Analysis by Simulation of the Over-voltages in PWM-Inverter Fed Induction Motors

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Abstract—**The aim and content of the present work consists of the over voltages at induction motor terminal, the voltage distribution in the stator winding of induction motor confronted by fast rising voltage, the primary objective of this research work is to develop a simulation model of PWM Inverter, cable and induction model in MATLAB or EMTP software. The system model is used to identify the over voltages as well as the distribution and magnitude of fast rising (steep fronted) voltage in the stator winding of electrical machines fed from PWM inverters. Voltage reflection analysis analyzed at the motor terminal considering different cable length between motor and inverter as well as rise time.**

Index Terms—**coil, mismatch impedance, induction motor, overvoltage, PWM Inverter, surge propagation**

I. INTRODUCTION

An increasing part of low voltage standard induction motors operates with PWM voltage source inverters using IGBTs and they are applied to a wide range of power 0.1 kW up to some MW. The PWM (Pulse Width Modulation) inverter mode of control generates a large frequency spectrum of overvoltages. The resulting undesired overvoltages at the motor terminals stress the motor insulation [1]. Usual standards applied to the induction motors recommend to limit the value of rate of rise of voltage to be less than (dv/dt) < 500-600V/μs for the motor insulation to be healthy condition. This value is suitable for a motor fed directly by the AC power supply, but when the motor is fed by an inverter without any filtering device, the dv/dt may reach up to 6000-7000V/μs or even more depending on the installation.

This section presents the simulation analysis of transient overvoltages on ac induction motors when connected through a cable to IGBT-PWM inverters. Considering classical transmission line and travelling-wave analysis with zero initial electric charge on cable, these transient over voltages are about twice the dc link voltage with a short rise time of about 200-300ns [2]. Nevertheless for long cables, these transient overvoltages may reach 3 or 4 pu. In this paper, by using the system representation consisting of inverter-cable-motor, simulation is carried out to assess the motor terminal overvoltages.

II. INVERTER-CABLE–MOTOR SYSTEM MODELLING AND REPRESENTATION

Overvoltages in inverter-cable-motor system are simulated using MATLAB software. MATLAB is powerful tool to solve different problems in various applications. In MATLAB, power system simulink tool is used for analyzing the overvoltages at motor and also to perform the parametric study. Also studies have been carried out to record the waveforms experimentally. Fig. 1 shows the MATLAB model for inverter-cable –motor system. First PWM inverter is modelled by using sinusoidal and saw tooth parameter blocks. The output pulse from the PWM inverter model is given to the motor through cable. For modelling of cable and motor in MATLAB simulink, series RLC parameters blocks are used. In cable modelling blocks represents the resistance, inductance and capacitance values per unit length of cable. Motor modelling parameters are represented by using RLC parameter blocks from simulink library. Fig 1 shows the MATLAB schematic of inverter cable motor system for 3 different cable lengths 4m, 10m and 14m with the inverter and motor being same [3] and [4].

Using the PWM Inverter with high frequency models of cable and motor, a simulation program has been developed in MATLAB and analysis of the terminal over voltages and rise times are carried out by varying cable length and varying HP Rating [5].

The Fig. 2(a) to 2(d) shows the overvoltage waveforms at motor terminals and inverter terminals for different levels of zooming for cable length of 20m and for a 3HP motor.
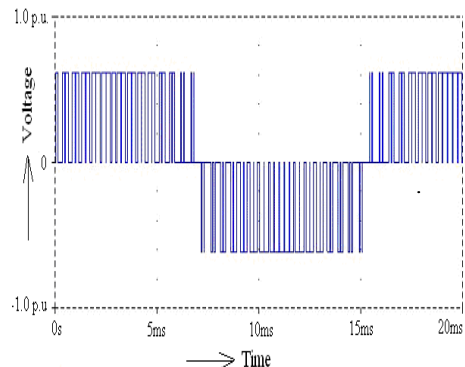

