The Influence of Static Contactor on the THD Generated by Currents on a High Frequency Electro Thermal Installation with Electromagnetic Induction

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Abstract: - This paper presents an analysis of the electrical parameters resulted during the functioning simulation of a high frequency electro thermal installation with electromagnetic induction. Modeling and simulation the electrical scheme were made using PSCAD-EMTDC tool. The authors followed the influence of the static contactor regarding the THD generated by phase currents in secondary winding of power transformer.

Key-Words: - Electro thermal installation, electromagnetic induction, harmonic distortion.

1. Introduction

In order to maintain the electrical parameters in optimal limits, the functioning analysis of the electrical installations is very important. Using an optimal system control there can be avoided the functioning problems.

Electro thermal installation that is analyzed in this paper contains an inverter source supplied by a diode bridge rectifier. This type of nonlinear load is a voltage harmonic source. Although the current is deeply distorted, the harmonics amplitude is more influenced by the impedance of the power distribution, while the rectifier voltage is typically, being less dependent by the impedance of the power distribution.

The frequency converters that are used in electro thermal installation sources lead to negative effects in the power distribution [1].

These problems [6] can generate a decreasing in productivity and a quality diminution in products or services, which lead to high costs for industrial and commercial activities.

2. Technical characteristics of the electro thermal installation

The hardening electro thermal installation presented in figures 1.a) and 1.b) is composed by a converter CTC100K15 [2], [3] and two inductors: one designed for melting and one designed for hardening the materials. CTC100K15 has the following electric characteristics:

- supplying voltage 3x400V, 50Hz;
- rated current 27A;
- control voltage 24Vdc;
- consumed power at high frequency 15kW;
- voltage at medium frequency 500Vac.

2.1 Power Supply System

The electro thermal installation is supplied from the three phase low voltage on 0.4kV, through a general distribution board equipped with an automat circuit breaker with thermal protection with Ir=40A, electromagnetic protection with Iem=5It, differential protection with Id = 300 mA and overvoltage at 50Hz protection at $U \geq 260$ - 280V. The power system voltage at 6kV is generated by a power transformer 6/0.4 kV, 400 kVA, Δ/Y connection.

2.2 Solid State Relay

The on/off switching of the installation is made with three static contactors WG480-D50Z (Solid state relay-SSR).

Input characteristics are:

- dielectric strength: 1500Vac;
- insulation resistance: 10^3-10^6MΩ;

2.3 Diode bridge rectifier

In the electric scheme are introduced two diode bridge rectifiers KBPC 3508 with the following electric characteristics:

-maximum recurrent peak reverse voltage 800V;
-maximum RMS bridge input voltage 560V;
-max. average forward rectified output current 35A;
-peak forward surge current 8.3ms single-half sine-wave superimposed on rated load 400A;
-maximum forward voltage drop per element 1.2V;

2.4 Single phase inverter

In order to control the frequency in the melting and hardening process, it is using an inverter with four IGBT transistors: FF150R12KS4 with the following characteristics:
-collector-emitter breakdown voltage 1200V;
-collector-emitter saturation voltage 3,2V;
-continuous collector current I_{Cmax}=225A;
-gate-emitter leakage current 400nA;
-power disipation 1,25kW.

2.5 High frequency transformer

For supplying the hardening inductors, there are two high frequency toroidal transformers:
- T1: 660/500V, 40kVA, 70-100 kHz;
- T2: 150 kVA, 70-120 kHz with primary winding voltage of 500V and variable transformation ratio of 3:1, 5:1, 6:1, 10:1.

2.6 Inductors

The electro thermal installation contains two inductors: one for melting and one for hardening process, following the electromagnetic induction heating principle: a winding that is crossed by alternative current will create a variable magnetic field that pass the material determining eddy currents that are heating the material.

3. Electro thermal installation modeling using PSCAD-EMTDC tool

PSCAD-EMTDC is a dedicated software that can be used to simulate electrical power schemes [4].

In simulation the scheme from figure 1, there was designed a model for static contactor command and another one for inverter command.

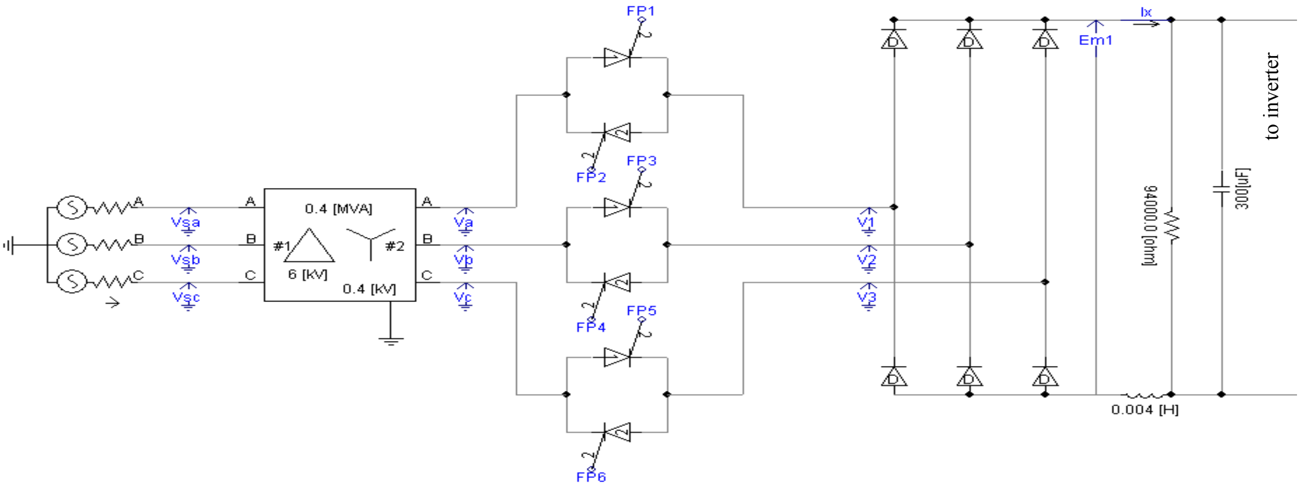

Fig.1.a) Electro thermal installation (connected with scheme from fig.1b).

