The Electric Machines and Power Electronics Laboratory at the University of Wisconsin

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ABSTRACT

This paper presents a preliminary report on the new electric machines and power electronics laboratory being developed at the University of Wisconsin-Madison. The major emphasis is on the new electric drive test stands which were selected as the primary means of introducing electric machines, electric drive controls and power electronics in a laboratory environment. A description of the test stands and some examples of its intended utilization in the first level electric machines laboratory course are presented. Some of the background leading to the selection of an integrated test stand and its design are also presented. A brief summary of some of the other equipment to be installed in the laboratory is also given.

INTRODUCTION

The electric machines laboratory at the University of Wisconsin was originally constructed in the early 1950's and the basic equipment and layout (somewhat reduced in size) was being utilized up to the present. Recently, through a state appropriation and a very generous gift from the Grainger Foundation, funds to carry out a major modernization and remodelling program became available. In planning the modernization, it was decided to organize the new facility around a set of test stands which would incorporate machines, power converters and some instrumentation in a single, stand-alone unit. The major portion of this paper describes the development and planned utilization of these test stands.

HISTORICAL PERSPECTIVE

The development of a wide range of power electronic controllers for electric machines has revolutionized the electric drive industry over the past two decades. In most cases, educational institutions have been able to incorporate electronic motor control into their laboratory courses only by adding stand-alone, commercial equipment to augment existing machine laboratory facilities. This was the approach followed at Wisconsin and our laboratory was soon equipped with a variety of one-of-a-kind commercial units most of which were received as very much appreciated gifts from manufacturers. We did, fortunately, receive one gift of five identical six-step variable frequency drives which became the workhorses of our beginning-level laboratories.

While this type of equipment did permit us to introduce some aspects of modern power electronic control of motors, it did not allow demonstrating the wide range of possibilities which exists. Although we did build some specialized equipment as part of our research efforts, very little of this could be worked into the instructional laboratories for lack of sufficient funding and because the equipment did not incorporate the required protective circuitry and ruggedness needed for laboratory instruction.

When the special funding became available, it was clear that we wanted to develop a means of including a wide range of control options along with the normal options of constant voltage, constant frequency operation. After considering a variety of possibilities, we chose to design a versatile test stand which would allow a wide range of operating modes and would be flexible enough to allow future addition of new concepts and strategies as software modifications. To allow use in the beginning-level laboratories, we also chose to incorporate a number of hardware modes which would allow simple exercises to be carried out without complex external programming requirements. The test stands were designed and built by Unico, Inc. in Franksville, Wisconsin following the design specifications produced by our group.

BASIC STRUCTURE OF TEST STANDS

The test stands consist of a main enclosure containing the primary three-phase and dc power distribution circuits and operator controls. Three fixed machine panels provide the interfaces to the machines, basic instrumentation test points for the machine electrical variables and the machine operator controls. In addition, three fixed computer control racks are provided, one for each machine. Four removable power converter modules are provided to provide versatility in the control and operation of the machines. A fixed instrumentation panel is also provided with three digital voltmeters and a two-channel digital storage oscilloscope. The three machines are also mounted in the main enclosure. An overall view of the complete test stand is shown in Figure 1.

Main Enclosure and Power Circuits

The main power circuits include a 230 V, 3.5 kVA isolation transformer, a three-phase, key operated contactor and a three-phase input circuit breaker. The three-phase power is routed out to each of the ac machine modules so that any of the ac machines can be operated directly from the three-phase supply if desired. The three-phase supply also feeds a three-phase 3 kW rectifier to provide a dc bus supply for the power converter modules. Although it is intended that the test stand normally operate with both the motoring and generating machines converter fed so the power is simply circulated

the final power connection. Two Hall effect current sensors are provided along with two differential amplifiers to provide buffered current and voltage measuring points at the machine panel. These buffered voltage and current signals are also carried internally to the instrumentation panel.