Figure 1.   Figure 2(a).Simulated output voltage waveform of an inverter.
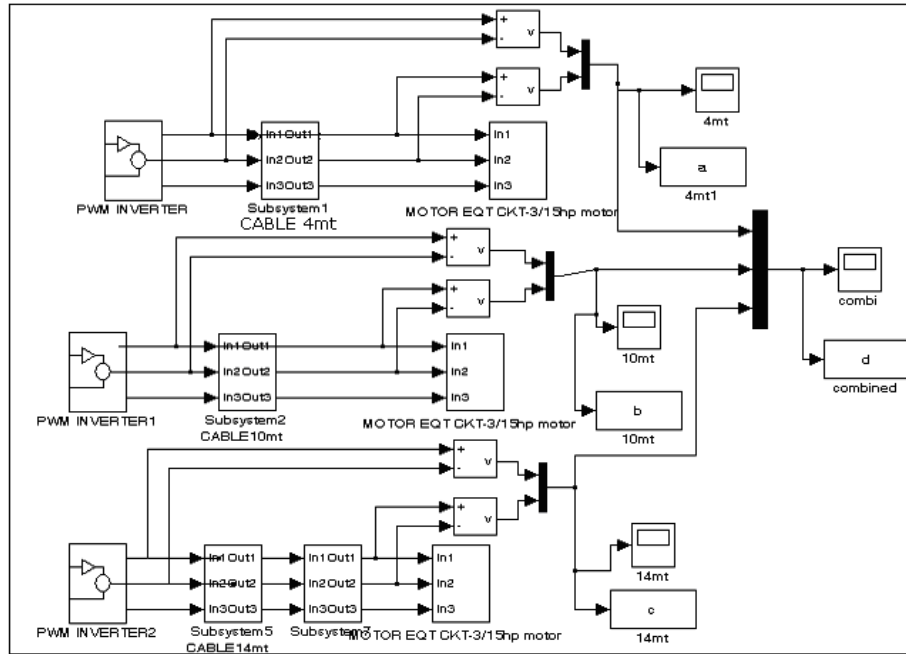
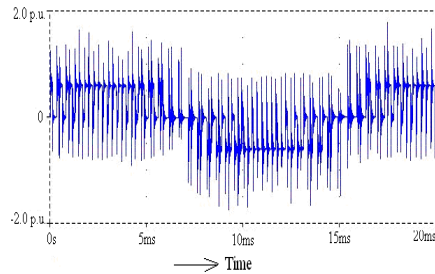Figure 2.   MATLAB model for inverter-cable-motor system.

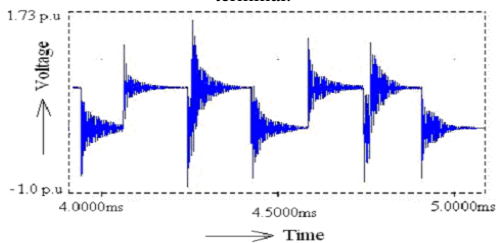Figure 2(b). Simulated overvoltage waveform at 3HP induction motor terminal.

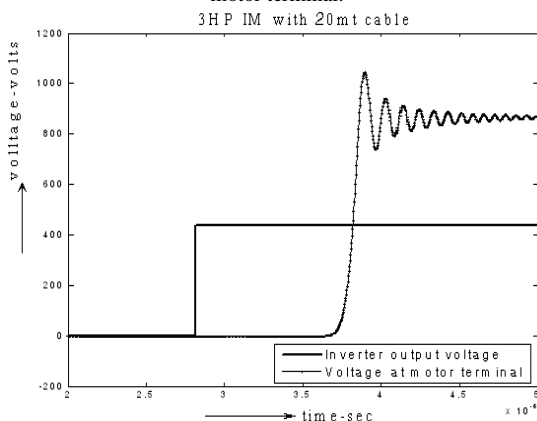Figure 2(c). Simulated zoomed overvoltage waveform at 3HP induction motor terminal.

Figure 2(d). Simulated single pulse zoomed overvoltage waveform at

motor terminal.

III.   SIMULATION RESULTS FOR OVERVOLTAGES AT MOTOR TERMINALS

Due to usage of PWM Inverter to induction motor and the long cable connected between inverter and motor, the overvoltages are produced at motor terminals. These overvoltages are mainly due to the steep fronted surges produced by PWM inverter and impedance mismatch between the motor and cable. In this section simulation of overvoltages is carried out by using MATLAB software.

In simulation, PWM inverter with different cable lengths and different rating induction motors are used. The supply voltage pulse of 420 Volts Amplitude with 20ns rise time is applied to the motor through cable. By using data from Appendix-I, simulation study has been carried out. Figs 3(a) and 3(b) show the simulated waveforms for terminal overvoltages and inverter output voltage for different cable lengths.
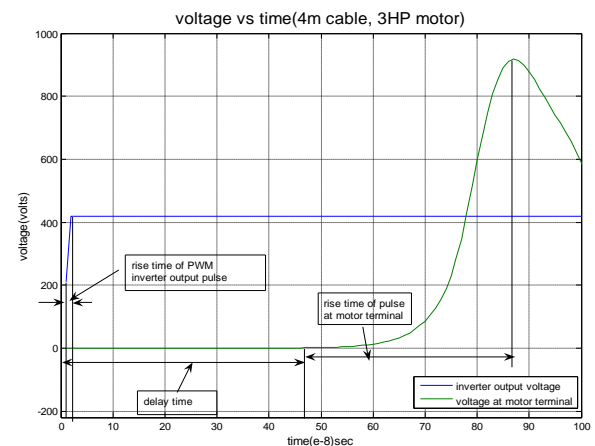

