DETERMINATION LOSSES OF TWO-STAGE ELECTRONIC SYSTEM WITH TWO-PHASE ORTHOGONAL OUTPUT USING MATRIX CONVERTERS

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Abstract

The paper deals with determination losses of two-stage power electronic system with two-phase variable orthogonal output. The simulation is focused on the investigation of losses in the converter during one period in steady-state operation. Modeling and simulation of two matrix converters with R-L load is shown in the paper. Results of simulation are compared to experimental verification ones.

1 Principles of Two-stage Two-phase DC/AC/AC converter with AC voltage interlink

Two-phase converter is possible to create:

- Single stage converter, Fig. 1
  - DC/2AC

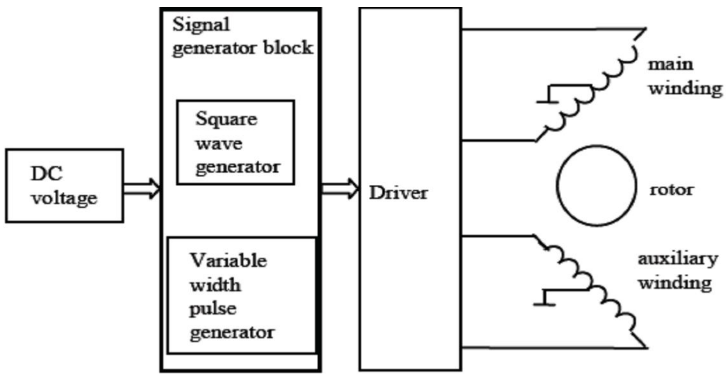

Figure 1: Block diagram for single-stage two-phase motor drive system supplied from DC source [1]

- Two-stage converter without HF transformer, Fig. 2
  - S HF TR - DC/HF_AC/2AC
  - Bez HF TR - DC/HF_AC/2AC

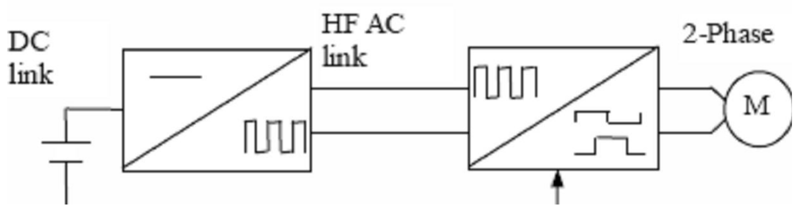

Figure 2: Principle block diagram of 2-stage DC/AC/AC converter (without HF transformer) and with 2-phase second stage [2]

Such a system usually consist of single-phase voltage inverter powered by battery or DC source (transfer of energy for zero distance), AC interlink (with, or without HF transformer), 2-phase converter and 2-phase AC motor. Block diagram of 2-stage DC/AC/AC converter without transformer and using 2-phase direct matrix converter is depicted in Fig. 2.

Two-stage DC/AC/AC converter system in Fig. 3 consists of a single-phase voltage inverter powered by battery or DC source. From output of voltage inverter are connected two single-phase matrix converters (full bridge), with switched output voltage, phase B is shifted by 90 degrees.