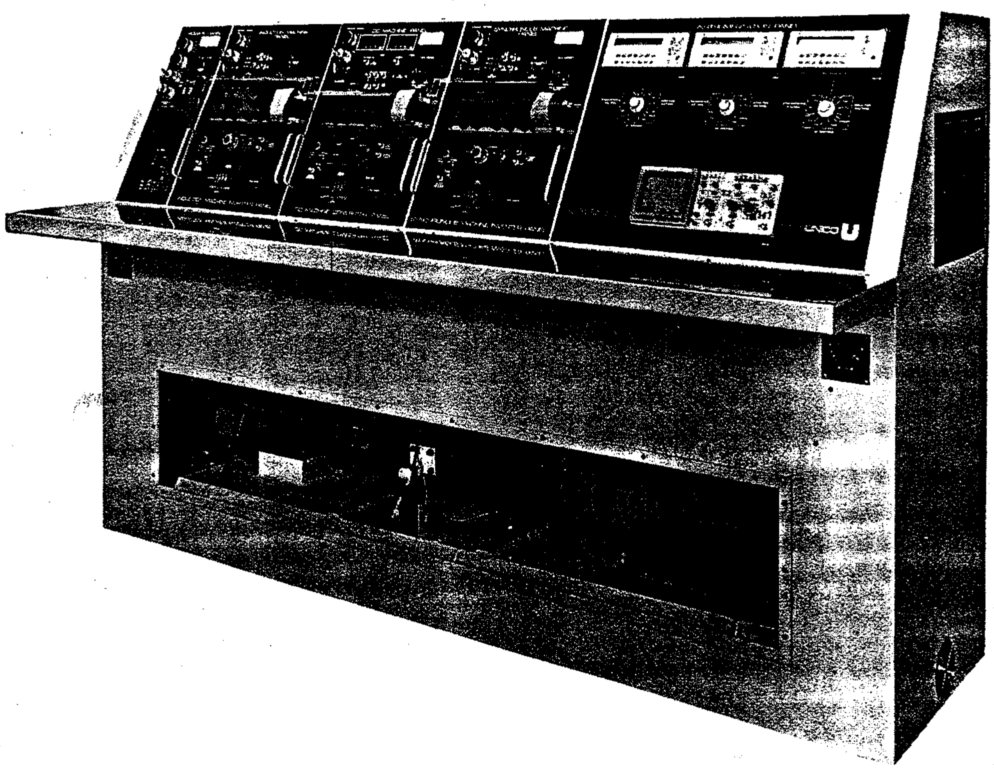

Figure 1 Electric Machine and Power Electronic Drive System Test Stand

through the dc bus, the bus is equipped with a dynamic braking resistor rated at 2.5 kW. This allows any one machine to regenerate into the bus with the power dissipated in the braking resistor (as will occur if a motor is line fed and loaded by the dc generator).

Machine Panels

Each machine interfaces to the main enclosure through a fixed panel which is machine specific. In the case of the ac machines, the machine terminals are located so they can be supplied either from the ac line or the appropriate power converter by a simple three-phase connector strap. The dc machine is only supplied from the dc power converter but this is also by means of a strap connector so the machine can be easily isolated.

Induction machine--The induction machine is a 2 hp, 230 volt, 60 hz, 1725 rpm high efficiency machine. A key operated three-phase contactor with thermal overloads is used to make

Synchronous machine--The synchronous machine is rated 2 kW as a motor and 1.5 kVA as a generator. It is a 230 volt, 4 pole machine with a wound field. The same type of contactor and buffered instrumentation is provided as for the induction motor. In addition, an analog field control and ammeter and a set of synchronizing lights are provided to complete the module.

DC machine--The dc machine is a cradle mounted dynamometer rated at 230 volts, 7.6 amps., 2 hp, 1750 rpm. A dc tachometer is directly coupled to the dc machine and a strain gage load cell is used to sense the reaction torque. A key operated dc contactor is provided to make the final connection to the power supply. Buffered measuring points for armature voltage, armature current, torque and speed are provided along with digital read-out of speed and torque and an analog field control and ammeter.

