A REVIEW PAPER ON: DESIGN AND EVALUATION OF FILTERS FOR REDUCING OVER VOLTAGES ON ASYNCHRONOUS MACHINES FED BY PWM INVERTER

K. Nooka Raju,
Assist. Prof
LITS,Hyd.

Sayed Mahaboob
M.Tech Student,
LITS, Hyd.

Abstract

It is not quite uncommon, in general, to use DC motors in industrial applications, but after the introduction of power electronics, AC motors grabbed much importance. Of these, induction motors are widely used in industrial and domestic applications due to the advantages like simple construction, ruggedness, flexible control, good efficiency and low cost. In order to control the stator voltage and speed, PWM inverters are used. But the usage of PWM inverters has the effects like non-uniform voltage distribution and increase in the temperature.

Recent advances in power electronic switching device technology have resulted in dramatic improvements and cost reduction of pulse-width modulated AC adjustable speed drives. Concomitant with the better performance enabled by the high switching speed and increased switching frequency they have also raised several concerns related to the consequences of high speed switching. One of these concerns is the over-voltage that appears at the motor terminals due to the impedance mismatch between the power cable and the motor. In this paper a developed accurate simulation models for power cables and motors that allow a better understanding of the over-voltage problems. The models can be readily implemented using computational tools like MATLAB, thereby providing a convenient method to develop the best dv/dt filter solution for a particular drive. The power cable is modeled using several lumped-parameter segments of a lossy representation of transmission line. An algebraic analysis is developed to choose an adequate number of lumped-parameter segments. The number of required segments is a function of the pulse rise time, cable characteristic parameters and cable length. Simulation results are presented analyzing the over-voltage problem for a wide range of cable lengths for 3hp, 15hp and 40hp motors. The most important filter networks are also designed and the solutions are investigated using the simulation programs.

Index Terms— PWM Inverter, induction motor, filter design, insulation failure, reflection analysis, mismatch impedance.

I. Introduction

Induction motors are widely used for driving various thermal power plant auxiliaries such as induced draft fans; boiler feed pumps, conveyers, coal crushers etc., as well as various drives in chemical and other industries. These are very critical to sustain plant production. A motor failure can have severe economic consequences.

Recently two independent surveys have been carried out to access the reliability of motors in utility and general industrial applications. Both the surveys found that the stator insulation failure accounted for about one third of the failures in all motors components. In motors, where form-wound multi-turn coils are always employed, stator insulation failures result from either the failure of turn-to-ground insulation itself or turn-to-turn insulation which leads to ground insulation failure. Reduction in the failure of stator insulation therefore greatly improves the reliability of plant operation. This has lead to detailed investigations for analysis of the mechanisms of such motor failures, their causes and methods of overcoming the same and their efficiency.

The flexibility of speed control and the ruggedness of induction motors have made inverter fed induction motors very common in variable speed applications. Voltage source Pulse Width Modulation (PWM) inverters fed induction motors are very commonly used once for small and medium sized induction motors. When the motor is fed by an inverter power supply, there will be non-sinusoidal voltages and currents in the motor windings which result in additional losses. This problem is often overcome by de-rating the motor depending upon the type of inverter used.

The insulation withstand capability of the motor is of real concern when voltage source PWM inverters are used. With a PWM inverter power supply, the motor winding is subjected to a train of wave fronts several times in a fundamental cycle. As high switching speed and frequency are enabling adjustable speed drives with better performance, concerns have arisen related to certain unintended consequences of the same. One of these concerns is the over-voltage problem due to steep voltage fronts and short pulse rise time from the inverter traveling along long power cable feeding the motors. The over-voltage is explained as a voltage pulse, initiated at the inverter, traveling along the cable and being reflected at the motor terminal due to the mismatch between the surge impedance of the motor and the cable. Its behavior is dependent, however, on the characteristics of voltage pulse rise time and of the cable. The objective of this paper is to present a definitive study of the motor over-voltage phenomena by developing accurate and fast simulation models for power cables and motors that allow a better understanding of the over-voltage problem. The models can also be used to provide a convenient tool to benchmark the best dv/dt filter solution for a particular drive.