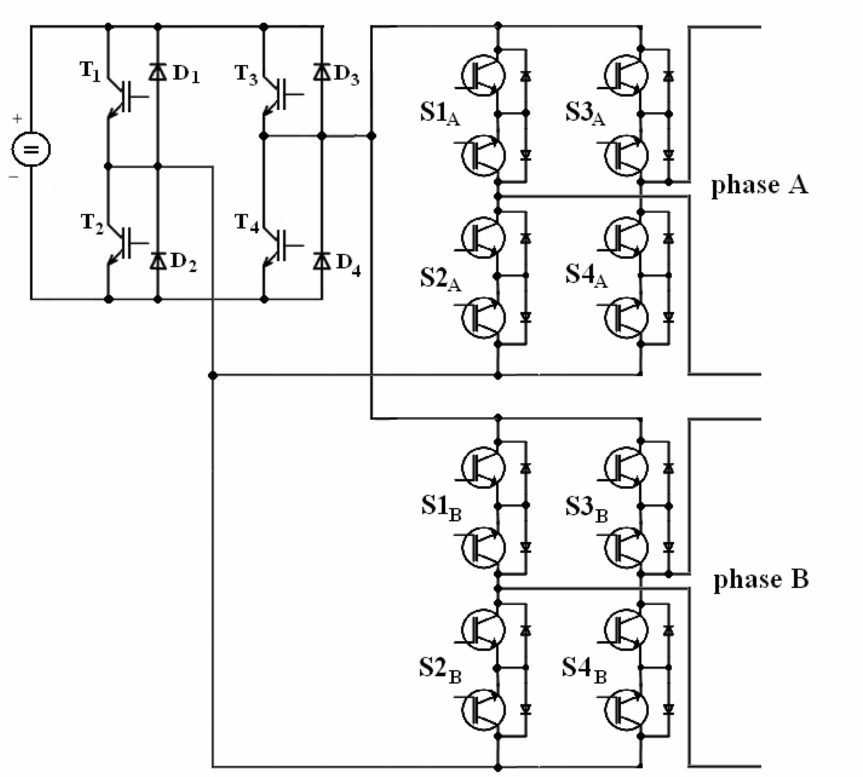

Figure 3: Two-stage two-phase DC-AC-AC converter

From output of first stage converter is DC voltage switched to AC – square-wave with duty cycle 0,5. Waveforms of inverter output voltage is shown in Fig. 4. Switches of first-stage inverter are hard commutated, but allows soft commutation to switches in second-stage matrix converters.

Switching frequency can be set from some kHz for high power applications up to several tens of kHz for low power applications.

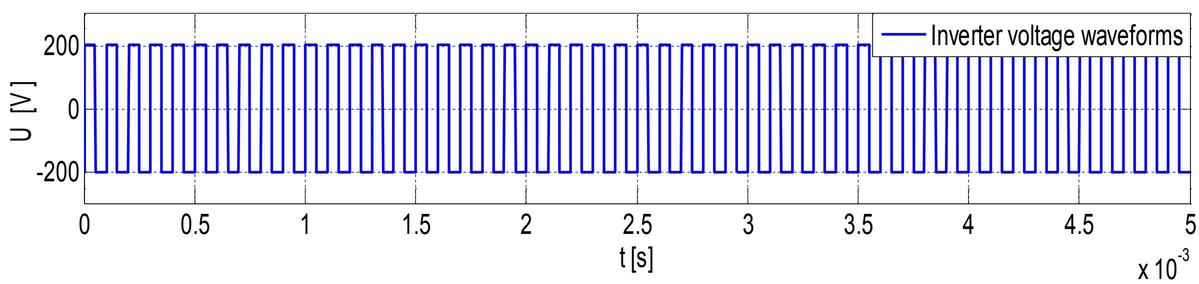

Figure 4: Voltage waveforms of AC HF interlink (first stage)

Switches of full-matrix converters are soft-commutated in the zero-voltage instants of the AC HF interlink voltage [3]. Therefore, the expected efficiency of the system can be higher as usually by using of classical DC/AC three-phase VSI inverter. On the other side, the phase current will be higher at the same output power and output voltages, using two-phase AC motor.

Output voltages of full-matrix converters are switched with unipolar PWM and phase of output voltages is mutually shifted by 90° electrical degrees, of course the output voltage supplies the RL load and waveforms of voltages are shown in Fig. 5.