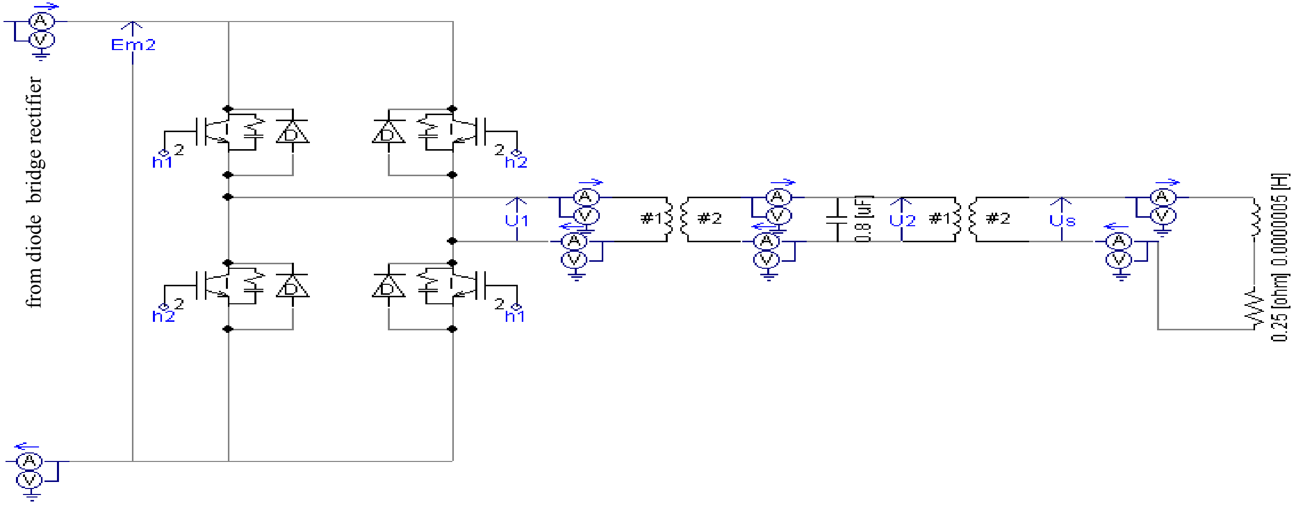

Fig.1.b) Electro thermal installation (connected with scheme from fig.1.a).

The static contactors are modeled using two thyristors in antiparalel lines on each phase. These six thyristors are commanded by a firing control device that generates the firing pulses signals FP1, FP2, FP3, FP4, FP5, FP6 as in figure 2. The output of firing control device is based on a comparison of high and low input signals. The low input is a firing angle noted with *Alph* and the high input is from a voltage controlled oscillator VCO that generates a sawtooth waveform signal.

The electric scheme contains a single phase inverter FF150R12KS4 that uses four IGBT transistors. These four transistors are commanded by a firing control device that generates the firing pulses signals h1 and h2 as in figure 3. Voltage control oscillator from figure 3 is functioning with frequency 100kHz and generates a sawtooth waveform signal noted with *Angle*.

In figure 3 *Angle* signal represents the high inputs of the firing control device. The low inputs are extinction angles *Alfast* and *Betast* for the firing control device that generates signal h1. For the firing control device that generates signal h2, the low inputs are *Alfast* and *Alfa*.

U_{cd} from figure 3 represents an angle that can control signals *Alfast* and *Betast* in one period.

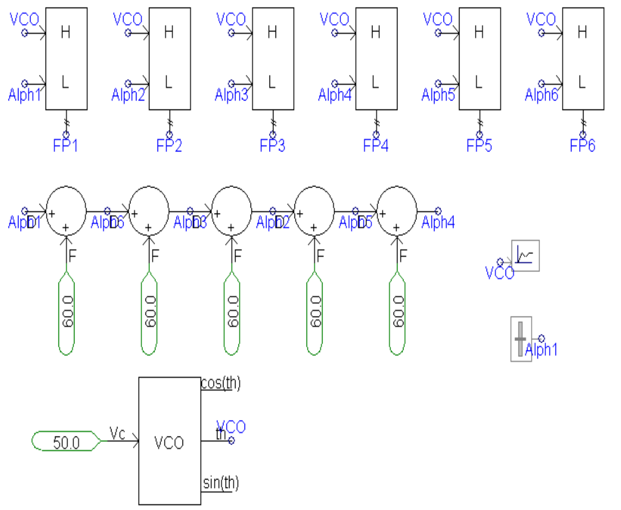

Fig.2. Model of static contactor command.

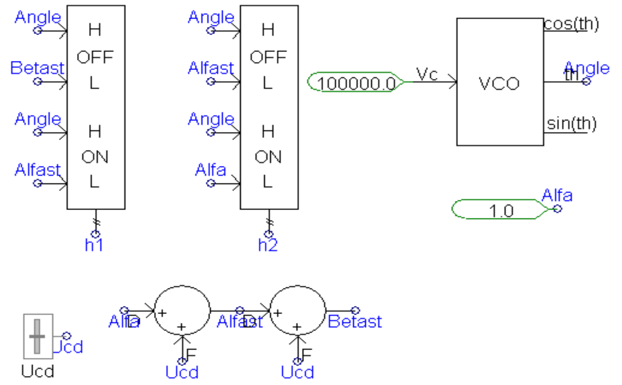

Fig.3. Model of inverter command.

The authors choose to calculate the total harmonic distortion generated by currents in the secondary winding of the power transformer using a Fast Fourier Transformer analyzer and a harmonic distortion calculator (fig.4).

In order to follow the variation of the active and reactive power, there were connected multimeters in the primary and secondary winding of HF transformers. These multimeters are referred to ground point, so the authors designed a model for measuring the correct powers (fig.5).

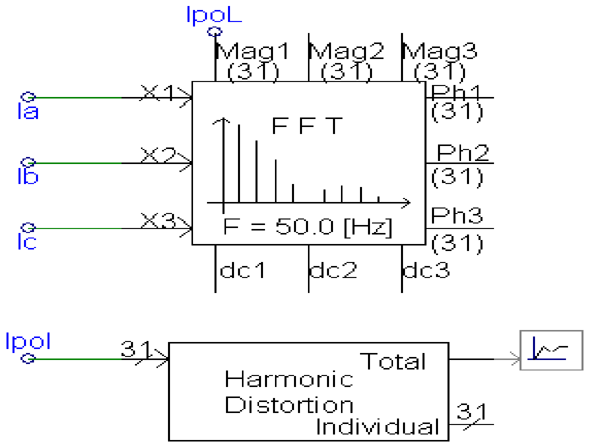

Fig.4. FFT block and THD calculator.

