

# Department of Electrical and Computer Engineering

## Electric Power and Power Electronics Institute

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One-day Short Course

### **ADJUSTABLE SPEED AC MOTOR DRIVES: APPLICATION PROBLEMS AND SOLUTIONS**

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#### **Summary**

Adjustable speed AC drives have become the preferred choice in many industrial applications where controlled speed is required. At the same time, the maturing of the technology and the availability of fast and efficient solid state power semiconductor switches (IGBTs) has resulted in voltage source, PWM controlled inverters becoming a standard configuration in the power range to 500kW. While high frequency PWM control represents the most advanced drive concept, when inappropriately applied, it also generates side effects, some which have been recognized only recently.

This course presents a comprehensive coverage of application issues of PWM inverter controlled ac motor drives which include: damage to motor insulation due to reflected voltages caused by long motor leads; the mechanism of motor bearing failures due to excessive common mode dv/dt and leakage currents to ground.

Following a description of the problems, several practical solutions are also presented and analyzed. Finally, line harmonic problems caused by the input diode rectifier are also described and several low cost solutions selected to meet IEEE 519-1992 are presented.

#### **Who should attend**

PWM Inverter/motor manufacturers, system designers as well as adjustable speed drive application engineers and users will find this course informative and beneficial.

#### **Contents**

##### **SECTION I. Introduction to ASDs and Application Problems**

- ASDs – Status Overview
- ASDs application requirements
- AC ASD Family
- PWM Control of output voltages
- ASD Manufacturers & their products
- Advantages of PWM drive technology
- Why the migration to IGBTs
- Application issues: motor heating, dv/dt problems, power quality

##### **SECTION II. Introduction: Application Problems Related to high dv/dt and Long Motor Leads**

- Effect of using long cables between the inverter and the motor
- Voltage reflection analysis and calculation of motor terminal peak voltage as a function of cable length and dv/dt of the PWM pulses
- Simulations, example calculations and experimental waveforms on 460V, PWM inverter fed induction motor drive system for 10ft, 50ft, and 100ft cable length.
- Inverter and motor currents with long leads

- Factors contributing to motor voltage transient  $> 2pu$  dc-bus voltage, example calculation and results
- Pspice simulation example - Demo

### **SECTION III. Over voltage stress on motor windings due to high dv/dt**

- Introduction: types of failure modes
- Voltage distribution
- Experimental evaluation of turn / coil voltage distribution
- Predicting transient effect of PWM voltage waveform on stator windings – SABER model
- Failure mechanism of interturn insulation of low voltage electric machines fed by PWM Inverter
- NEMA MG-31 - Definite purpose inverter-fed motor specification
- IEC-60034-17 (1998) "Guide for the application of cage induction motors when fed from converters"

### **SECTION IV. Effect of high common mode dv/dt at the terminals of an inverter fed induction motor**

- Introduction
- Why there is common mode voltage at the inverter output ?
- Test Results
- Common mode impedance plots of typical induction motors & equivalent circuits
- Common mode dv/dt at the motor terminals is a function of Converter topology: Example motor powered by a PWM rectifier/PWM inverter system
- Shaft voltages, bearing currents and leakage currents to ground
- Equivalent circuit model
- Example experimental shaft voltages and bearing currents

### **SECTION V. Solutions to minimize motor failures**

#### **A- Filters**

- Introduction
- Application of series reactors
- Motor terminal filter to reduce dv/dt
- Conventional Inverter output filter
- A New Inverter Output Filter
- Comparison of various filtering methods
- Application of common mode choke to reduce leakage currents/EMI
- Software modifications in PWM generation to avoid  $>2pu$  over-voltages at the motor terminals

#### **B- Possible Motor design modifications**

- In-slot winding method by Lincoln electric motor div., Cleveland, OH
- New magnet wire – Thermaleze Q<sup>S</sup> by Phelps Dodge – Pulse endurance index
- Solutions to enhance bearing life in PWM drives

### **SECTION VI. Other ASD Related Issues & Emerging trends**

- Harmonics generated by ASD equipment
- Low cost clean power rectifiers for ASDs
- Nuisance tripping of ASDs for voltage sags
- Smart motors – motor mounted converters
- Emerging medium voltage (2300V, 3300V and 4160V) drive systems