OVERVOLTAGE SUPPRESSION IN INVERTER DRIVEN INDUCTION MOTORS

Ioan **ŢILEA**, Călin **MUNTEANU**
Technical University of Cluj-Napoca,
Ioan.Tilea@ethm.utcluj.ro

Key words: ***electromagnetic interference, inverter, induction motor, overvoltage suppression***
Abstract*:* *The motor overvoltage in inverter driven induction motors is one of the most difficult current technical problem in variable speed system. The conducted electromagnetic interference (EMI) in inverter driven motor system is essentially related to the electric behavior of the frequency converter`s load which is the induction motor and motor cable. Obtained results illustrate that the overvoltage problem in variable speed system with high power motors and long cables can be suppressed using the method presented in this paper that consists of a filter which bypasses the motor overvoltage to the ground.*

1. INTRODUCTION

The increase in the carrier frequency of pulse width modulation and fast switching rates of the power electronics can induce serious problems in inverter fed induction motor drive system. Many small capacitive couplings exist in the motor drive systems which may be neglected by the low frequency analysis but the conditions are completely different at high frequencies were the influence of the parasitic capacitance is noticeably higher. When the inverter is connected to the motor through a long cable because of the cable inductance, the stray capacitance distributed between the cable wires and the high rise times of the pulse width modulation (PWM) voltage from the inverter, overvoltages appear at the motor terminals, as presented in Figure 1, [1]-[4].

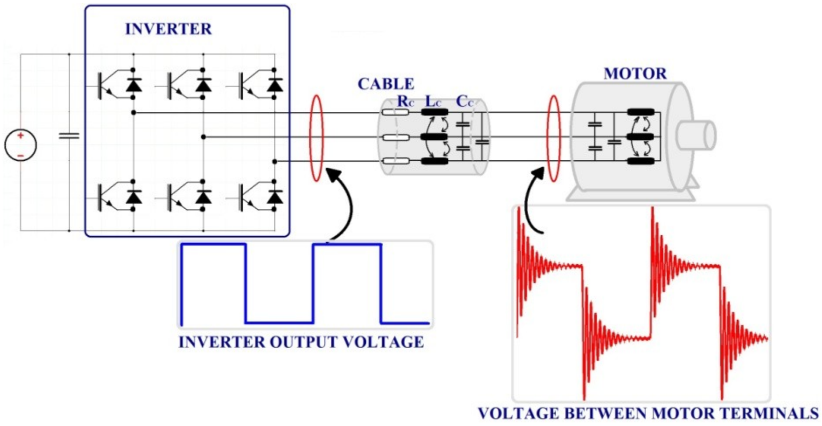


Fig. 1 – Motor terminal overvoltage

The cable and motor can be considered a resonant circuit, which is excited by the rectangular pulses of the inverter. The overvoltages at the motor terminals stress the motor winding insulation reducing its life, causing partial discharges that damage the insulation of the motor. This paper analyzes a new method for suppressing the overvoltage phenomenon in inverter driven induction motor system.

2. METHOD USED

For analyzing the motor terminal overvoltage propagation in inverter driven induction motors a field-circuit coupled method is used, first carrying out a finite element analyses of the investigated induction motor with a 3D software for the extraction of the motor high frequency equivalent circuit, using a 2D software for extracting the high frequency equivalent circuit of the cable and a circuit analysis for the inverter fed induction motor drive system.