Power Converter and Control Modules

Four removable power converter modules with integrated controllers are provided to facilitate a broad range of experimental activity. Three of the modules are machine specific, current regulated, PWM converters with dedicated, software-reconfigurable, microprocessor controllers and the fourth is a standard, constant volts/hz, variable-speed drive which can be used with either of the ac machines. The volts/hz drive has front panel adjustments for acceleration limits and for low speed voltage boost. The machine specific, current regulated PWM modules can be controlled with an external computer but also have built-in operating control modes selected by a mode switch. One of the built-in control modes allows command inputs from a reference potentiometer on the module while another allows analog reference signal inputs. Each of the ac inverter modules has internal computer control modes for position, speed and torque control, and both of the modules employ field orientation control (only the speed and torque modes are hardware selectable). The shaft position information is provided via an encoder on the induction machine and a resolver on the synchronous machine. The dc chopper module also has speed and torque control modes and in addition has an armature voltage control mode. An external analog reference signal can also be applied to the reference input for any of the control modes on any of the modules.

Instrumentation Panel

The instrumentation panel provides a direct means of accessing all of the isolated measuring points via three multiposition selector switches, one for each of three permanently mounted digital voltmeters. The selectable signals include two line voltages and two line currents for each ac machine, the armature voltage and current of the dc machine and the speed and torque signals. All of the signals are also accessible on a buffered computer interface instrumentation signal bus. A two-channel digital storage scope is also provided for observing waveforms and associated measurements. A two-channel signal isolator is part of the test stand equipment but is not built-in.

The buffered voltage and current signals are filtered to remove the PWM carrier and thus provide information on the fundamental component of the respective variables. Matched filters are used to preserve relative phase information.

USE OF THE TEST STANDS

The test stands are intended to support the major share of experimental activity in our instructional laboratory program in electric machines and drives. They will also be available for limited amounts of research activity, especially the fifth stand which serves as a back-up unit and as a tool for laboratory exercise development.

Since the first two of the test stands have only recently been delivered, our focus up to the present has been on integrating their use into our elective laboratories on electric machines and electric drives. The first of these is a junior-level course on electric machines which is followed by a senior-level course on electric drives. As an illustration of the flexibility of the stands, some of the planned exercises in the junior course on electric machines will be outlined. In this course, the focus will be on the machine properties and the various control modes will be employed strictly as a means of examining machine behavior. The control modes will therefore be treated as functional elements with only a brief explanation of how they are created and what limitations exist.

DC Machine Studies

With the dc machine physically disconnected from its power converter, either of the ac machines operated in the speed mode can be used as a variable speed source and the full range of open circuit characteristics can be readily examined using only the test stand instrumentation. To examine generator performance, an external resistor load could be used. Alternatively, with the dc machine tied to its power converter and operated in its torque mode, generator characteristics can be readily obtained over a very wide range of speed, field current and load. DC motor characteristics can be equally easily measured by running the dc machine in the voltage mode and using either ac machine in the torque mode. Constant speed motoring can also be observed and the required variation in armature voltage explored. Since all the controlled modes are capable of four quadrant operation, virtually any speed-torque point can be attained.

Certain parameter measurements can also be very conveniently made by careful use of the control modes. For example, using one of the ac machines in the speed mode to hold the speed at zero and operating the dc machine in the torque mode allows measurement of the armature resistance of the machine. A very informative oscilloscope plot of the armature resistance V-I characteristic can be obtained by feeding an external low frequency signal into the torque reference to cycle the machine over its current range.

The controlled torque modes of the ac machines combined with the ability to supply external reference signals provides a very powerful means of demonstrating the effects of variable loads on the dc machine. A pulsating torque load, for example, is readily investigated by simply adding an appropriate sinusoidal signal to the dc torque reference available on the control module. External reference inputs can also be applied in any of the dc machine modes making possible direct observation and measurement of various transfer characteristics in the frequency domain or observation of time domain transient response.