II. SYSTEM MODELING IN MA TLAB

The above PWM inverter, cable and induction motor models are Combined together to form total system model and simulated in MA TLAB. As shown in Fig.1 in this model a certain length of cable is connected in between the inverter and the motor of 3HP, and a 420V pulse voltage is applied to the Motor through a cable. The pulse initiated at the cable will be reflected at the motor terminal due to impedance mismatch between the cable and the motor. The effect of voltage reflection causes over voltage at the motor terminal. The simulation results showing the over voltage at motor terminal for different cable lengths and HP ratings are shown in the next section. The different filters are designed and located in between inverter and motor and effects are also shown in next section.

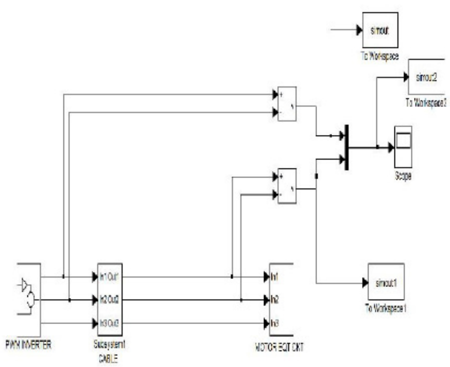

Fig.1 System representation in MATLAB

III. SIMULATION RESULTS FOR DEFFERENT CABLE LENGTHS

Using the high frequency models presented in the preceding sections, a simulation program has been developed in MATLAB to calculate the over voltage, driving three different induction motor power ratings (3hp, 15hp and 40 hp).

The following figures show the maximum line-to-line voltage at the motor as a function of terminal voltage pulse rise times for different cable lengths (10m, 20m and 50m) for a 3hp motor.

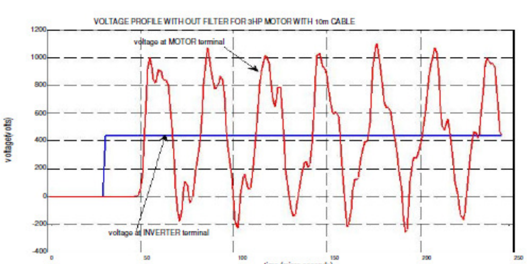

Fig.2 Voltage profile with out filter for 3HP Motor with 10m Cable

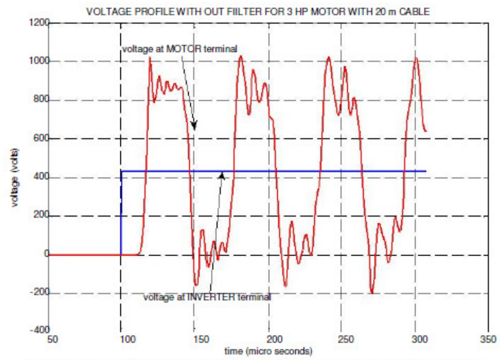

Fig 3.Voltage profile with out filter for 3HP Motor with 20m Cable

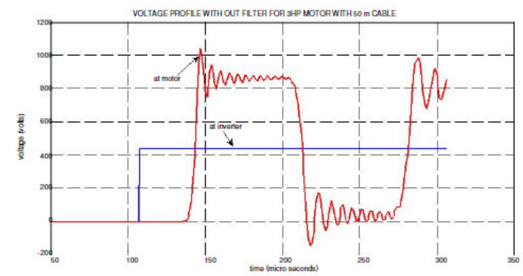

Fig.4.Voltage profile with out filter for 3HP Motor with 50m Cable

TABLE 1
3HP MOTOR FOR DIFFERENT CABLE LENGTHS

Cable length (m)	Peak Voltage (volts)
10	1000
20	1033
50	1048

Table 1.shows the value of delay time, rise time of both inverter output and motor output voltage and peak voltage for different cable length for 3 HP motor

From the waveforms and the table1, it is observed that the voltage at the motor terminals becoming higher as the length of the cable increase for the same rise time and as the rise time increases the over voltage reduces for the same length of cable.