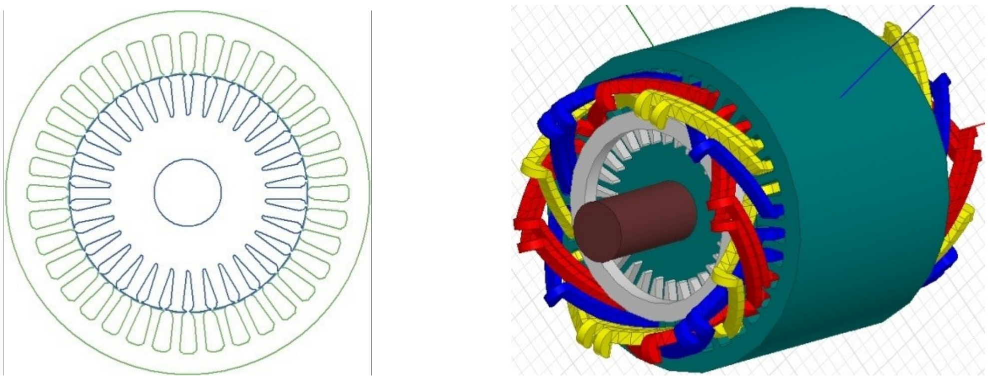
Using the 3D software a finite element analysis of the induction motor is carried out to obtain the inductances and the capacitances of the induction motor necessary for the motor high frequency equivalent circuit, first performing a magnetic regime simulation for obtaining the inductance matrix and an electrostatic simulation for the capacitance matrix.

The induction motor inductances and capacitances obtained from the software's Matrix solution are exported in a circuit simulator, composing the high frequency equivalent circuit of the induction motor used for the inverter fed induction motor drive system to analyze the overvoltage phenomenon accruing at the motor terminals.

2. 1. Induction motor and cable model

At low frequencies, the equivalent circuit of the electric motor consists of inductances and resistances without considering the motor capacitances. At high frequencies, the electric motor can be modeled as distributed capacitors, inductors and resistors. The stray capacitance of electric motors is very important in predicting EMI problems, asynchronous motor winding physical construction is very complicated and detailed determination of its capacitance is difficult [5]-[8].

For an accurate determination of the induction motor capacitance and inductance a 3D model of the motor must be analyzed for the reason that it incorporates the end winding of the induction motor. The investigated motor is a three phase induction motor with a single layer winding and an output power of 0.3 kW, a rated voltage of 400 V and a speed of 1360 rpm. The numerical 3D model and a 2D section of the induction motor simulated is presented in Figure 2.



a) b)

Fig. 2 – Numerical model of the induction motor: a) 2D section, b) 3D model

The high frequency model of the motor cable is obtained by extracting the inductances and capacitance of the cable using a 2D software. Because the power cable that connects the motor to the inverter has a very simple physical construction a 2D model of the motor cable is use, the results from the magnetostatic simulation (Fig.3.a) and electrostatic simulation (Fig.3.b) are presented in Figure 3.

Parameter: Matrix1 Type: Inductance
Pass: 2 Inductance Units: H

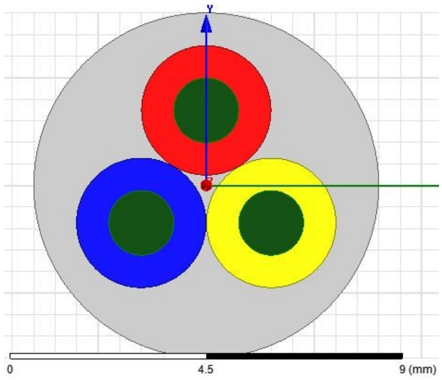
	Current1	Current2	Current3
Current1	8.6709E-007	5.3946E-007	-5.3947E-007
Current2	5.3946E-007	8.671E-007	-5.3947E-007
Current3	-5.3947E-007	-5.3947E-007	8.6712E-007

a)

Parameter: Matrix1 Type: Capacitance
Pass: 2 Capacitance Units: farad

	Voltage1	Voltage2	Voltage3
Voltage1	8.2245E-011	-3.7617E-011	-3.7616E-011
Voltage2	-3.7617E-011	8.2245E-011	-3.7617E-011
Voltage3	-3.7616E-011	-3.7617E-011	8.2244E-011

b)



c)

Fig. 3 – Results of the motor cable simulations: a) Inductance Matrix; b) Capacitance Matrix; c) 2D model of the investigated motor cable

2.2. Overvoltage analysis and suppression in inverter driven induction motors

To analyze the overvoltages at the motor terminals when the motor is connected to a PWM inverter the simulation model presented in Figure 4, is used. The model consists of an inverter, the equivalent high frequency model of the cable composed of the inductances matrix and capacitances matrix imported from the 2D simulation and the induction motor capacitances matrix and inductances matrix imported from the 3D simulation which will compose the high frequency model of the induction motor.