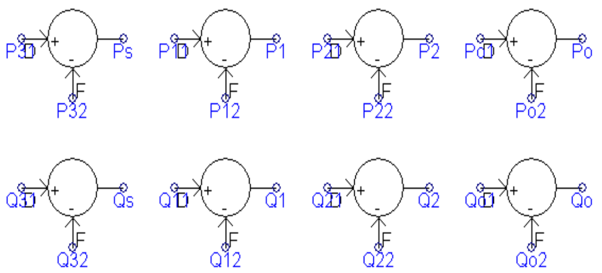

Fig.5. Model of active and reactive powers measuring.

Inductor is modeled using a series RL : $R=0.25ohm$, $L=5 \cdot 10^{-7}H$.

4. Simulation results

During the functioning simulation, the authors have studied the variations of the most representative electrical parameters. The authors followed the variation of electrical parameters for some values of the *Alph1* angle. The waveforms graphical representation are depicted in figures 6-14. In figures 6, 7, 8 are presented the variation of parameters for *Alph1*=0.3, in figures 9, 10, 11 for *Alph1*=30, and in figures 12, 13, 14 for *Alph1*=60.

There were used the following notations:

- V_{Sa}, V_{Sb}, V_{Sc} [kV] are phase voltages in the primary winding of power transformer;
- I_{Sa}, I_{Sb}, I_{Sc} [A] are phase currents in the primary winding of power transformer;
- V_a, V_b, V_c [kV] are phase voltages in the secondary winding of power transformer;
- I_a, I_b, I_c [A] are phase currents in the secondary winding of power transformer;

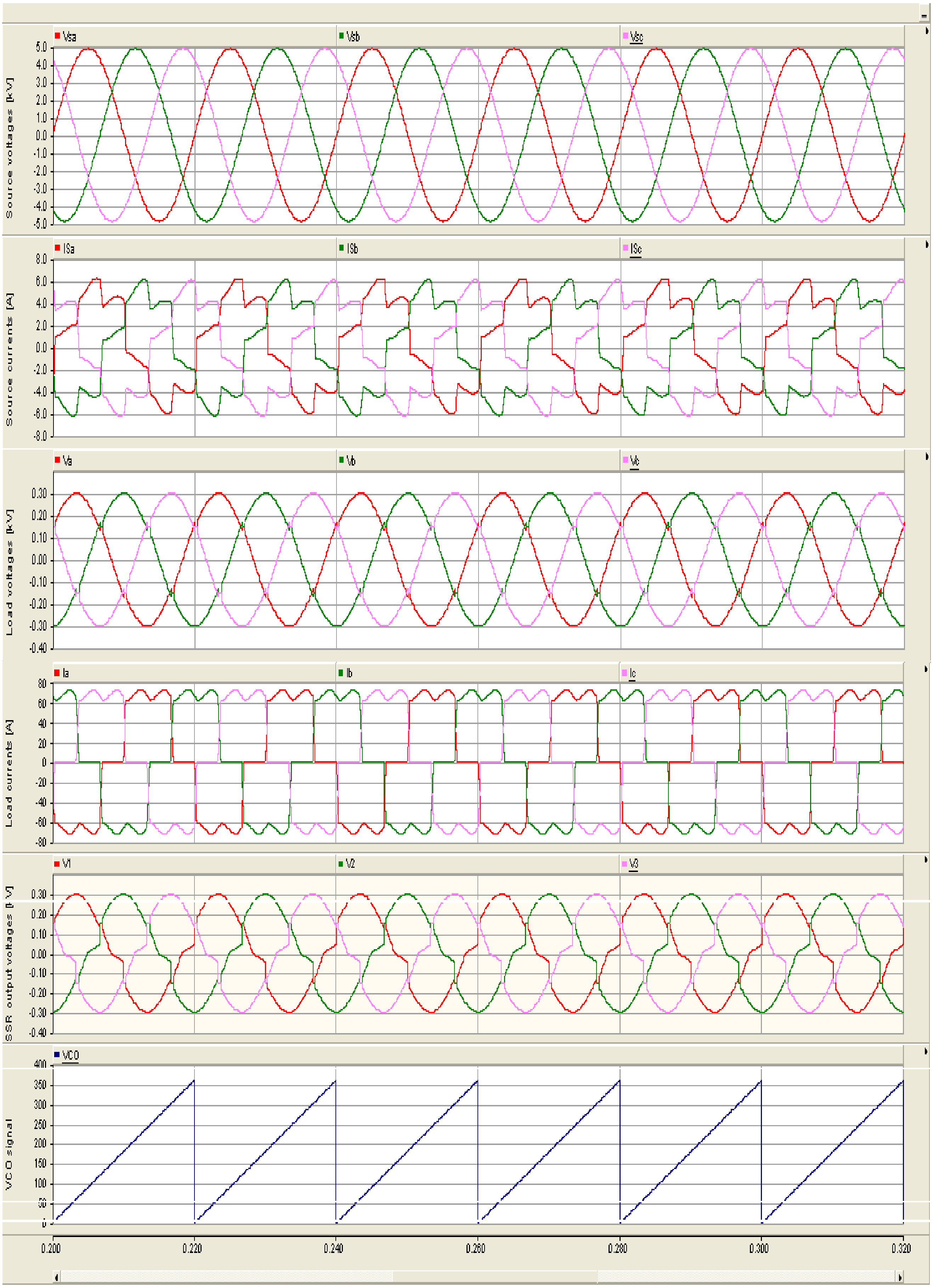

Fig.6. Simulations results of time variations of source and load voltages and currents for *Alph1*=0.3°.