If we draw HP rating vs peak over voltage as shown in Fig.5, the over voltages reduces for higher rating of the motor.

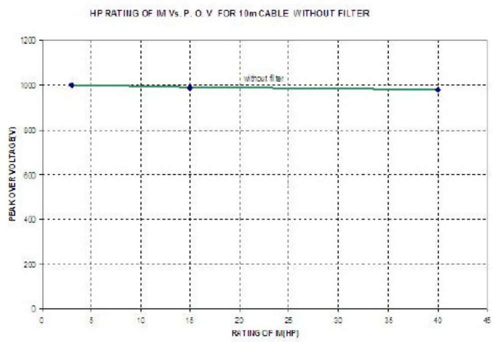

Fig.5. Hp rating vs. POV for 10 m cable without filter

IV. Reduction of over Voltage By using Different Filters

Several filtering techniques have been proposed to mitigate the over-voltage problem in long cable PWM drives. In general, these techniques include matching the cable surge impedance to the motor input impedance and increasing the voltage pulse rise time initiated at the inverter. The most relevant filter networks are found to be RC and RLC filters at the motor terminals and RLC at the inverter terminal.

For each filter topology, design equations can be derived based on the principles of matching motor input impedance to the cable surge impedance and decreasing the voltage pulse rise time. If the design aims at finding the filter parameters in order to give the system a certain behavior, the design equations are not sufficient. A closed form expression that gives the voltage peak in the motor terminal and losses in the filter as a function of the filter parameters is extremely complex; it would appear likely to involve many approximations that could compromise the peak voltage and loss evaluation. In this section equations and filter model are explained for one section and for remaining section system representation is with type and location of filter.

A. RC FILTER AT THE MOTOR TERMINALS

The representation for basic RC filter is as shown in Fig.6 and its MATLAB representation is shown in Fig.7. The complete system representation in MATLAB involving PWM inverter, cable and motor with RC Filter at motor terminals is shown in Fig.7.In our work, this system has been used in the design and evaluation of RC Filter for reducing over voltages at the terminals of ASM.

By solving equations (1) and (2) for different cable gauge and inverter output pulse wave form we get values of R_f and C_f.

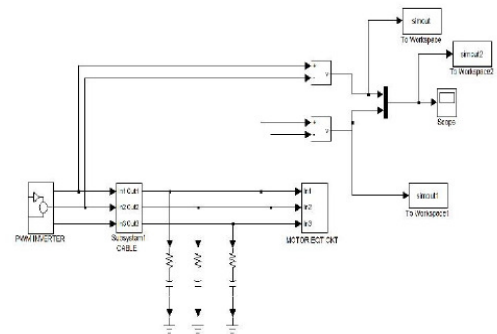

Fig.7. System representation with RC Filter at motor terminal in MATLAB

B.RLC FILTER AT MOTOR TERMINALS

A system comprising PWM inverter, cable, Induction motor and RLC Filter at motor in MATLAB that is used for obtaining simulation results is shown in Fig.8.

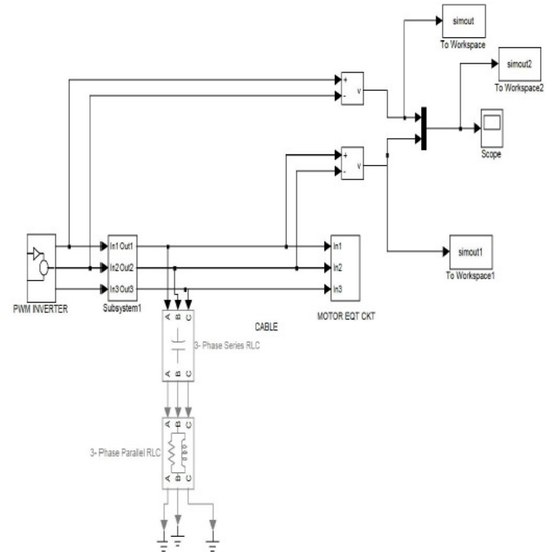

Fig.8. System representation with RLC Filter at Motor in MATLAB

C.RLC FILTER AT INVERTER TERMINALS

A system comprising PWM inverter, cable, Induction motor and RLC Filter at Inverter in MATLAB that is used for obtaining simulation results is shown in Fig.9.