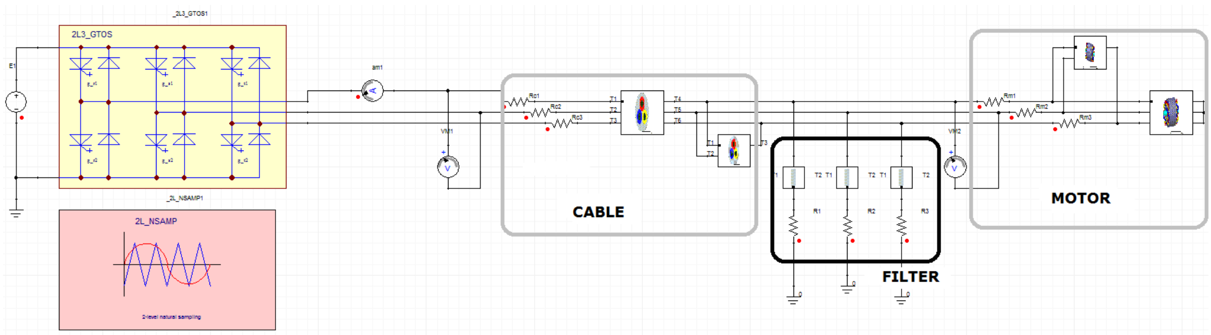
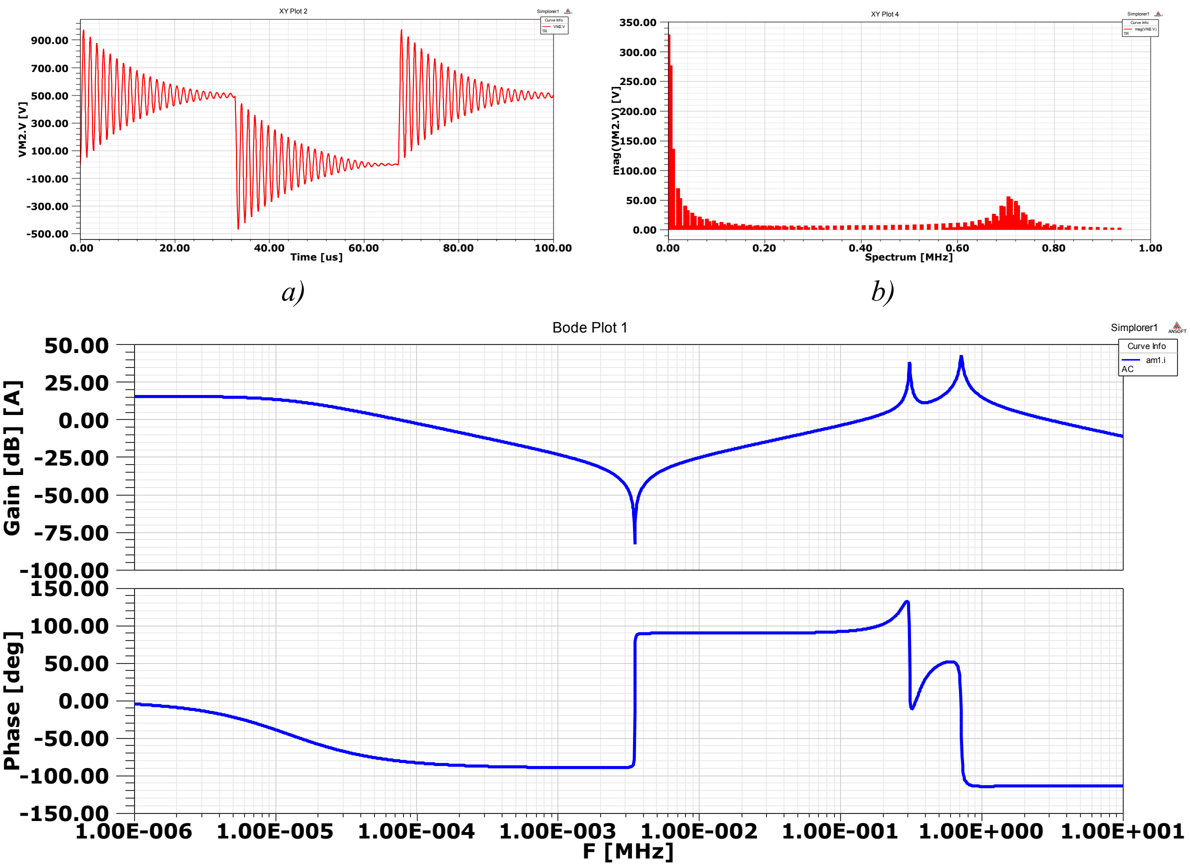