Figure 3(a).   Line to line peak voltage vs time at the inverter and motor terminals for 3HP motor and 4m cable.
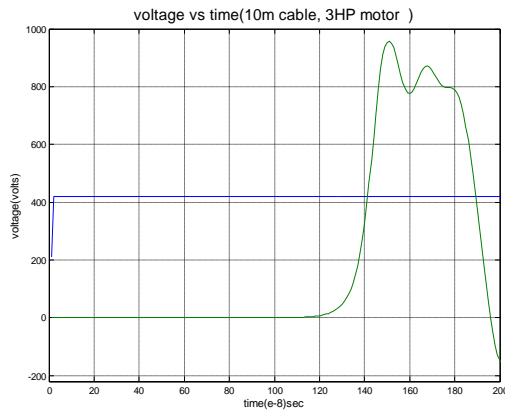
Figure 3(b). Line to line peak voltage vs time at inverter and motor terminal for 3HP motor connected with 10m cable.
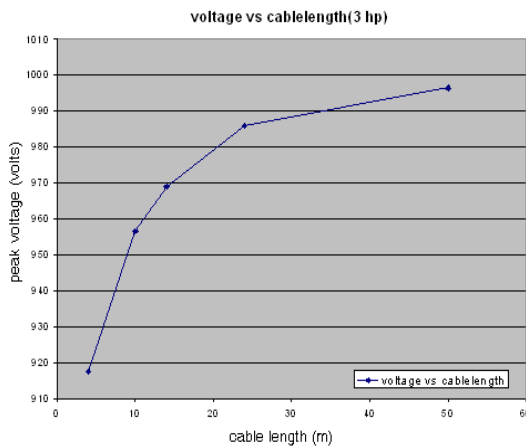

Figure 4. Peak voltage vs cable length at motor terminal.

Waveforms of Fig. 4, it is observed that the voltage at the motor terminals becoming higher as the length of the cable increases for the same rise time.

By observing the simulation and experimental waveforms of Fig 3 to Fig. 4, it is seen that voltage at the motor terminal is more compared to the inverter output voltage. Hence overvoltage occurs at motor terminal. This is due to impedance mismatch between the cable and motor winding. It is observed that this overvoltage in some cases may go up to 4pu, which depends on the instant of inverter switches in different phases.

By comparing the simulation waveforms and experimental waveforms, it is observed that, as cable length increases propagation time as well as peak voltage increases and peak voltage will occur at different instants of time. This will happen up to critical cable length, for which voltage doubling occurs. Hence by increasing cable length up to some extent, rise time increases and insulation stress decrease, so that motor life increases.

Thus simulation results are in good agreement as compared with experimental results. Another observation made in this section, as cable length increases propagation time is also increases. The propagation times observed in simulation and experiments are compared. Though they there is difference between simulation and experimental results, considering the complexities involved in modeling and simulation, the deviation is considered to be within engineering accuracy.

IV. ANALYSIS OF THE OVERVOLTAGES MORE THAN 2PU

Using the high frequency models of Induction motor and cable, a simulation of the drive system is carried out using MATLAB to calculate the over voltage magnitude and rise times. The special conditions under which severe overvoltages are produced, is discussed below.

If two inverter phases switch simultaneously, one from positive to negative and other from negative to positive ($\Delta V = 2*V$) peak line to line voltage will be as shown in Fig. 5(a) 3V.
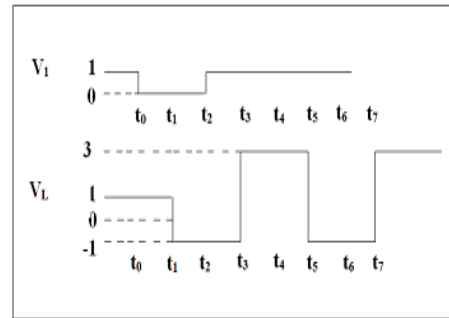

Figure 5(a). Two inverter phases switch simultaneously.

In Fig. 5(a) the output voltage switches from 1 to 0 at time t = to. After a delay at t = t1 the voltage at the motor terminal switches twice that amount i.e. to −1. Now if the inverter voltage switches back to 1 at t = t2, then at t = t3 the two waves coincide at the motor terminals causing the voltage to go up to 3pu. Thus, a single narrow pulse with only one line switching can cause the motor voltage to reach 3pu.