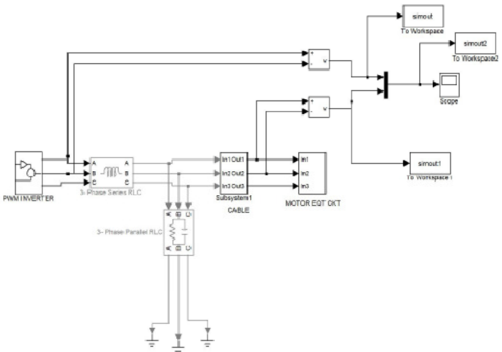

Fig.9. System representation with RLC Filter at inverter in MATLAB

V. SIMULATION RESULTS USING DIFFERENT FILTERS

By making use of systems representations in MATLAB for no Filter, with RC Filter at Motor, with RLC Filter at Motor and with RLC Filter at Inverter, being given by Figures 10-24 respectively, several MATLAB programs are run for 3HP, 15HP and 40HP Induction Motors with different cable lengths (10m, 20m and 50m) and the results of peak over voltages are tabulated in Table 3 as shown.

A. CONNECTING RC FILTER AT MOTOR TERMINAL

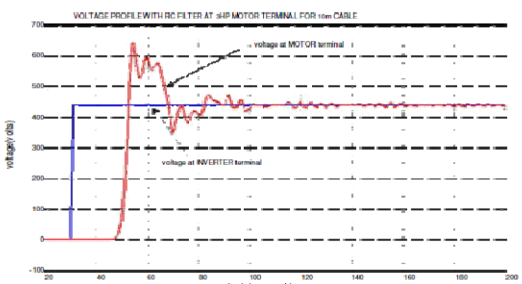

Fig.10 Voltage profile with RC filter at 3HP Motor terminal with 10 m cable

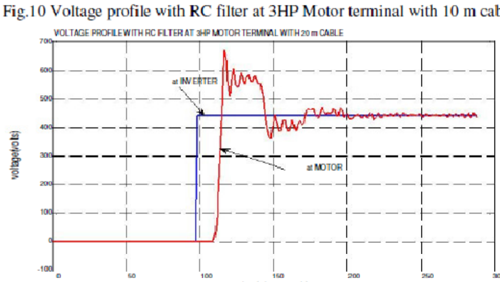

Fig.11 Voltage profile with RC filter at 3HP Motor terminal with 20 m cable

Considering the values given in the reference [2] the typical values of the filter parameters are used for designing various Filters used for obtaining the results of simulation.