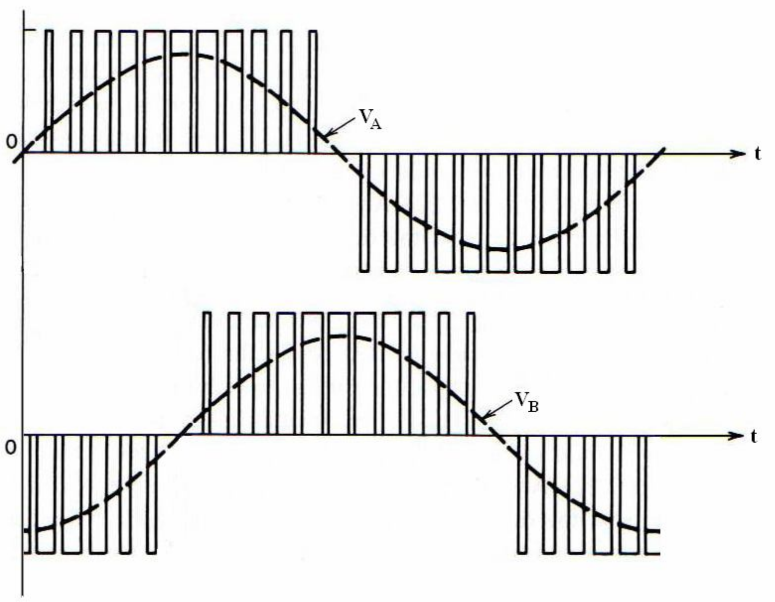

Figure 5: Voltages waveforms of unipolar PWM

2 Switching strategy

The switching frequencies can be increased to such high values only if the problem of switching stresses, switching losses. In both matrix converters is used zero voltage switching to reduce switching losses. Turn-on switching is performed at full voltage and turn-off switching is realized as ZVS, because turn-off losses are higher than turn-on losses.[4]

Lower switching frequency is used for high power applications where THD is bigger, lower THD is in low power applications with higher switching frequencies.

The total harmonic distortion of the current is given by [5]:

$$\frac{\sqrt{\sum I_v^{\,2}}}{I_1} = \sqrt{\frac{I^2 - I_1^{\,2}}{I_1^{\,2}}} = \sqrt{\left(\frac{I}{I_1}\right)^2 - 1} =$$

$$\sqrt{[(8.34822/8.34386)2-1]} = \sim 2\,\% \qquad (1)$$

Fourier analysis is useful and needed for determination of total harmonic distortion of the phase current of the matrix converter [5 - 6]. Switching strategy of one full-bridge matrix converter, based on 'even' unipolar PWM, can be explained using Figs. 6a and 6b in greater details.

Switching principles in matrix converter:

If $u(t)>0$ and $u_{AC}>0$:	$u_{tri}<u(t)$	$U=U_{DC}$	(S_1, S_4)
	$u_{tri}>u(t)$	$U=0$	(S_2, S_4)
If $u(t)>0$ and $u_{AC}<0$:	$u_{tri}<u(t)$	$U=U_{DC}$	(S_2, S_3)
	$u_{tri}>u(t)$	$U=0$	(S_2, S_4)
If $u(t)<0$ and $u_{AC}>0$:	$u_{tri}>u(t)$	$U=-U_{DC}$	(S_2, S_3)
	$u_{tri}<u(t)$	$U=0$	(S_2, S_4)
If $u(t)<0$ and $u_{AC}>0$:	$u_{tri}>u(t)$	$U=-U_{DC}$	(S_1, S_4)
	$u_{tri}<u(t)$	$U=0$	(S_2, S_4) (2)

