage and current waveforms are presented for operation at 50 and 33.33 Hz, respectively, in Figure 9 and Figure 10.

Fig. 9 Voltage and current waveforms of auxiliary phase with LC filter at 50 Hz

Fig. 10 Voltage and current waveforms of auxiliary phase with LC filter at 33.33 Hz

Operation of 100 Hz appliances at full speed needs to adaptation schematic of two-phase one-leg matrix converter as shown in Fig. 5. It is due to non-harmonic waveforms of both main and auxiliary phases. Therefore, additional LC circuit should be connected at both phases. The values of LC elements will be the same because of power and supply voltage are the same. Common voltage waveform is given in Fig. 11.

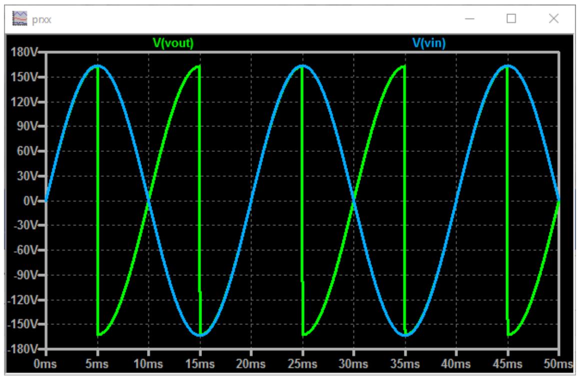

Fig. 11 Output voltage of converter main phase at 50 Hz input and 100 Hz output frequency.

There is possible to use also pulse-with-modulation technique at variable frequency regime due to lower voltage needed at lower frequencies as is possible to generate by one-leg matrix converter.

That is similar to pulse-with-modulation control technique of VSI single-leg inverter [4], [12].

Simulation results of voltage and current waveforms of main and auxiliary phases are presented operating at 100 Hz, respectively, in Figure 12 and Figure 13.

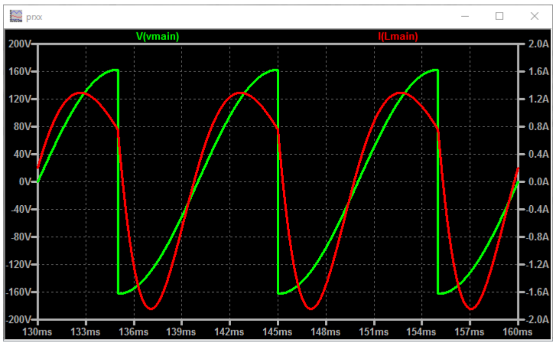

Fig. 12 *Voltage and current waveforms of* ***main*** *phase with LC filter at 100 Hz.*

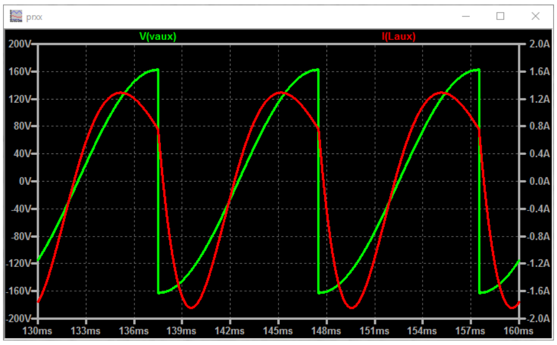

Fig. 13 *Voltage and current waveforms of* ***auxiliary*** *phase with LC filter at 100 Hz.*

Note: The current waweforms in Fig. 12 and Fig. 13 doesn't have completly symmetrical shapes of the possitve and negative half periods and at first glance it seems that there is a DC current component. But the area integral over one period is zero and therefore the DC curent component is also zero.

3. CONCLUSION

The article describes analysis, modeling and SPICE simulation of the derived one-leg matrix converter which is supplied with 2x115 V and neutral point. It has been shown in the previous analysis and simulation that the maximal reachable fundamental harmonics magnitude of auxiliary phase is just 50% of the original input phase. And therefore the input voltage must be twice of the nominal value of the voltage on output load. From this results is obvious that the switching elements should be dimensioned to withstand minimally twice the input voltage. The maximal fundamental harmonic magnitude is 82-90% of the nominal under frequency control. A future research will continue to test the single-leg MxC converter with passive and active motor load whit the help of dSpace hardware environment.

ACKNOWLEDGMENT

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