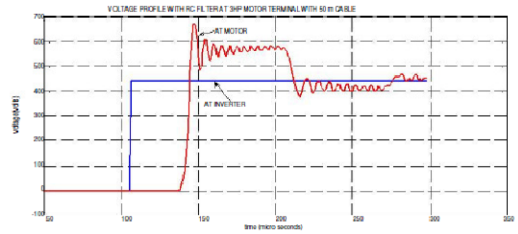

Fig.12 Voltage profile with RC filter at 3HP Motor terminal with 50 m cable

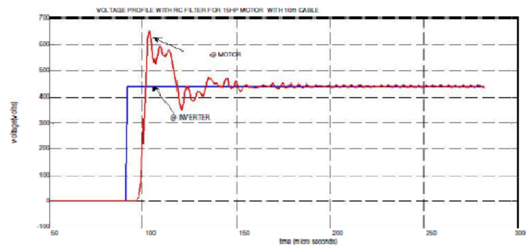

Fig.13 Voltage profile with RC filter at 15HP Motor terminal with 10 m cable

B. CONNECTING RLC FILTER AT MOTOR TERMINAL

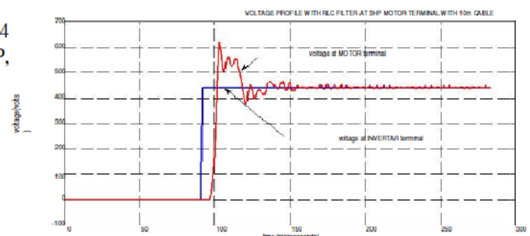

Fig.14 Voltage profile with RLC filter at 3HP Motor terminal with 10 m cable

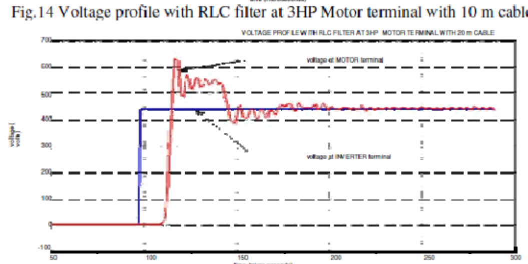

Fig.15 Voltage profile with RLC filter at 3HP Motor terminal with 20 m cable

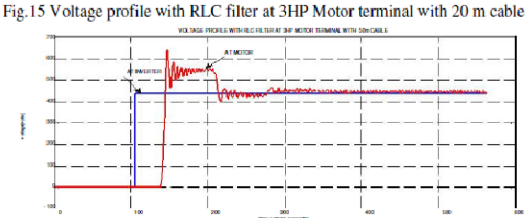

Fig.16.Voltage profile with RLC filter at 3HP Motor terminal with 50 m cable

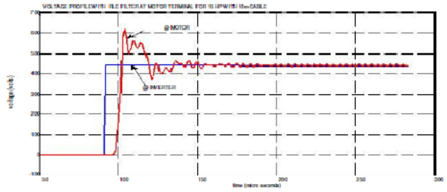

Fig.17 Voltage profile with RLC filter at 15HP Motor terminal with 10 m cable

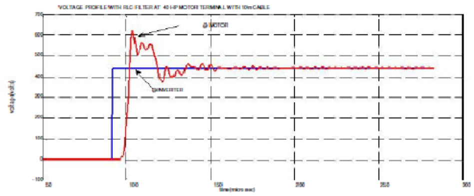

Fig.18.Voltage profile with RLC filter at 40HP Motor terminal with 10 m cable

C. CONNECTING RLC FILTER AT INVERTER TERMINAL

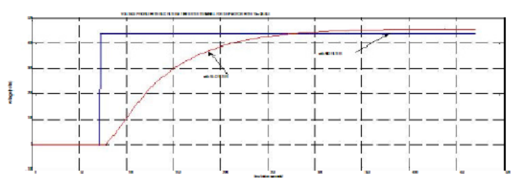

Fig.19 Voltage profile with RLC filter at Inverter for 3HP Motor terminal with 10 m cable

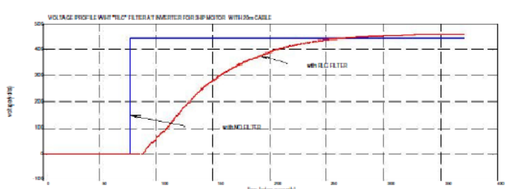

Fig.20 Voltage profile with RLC Filter at Inverter for 3HP Motor terminal with 20 m cable

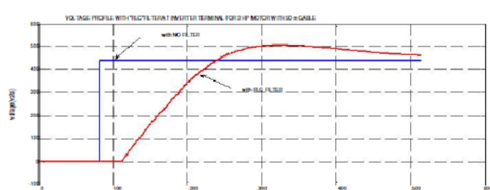

Fig.21 Voltage profile with RLC filter at Inverter for 3HP Motor terminal with 50 m cable