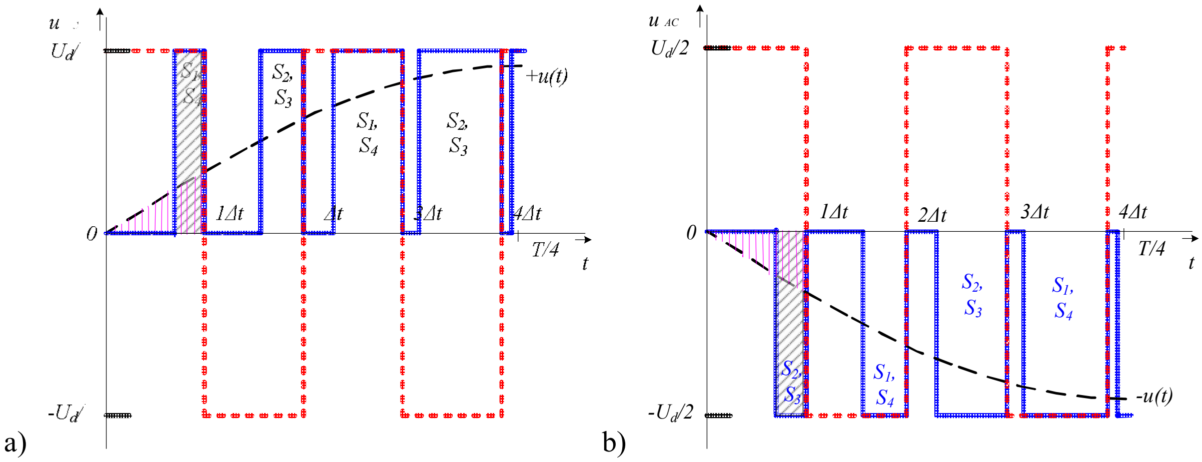

Figure 6. Switching strategy of half bridge converter for a) positive and b) negative half period of operation

It is important and clear visible from these figures that during switching at the end of the period of HF AC supply ($n.T_s$) the switching losses will be zero due to zero value of commutation voltage.

3 PC simulations

In Matlab m-file is created simulation program of two-stage two-phase converter, where at first is created square-wave of inverter, and them is calculation average value of output voltage matrix converter, from average value is calculated switching time for individual switches.

```
%calculation of inverter voltage with duty cycle = 0,5
if (t>((c-1)*T1)) && (t<=((c-1)*T1)+T1/2)
    Ua=Udc;
else
    Ua=-Udc;
end
Ustrie(i)=Ua;
if t>=c*T1
c=c+1;
end

%calculation average value for matrix converter voltage in phase A
U1=Umax*sin(2*pi*f*t);
u1=Umax*sin(2*pi*f*n1*dh);
Uav1=(a1+u1)/2;
if t>=(n1*dh)
    a1=u1;n1=n1+1;

%calculation switching time for matrix converter in phase A
end
Tsp1=(dh*abs(Uav1))/Udc;
A1=n1*dh;                              doba1=A1-Tsp1;
if  ((t>(doba1)) && (U1>0))
    UspiA(i)=Udc;
else
    UspiA(i)=0;
end
if  ((t>(doba1)) && (U1<0))
    UspiB(i)=-Udc;
else
    UspiB(i)=0;
end
Uspin1(i)=UspiA(i)+UspiB(i);
```

```
%calculation current on RL load
prud1(i)=prud1(i-1)*((L-h*R)/L)+h*Uspin1(i)/L;
```

Simulated waveforms of voltage and current on each matrix converter with RL load are depicted in Fig. 7.

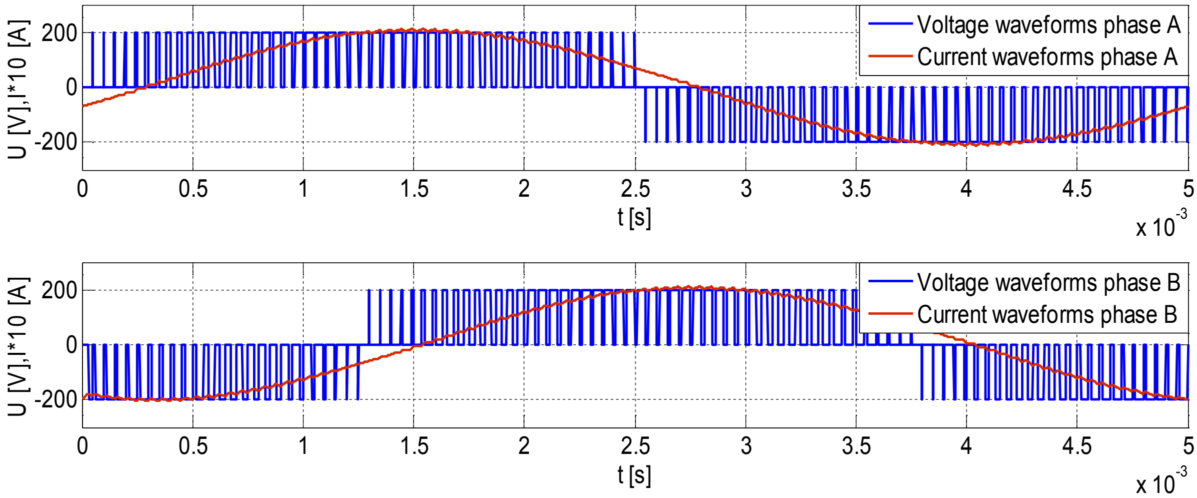

Figure 7: Voltage and current waveforms of matrix converter

Simulation parameters:

U_{DC}=200V, U_{max}=160V, $f_{switching}$=20kHz, f_{output}=200Hz, R=7.16Ω, L=2mH, I_{RL}=20.6138A

4 Experimental results

Experimental verification has been done using single-phase full-bridge inverter and single-phase full-bridge matrix converter for test rig system. There is shown test rig in Fig. 8. The whole test rig system is controlled by Freescale DSP 56F8013DEMO.

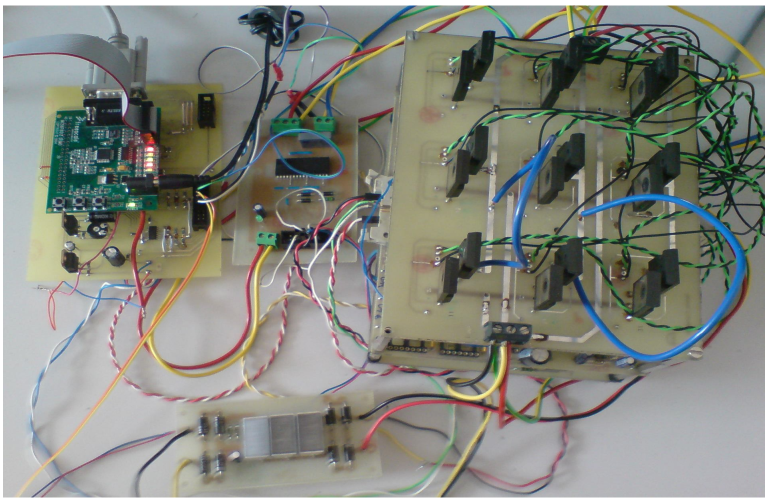

Figure 8: Physical model of single-phase inverter and matrix converter [7]

Measured waveforms of current in HF interlink is depicted in Fig. 9.

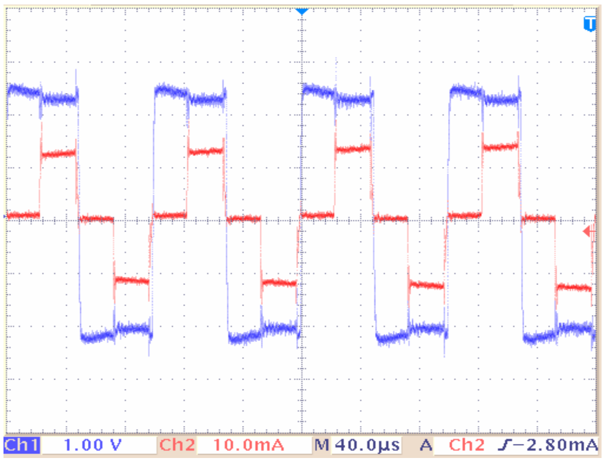

Figure 9: Waveform of voltage and current in AC HF interlink (f_{SW}=20kHz) [7]

Measured waveforms of output voltage (switched waveform) and current (continuous waveform) are depicted in Fig. 10.