A narrow pulse combined with two phase switching in opposite direction simultaneously is the worst case. In this case switching event adds $\Delta V = 2pu$, such that the motor terminal voltage is 4pu after t=t2, and this adds to the input voltage. Thus, a single narrow pulse with both lines switching (polarity reversal) simultaneously can cause the load voltage to reach 4pu the dc-link voltage as shown Fig.5 (b).
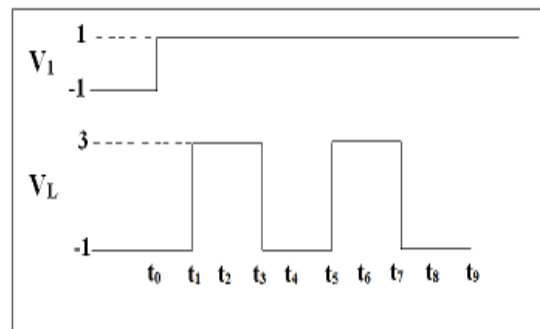

Figure 5(b). Two pulses switching in opposite direction.

The above explanations can be proved by using MATLAB simulation results as shown below in Fig. 6, 7 and 8.
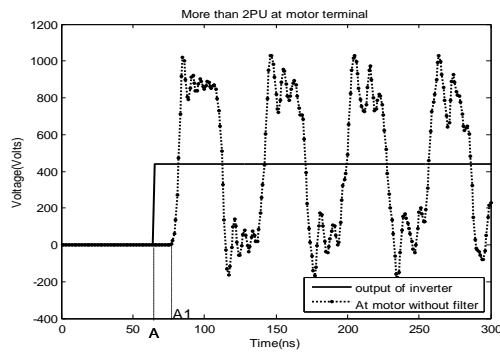
Figure 6. Overvoltages of more than 2PU at motor terminal.

Fig. 6 shows the simulation results for the voltage at the inverter/motor terminals connected with 20m cable. Capacitance of the motor winding is included. The inverter is switched from 0 to 420V at point A and the peak voltage at the motor terminal is found to be approximately 1000V (>2PU) at point A1 after some propagation delay due to cable length.
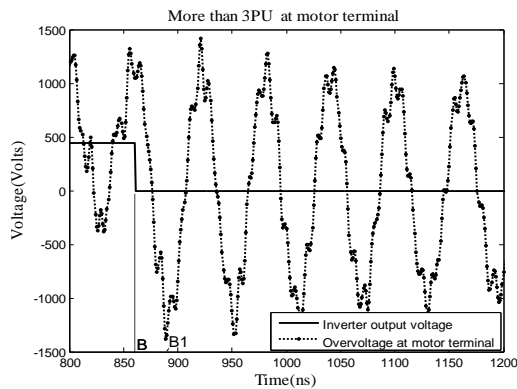

Figure 7. Overvoltage of more than 3PU at motor terminal.

Fig.7 shows the simulation results for the inverter/motor voltage when the inverter output takes transition from 420V to 0 at point B. When this voltage transition (1PU) reaches the motor terminal, which is at a voltage of around 2PU, adds to the motor terminal voltage resulting to 1450V ($\approx$3PU) at point B1.

Again, when the inverter voltage takes transition from 0 to 420V at point C, overvoltage of about 1500V ($\approx$4PU) appears at motor terminal at point C1 as shown in Fig.8.
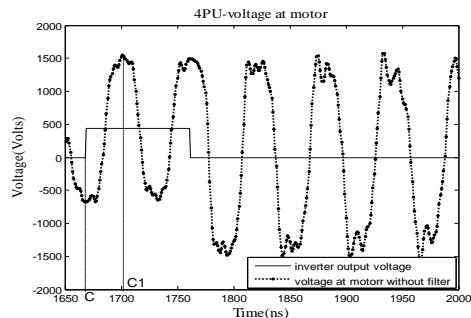

Figure 8. Overvoltages of nearly 4PU at motor terminal.

From the above simulation results, it is observed that, when the inverter output pulse takes transitions, there is increase in the motor terminal voltage due to the reflection of an incoming incident wave on top of a reflected wave from the inverter.

The overvoltages at motor terminal go up to 4 times the inverter output voltage. The simulation results for such case are presented. It is observed that, when ever two inverter phases switch simultaneously one from positive to negative and other from negative to positive, the peak line to line voltage can go up to 3p.u. In other case, a single narrow pulse with both lines switching (polarity reversal) simultaneously can cause the load voltage to reach 4 p. u. is also analyzed by using simulation results.

V.   CONCLUSIONS

In this paper discusses the analysis of the over-voltage phenomena in long cable PWM drives due to voltage reflection theory. Simulation results are compared. Effect of cable length, rise time and HP rating on the over voltages are analysed. As the cable length increases, overvoltage magnitude increases. Also the effect of rise time on dv/dt is presented. Shorter rise time results in high dv/dt which stresses the motor insulation. For large HP ratings over voltage is less. Also simulation results of mitigating high dv/dt is explained by adopting filter.

ACKNOWLEDGEMENT

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