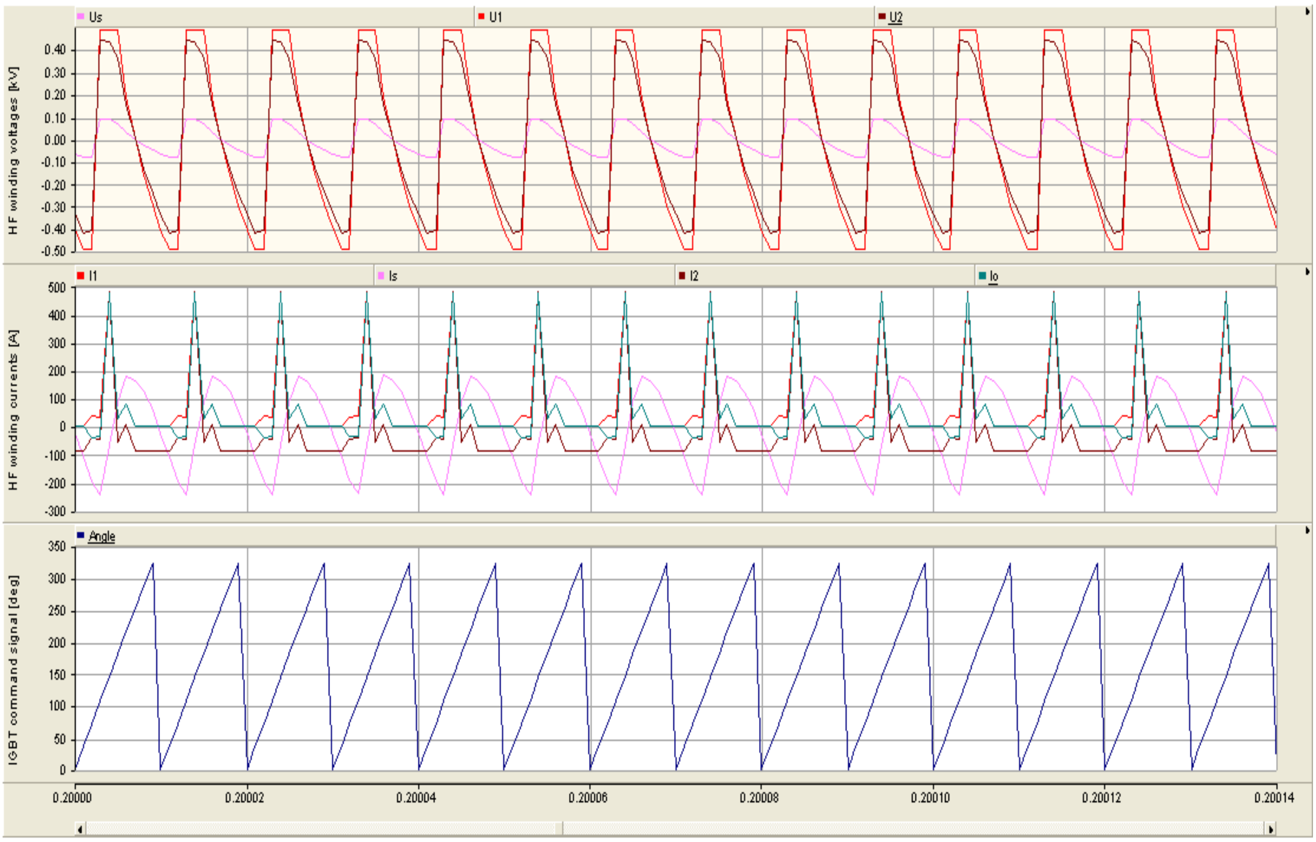

Fig.7. Simulations results of time variations of HF voltages and currents for *Alph1*=0.3°.

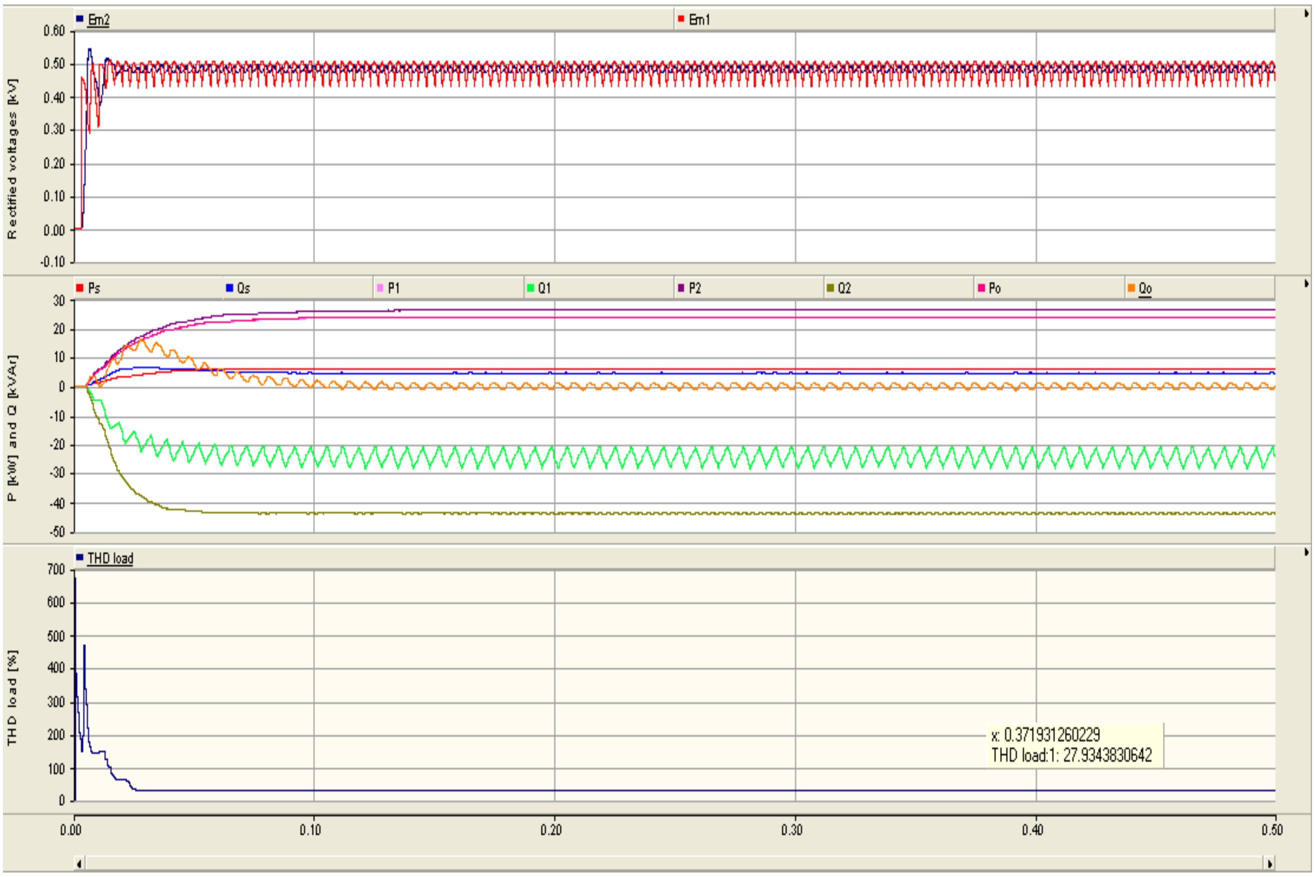

Fig.8. Simulations results of time variations of rectified voltage, active and reactive powers and THD for *Alph1*=0.3°.