Induction Machine Studies

Conventional induction machine operation can be studied by supplying the induction machine from the line and using the dc machine in the torque mode. Both motoring and induction generator performance can be examined (in the motoring case the output power is dissipated in the dc bus dynamic brake). The serious consequences of low voltage motoring with a constant torque load are easily demonstrated by simply including a variac for line voltage control. By utilizing the speed or voltage mode on the dc machine, the entire induction motor speed torque curve can be examined (at reduced line voltage). Less conventional but very informative measurements of the difference between peak torque for constant voltage and peak torque for constant current can readily be made by using the speed mode of the dc machine. Pulsating loads and suddenly applied loads are also readily obtained by using the dc machine torque mode and external reference inputs.

Parameter measurements can be carried out by using the dc machine in the speed mode as a speed source. Exact, no-load operation is attainable and permits demonstrating some of the parasitic effects, such as residual rotor flux and rotor asymmetry, inherent in real machines. Commanding zero speed on a position loop allows normal locked rotor testing and again the effects of parasitics can be observed.

Installing the volts/hz module and using the dc machine in the torque mode will allow examining conventional open loop speed control of the induction motor. Since the dc supply for the volts/hz module is the test stand dc bus, even regenerative operation can be examined if desired. Loading the machine, even at very low speed, poses no special problem as a result of the controlled torque mode on the dc machine.

Finally, the requirements for precise speed or torque control of an induction machine can be studied by installing the induction machine converter module and examining the required variations in motor voltage, current and slip when it is operated in either the torque or speed control modes. These observations will reinforce the important role of slip in characterizing induction motor performance even though the full extent of the complexities of control are not fully explored (in the first course).

Synchronous Machine Studies

The same full range of possibilities as for the induction machine also exist for the synchronous machine. A full demonstration of normal line connected operation, including synchronization to the line, is readily accomplished. Constant volts/hz performance and torque control can be examined in some detail and the difference between synchronous operation from a frequency regulated supply and self synchronous operation can be made apparent.

Drive and Power Electronics System Studies

The second course will focus primarily on the drive and power electronics system aspects as opposed to the machine itself. Here the intention is to examine the control strategies and power electronics topologies employed in modern machine control. A wide range of possible exercises can be created by simply examining the performance variables of the power electronics hardware and by reconfiguring in software the machine control modes. For example, both the induction and synchronous machines can be run under current regulated PWM, field oriented control algorithms using built-in hardware and control software. Such controls can be intentionally mistuned by merely revising software coefficients which are available to the instructor and/or student user via a computer interface. The state variable controllers for motion control for either of the AC machines can be similarly modified via a computer interface. It is also possible to create entirely new controllers by writing new computer control software. This opens up a very wide range of potential exercises. This last aspect of test stand operation has yet to be explored.

OTHER LABORATORY EQUIPMENT

In addition to the test stands, the laboratory will contain two modern dynamometers for advanced laboratory work and research. There are also ten additional machine bases equipped with conventional machines which can be used for specific projects or laboratory exercises.

For power electronic laboratory work, a set of five modular units containing basic power electronic components will be available. Three types of modules have presently been fabricated in the laboratory. These include MOSFET, BJT and thyristor modules. Each module is capable of being interconnected as per a specified power circuit and contains all gating circuits required. These modules interface with a standard controller which can be programmed for a wide variety of converter circuits. This equipment is aimed at exposing students to control requirements, dynamic processes and switching behavior in power converters in separate laboratory courses in power electronics.

Computer support for instrumentation and control in the laboratory will be provided by five MAC IIx computers totally dedicated to the laboratory. The complete signal bus is available to each computer. Each of these computers will run software enabling them to act as software reconfigurable virtual instruments so that numerous experiments can be prepared and the instrumentation "stored in software".

CONCLUDING REMARKS

The advantages of a fully integrated and virtually self-contained test stand as a laboratory instructional tool have been emphasized. There are also clearly disadvantages such as using only one set of small machines, having much of the experimental controls obscured and in the background, and eliminating some of the hands-on experience of connecting equipment. Some of these we plan to address by means of other facilities available in the laboratory. We are hopeful that we will be able to bring new excitement to our courses and provide laboratory experiences for our students which we were previously unable to accomplish.