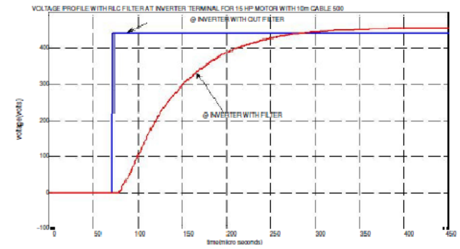

Fig.22.Voltage profile with RLC filter at Inverter for 15HP Motor terminal with 10 m cable

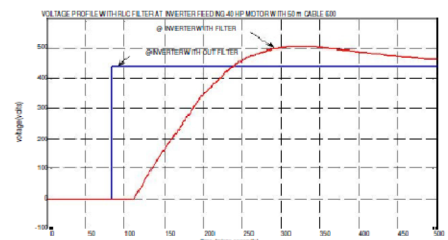

Fig.23 Voltage profile with RLC filter at Inverter for 40HP Motor terminal with 50 m cable

TABLE 3
COMPARISON OF OVER VOLTAGES WITHOUT AND WITH ALL FILTERS

CABLE LENGTH (m)	WITH/WITHOUT FILTER	PEAK OVER VOLTAGE(V) FOR		
		3 HP IM	15 HP IM	40 HP IM
10	With NO Filter	1000	990	980
	With RC Filter @ MOTOR	644	656	657
	With RLC Filter @MOTOR	623	623	624
	With RLC Filter @ INVERTER	459	458	457
20	With NO Filter	1033	1032	1032
	With RC Filter @ MOTOR	672	674	675
	With RLC Filter @MOTOR	632	633	634
	With RLC Filter @ INVERTER	460	460	461
50	With NO Filter	1048	1048	1048
	With RC Filter @ MOTOR	675	675	676
	With RLC Filter @MOTOR	643	643	643
	With RLC Filter @ INVERTER	507	507	507

D.WITH ALL FILTERS INCLUDED (WITH OUT FILTER, RC AT MOTOR, RLC AT MOTOR, RLC INVERTER)

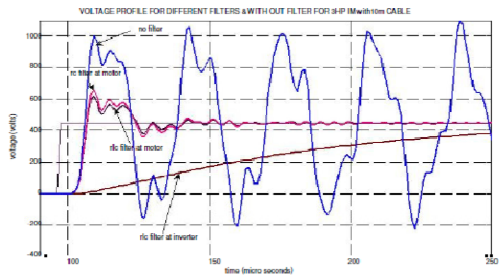

Fig.24.voltage profile for different filters & without filter for 3HP IM with 10 m cable

From the simulation results, we observe that the Filters placed at the motor terminals are incapable of reducing the dv/dt as much as those placed at the inverter terminals. This result happens because the filter networks at the motor terminals, which match the cable impedance, can only reduce the voltage to the dc bus value but cannot slow down the pulse rise time. In a different manner, the topologies placed at the inverter output can greatly reduce the dv/dt at the motor; since they decrease the pulse rise time before the pulse travels through the cable

VI.CONCLUSIONS

In this paper we have proposed a MATLAB based program intended to analyze the over-voltage phenomena in long cable PWM drives and effect of different filters to reduce the over voltages.

Several simulation results have been presented demonstrating the suitability of the simulation package. In the case of the over-voltage analysis, the simulation program is useful for the generation of charts that give the peak voltage at the motor terminals as a function of voltage pulse rise time and length of power cable. Using such over-voltage charts one can predict a priori the conditions under which the increased voltage stress will occur.

The most common dv/dt filter topologies for mitigating over voltage problems were analyzed using the proposed simulation package. The main conclusion from this analysis is that the Filters placed at the motor terminals are incapable of reducing the dv/dt as much as the filter placed at the inverter terminals. This occurs because the filters at the motor terminals, which match the cable surge impedance, can only reduce the voltage to the dc bus level but are not capable of reducing the pulse rise time. On the other hand, the filters placed at the inverter terminals can greatly reduce the dv/dt at the motor, since they decrease the pulse rise time before it travels through the cable.

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