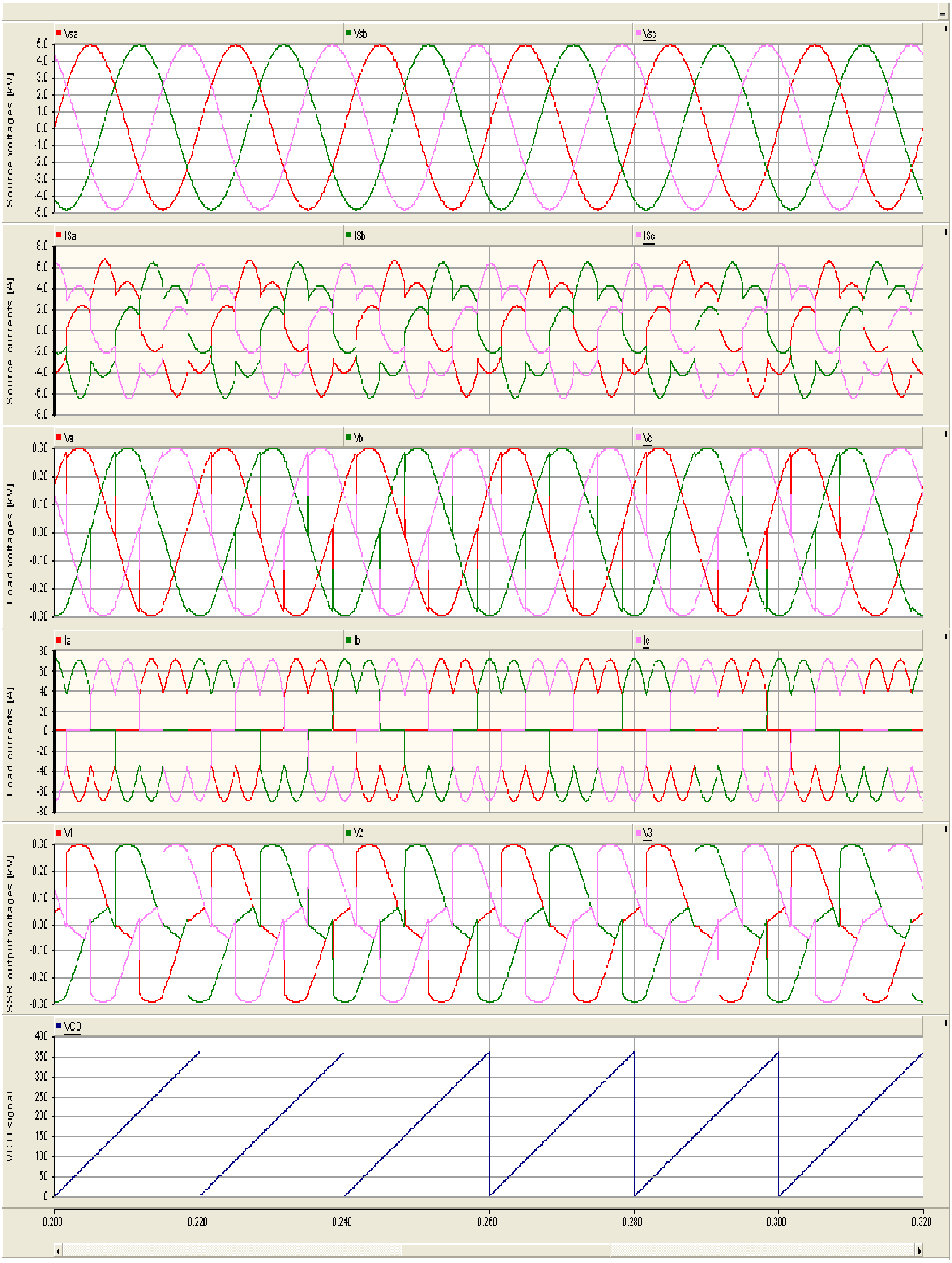

Fig.9. Simulations results of time variations of source and load voltages and currents for *Alph1*=30°.