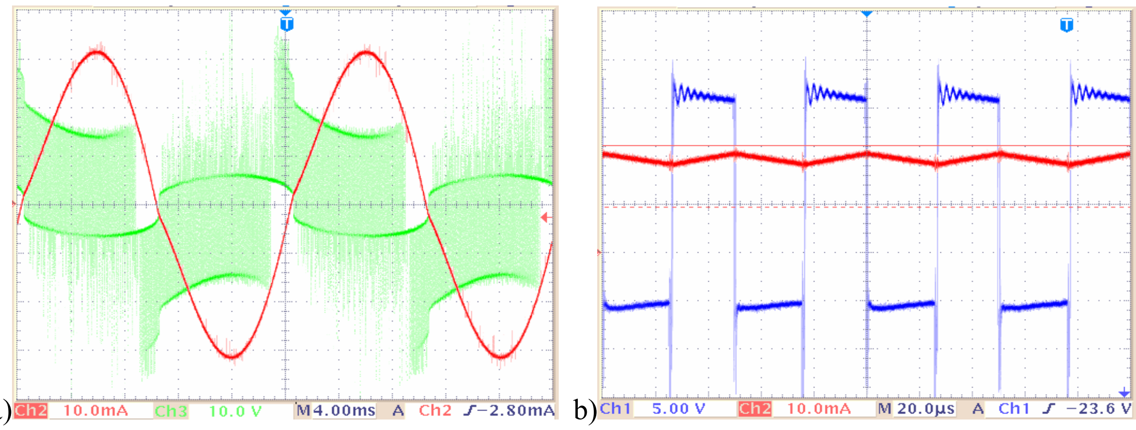

Figure 10: a) Output voltage (switched waveform) and current (continuous waveform) of DC/AC/AC converter and b) it's detail view (f_{SW}=20kHz, f_{OUT}=50Hz) [7]

Waveforms of electrical and mechanical power of DC/AC/AC converter with two-phase motor load are depicted in Fig. 11.

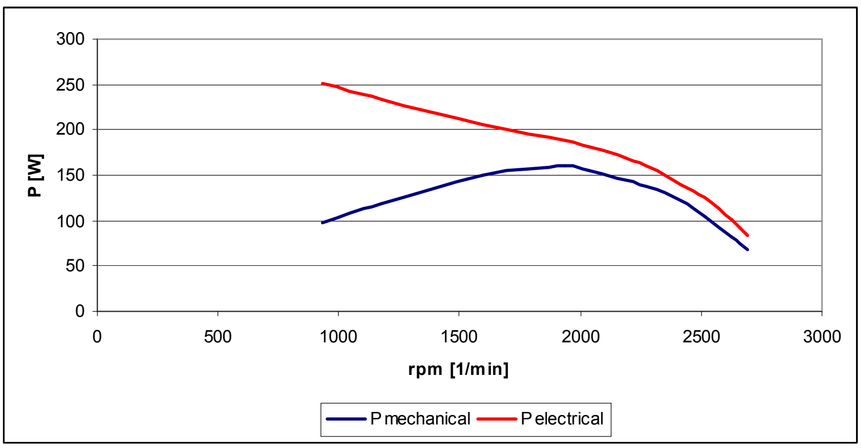

Figure 11: Waveform of electrical power of DC/AC/AC converter and mechanical power from 2-phase ASM motor

Waveforms of efficiency of DC/AC/AC converter with two-phase motor load are depicted in Fig. 12.

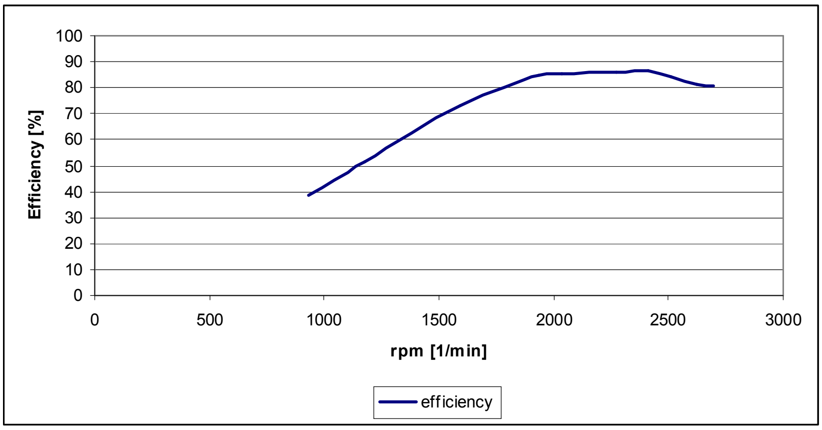

Figure 12: Efficiency waveform of DC/AC/AC converter and 2-phase ASM motor system

5 Conclusion

To reduce switching losses in DC/AC/AC converters can use half-hridge conection of inverter and half-bridge matrix converters, disadvantage is the need to use high frequency transformer. Inverter can be replace by LLC converter, which using soft commutation to reduce switching losses. There is shown in the paper the good results regarding to output quantities of matrix converters.

6 Aknowlegment

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