Fig. 4 – Inverter fed induction motor simulated model

The method for suppressing the overvoltage at the motor terminal consists of a filter that bypasses the motor overvoltage to the ground; the inverter-filter-motor layout is presented in Figure 4. The filter consists of a capacitor and a resistance, the values of the capacitor and resistor must be chosen in such a way that the series resonance of the motor and cable would be cancel so the cable and motor resonance phenomenon must be taken into account when choosing the values for the filter components.

3. RESULTS

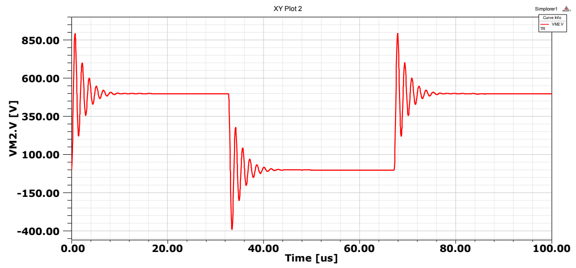
In Figure 5 the motor terminal voltage, Fourier analysis of the voltage and a Bode plot of the motor current are presented, the overvoltage at the motor terminal is clearly visible with a peak amplitude of 1000 V, were the inverter output voltage presents no voltage spikes. The inverter output voltage has an amplitude of 500 V and a fundamental frequency of 50 Hz with a carrier frequency of 20 kHz and the induction motor is connected to the inverter through a 35 m cable. The induction motor behavior in high frequency is that of an LC parallel circuit having a parallel resonance at a frequency of 3.5 kHz, when the electrical parameters of the motor cable are taken into account besides a parallel resonance it can be observed that there are two series resonances at 300 kHz and at 700 kHz, the first series resonance (300 kHz) appear only if the motor cable model incorporates the cable mutual inductances. The series resonance of the motor and cable is very important in predicting serious overvoltage problems in inverter driven asynchronous motors, and it is the key reason for the appearance of motor overvoltage, as seen in Fig. 5 the frequency of the overvoltage at the motor terminal is 700 kHz the same as the second series resonance of the motor and cable, the resonance is due to the cable induction and motor winding capacitance.



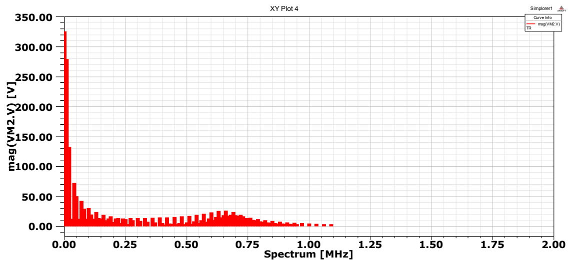
c)

Fig. 5 – Results from the simulation without using the filter: a) Motor terminal voltage, b) Fourier analysis of the motor terminal voltage, c) Bode plot of the motor and cable.