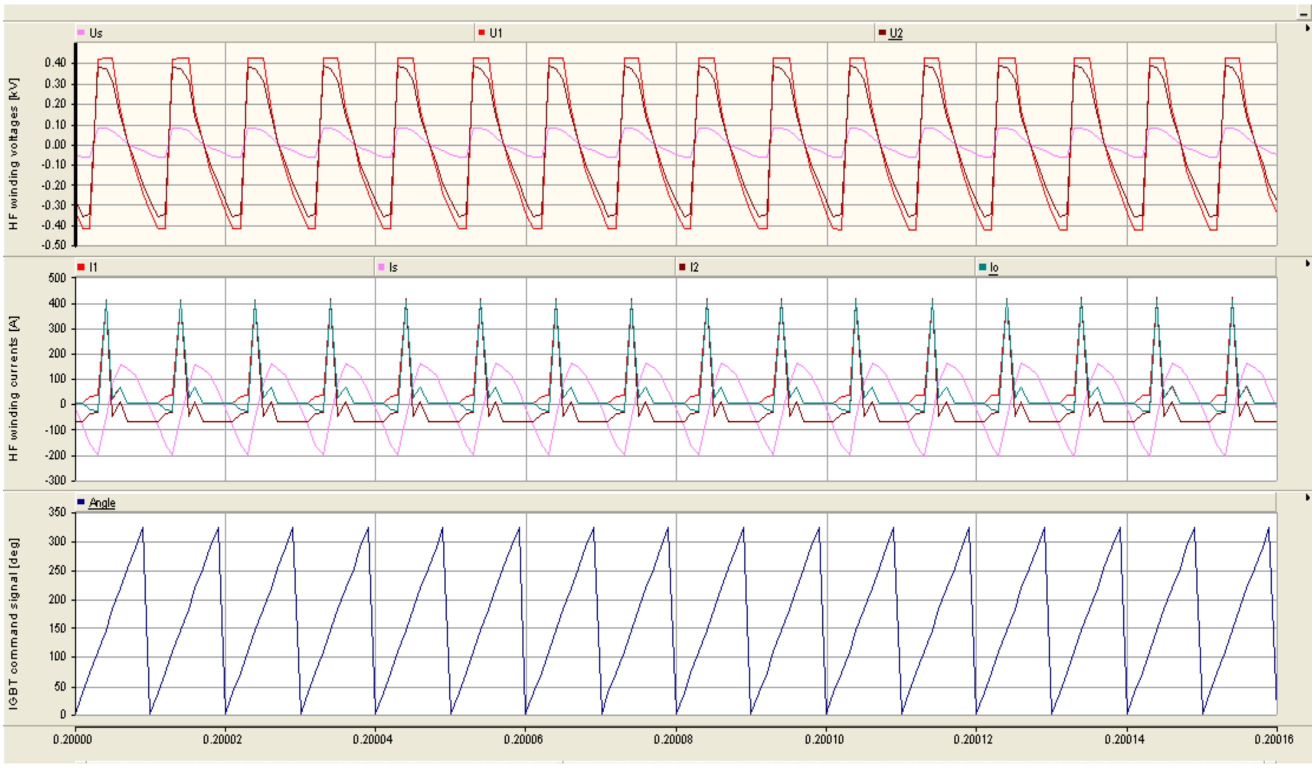

Fig.10. Simulations results of time variations of HF voltages and currents for *Alph1*=30°.

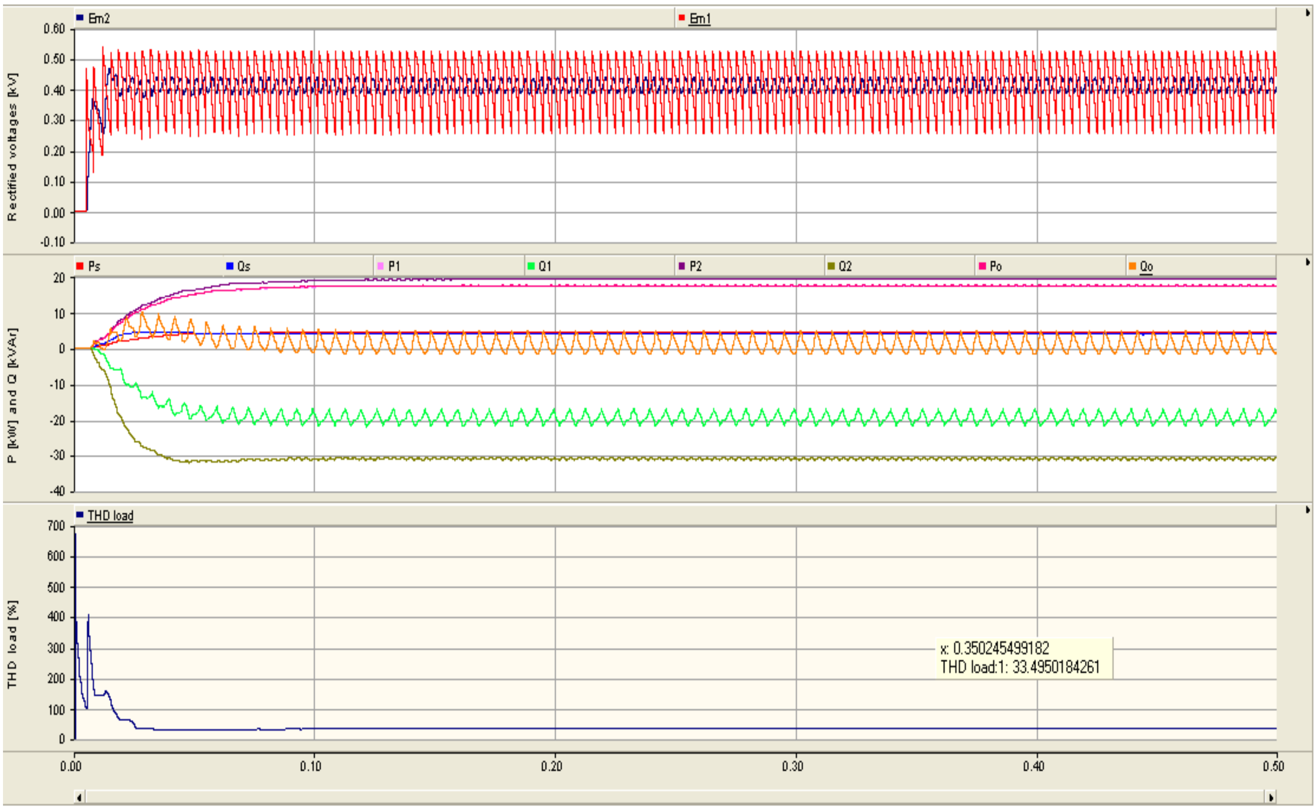

Fig.11. Simulations results of time variations of rectified voltage, active and reactive powers and THD for *Alph1*=30°.

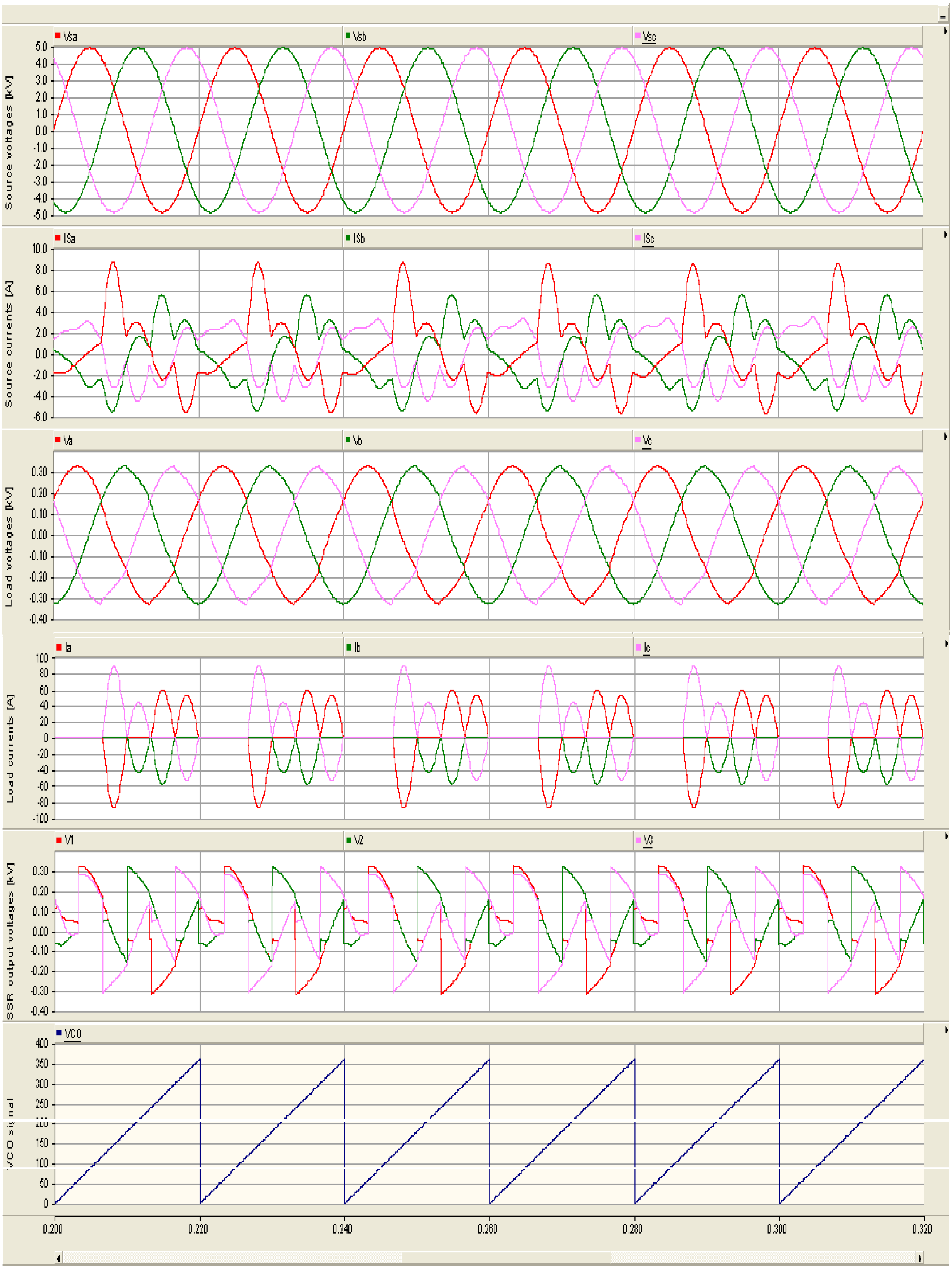

Fig.12. Simulations results of time variations of source and load voltages and currents for *Alph1*=60°.

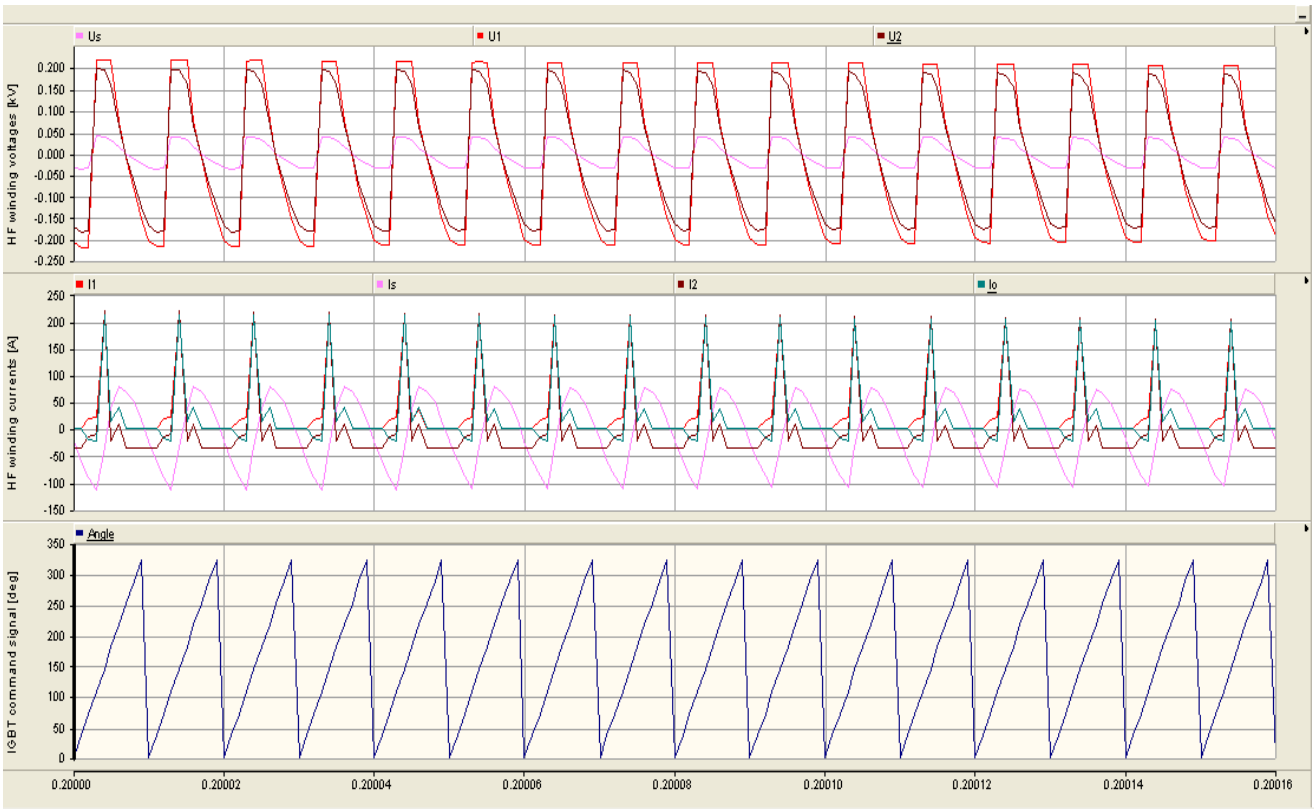

Fig.13. Simulations results of time variations of HF voltages and currents for *Alph1*=60°.