In Figure 6 the motor terminal voltage, Fourier analysis of the voltage and a Bode plot of the motor current are presented when using the filter, the overvoltage suppression effect of the filter is clearly visible the maximum amplitude of the voltage at the motor terminal is reduce by 100 V and the number of the overvoltage oscillations are drastically reduce.



a)



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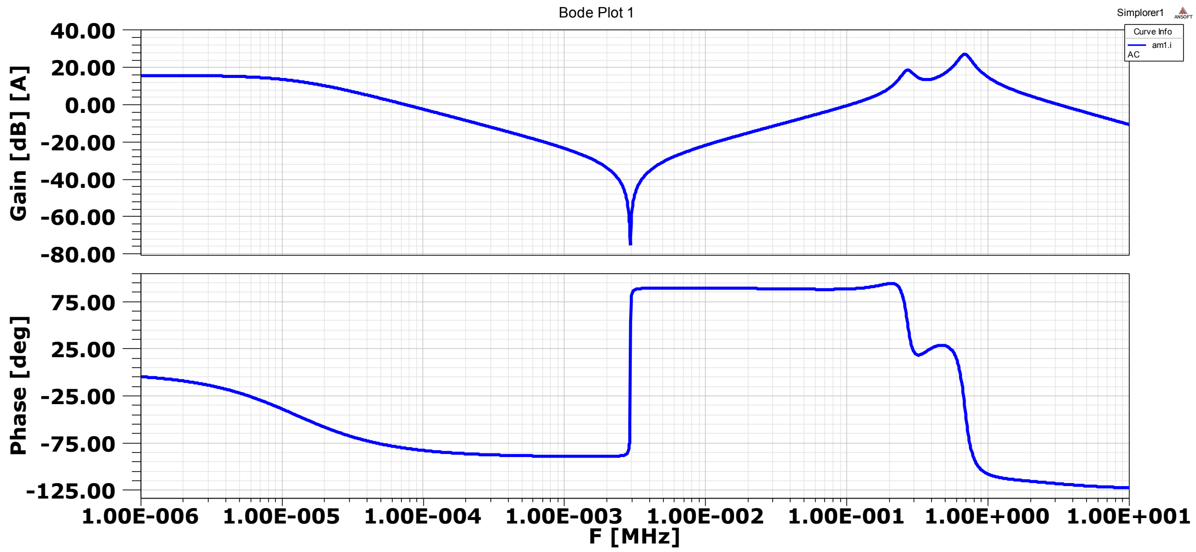

c)

Fig. 6 – Results from the simulation using the filter: a) Motor terminal voltage, b) Fourier analysis of the motor terminal voltage, c) Bode plot of the motor and cable.

4. CONCLUSION

The characteristic frequency range where the overvoltage problems appear can be relatively easily determined based on the motor and cable resonant frequency. The series resonant frequency of the motor and cable is very important for the reason that the voltage spikes at the motor terminal have the same frequency. Determining the resonant frequency of the motor and cable is very helpful in predicting serious EMI problems in inverter driven motor system. Overvoltages in inverter fed induction motor system, with long motor cable can be predicted using the field-circuit coupled method presented in this paper.

At high switching frequencies the inverter power losses dramatically decreases so there is an interest in making inverters that can work at high switching frequencies. Using a

LC power filter will minimize the effects of the high switching frequency of the inverter on the motor but the filters are very expensive and inefficient, up to 50% of the inverter power is lost due to losses in the LC filter, some application such as vector control used in variable speed drives cannot work using inverter with output power filters.

The method for motor overvoltage suppression presented in this paper can be used in variable speed system with high power motors and long cables.

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