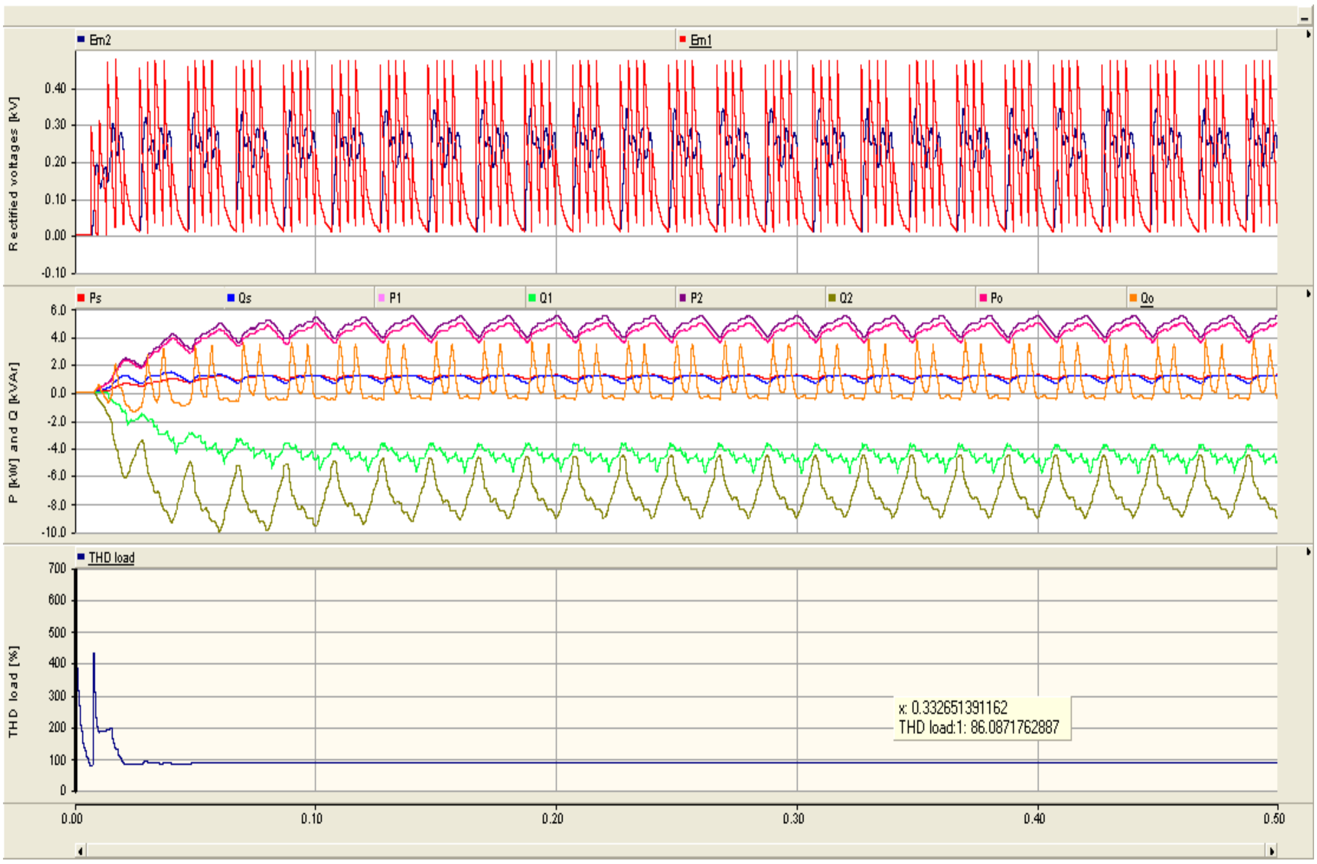

Fig.14. Simulations results of time variations of rectified voltage, active and reactive powers and THD for *Alph1*=60°.

- U_2 [kV] is voltage in the secondary winding of HF transformer T1;
- U_1 [kV] is voltage in the primary winding of HF transformer T1;
- V_1, V_2, V_3 [kV] are phase voltages after the static contactor;
- U_S [kV] is voltage in the secondary winding of HF transformer T2;
- I_o [A] is the inverter input current;
- I_1 [A] is current in the primary winding of HF transformer T1;
- I_2 [A] is current in the secondary winding of HF transformer T1;
- I_S [A] is current in the secondary winding of HF transformer T2;
- P_S [kW], Q_S [kVA] are active and reactive powers measured on RL load;
- P_0 [kW], Q_0 [kVA] are active and reactive powers measured on the inverter inputs;
- P_1 [kW], Q_1 [kVA] are active and reactive powers measured in the primary winding of transformer T1;
- P_2 [kW], Q_2 [kVA] are active and reactive powers measured in the primary winding of transformer T2;
- Em1 [kV] is voltage after diode bridge rectifier;
- Em2 [kV] is voltage after smoothing filter.

THD [%] is total harmonic distortion generated by phase currents in the secondary winding of power transformer.

5. Conclusions

As it was related in the first chapter of this paper, this type of nonlinear load generates waveform distortion for currents and voltages.

From figures 6, 7 and 8 there can be taken the following conclusions:

In the primary winding of power transformer the amplitude of phase voltages V_{Sa}, V_{Sb}, V_{Sc} variate between -5kV and 5kV and they are sinusoidal. The same case is at the variation of phase voltages in the secondary winding of power transformer where the amplitude variates between -0.3kV and 0.3kV. Phase currents in both windings of power transformer I_{Sa}, I_{Sb}, I_{Sc}, I_a, I_b, I_c are deeply distorted because of nonlinear load.

Inverter is a power electronic switch that generates an almost rectangular voltage waveform U_1 (fig.7).

The LC smoothing filter generates voltage Em2 that variates between 0.43 and 0.51kV.

Total harmonic distortion generated by phase currents I_a, I_b, I_c in secondary winding of power transformer is 27.934% in permanent mode. Studying the waveforms from figures 6-14, it can be observed that as long as the value of *Alph1* angle is increasing, the amplitudes of the currents and voltages are decreasing, they are not sinusoidal anymore and the level of harmonic distortion becomes higher at the interface with the power distribution, like in the following table:

Alph1 [°]	THD[%]
0.3	27.93
30	33.49
60	86.08

IEEE 519 Standard [6] is a recommended practice for power factor correction and harmonic impact limitation at static power converters. IEEE 519 limits the total harmonic distortion for voltage and currents bellow 5%. In order to respect this value is necessary to connect power conditioning devices at the interface with the power distribution.

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