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Power Engineering Laboratory Facilities at the University of Missouri-Rolla

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I. INTRODUCTION

The University of Missouri - Rolla (UMR) is a unique university having the highest percentage of engineering majors of any college in the country. UMR has also placed a great emphasis on its power program and invested in it over the years whilst other universities have scaled theirs down or eliminated them altogether. In Missouri, UMR is the only university where students can emphasize in power. This puts UMR in a unique position for the future considering new applications of power electronics which include the hybrid electric vehicle, the Navy's electric ship program, and flexible ac transmission systems (FACTS) on the electric utility grid.

UMR puts considerable emphasis on experiential learning and student design since the instructional and research laboratories play a large part in the student learning process. This paper describes the major laboratories to which the students in the power engineering curriculum have access.

II. THE LABORATORIES

A. Emerson Electric Company Energy Conversion Laboratory

This laboratory was created by a grant from Emerson Electric Company in 1984 and is now valued at approximately $950,000 and is designed for computer controlled research and testing of machines and drives. It is used by faculty and graduate electrical engineering students for research and by undergraduate students for power engineering education. Computer-aided testing is accomplished by near real-time computer control of machines and simultaneous data acquisition. Data acquisition can be done at a swift sampling rate to allow for many test data points to be gathered on the state of motors. The data is easily processed and displayed for quick feedback on a test run. The laboratory consists of six identical independent stations. Figure 1 shows a photo of one station. The dynamometer is a 14.9 kW dc machine which interfaces to 230 V ac through a regenerative drive (not shown in the photo). The dynamometer supplies a 3.7 kW test motor which can be a synchronous machine (shown in the photo), an induction machine, or a dc machine. The test motor is mounted on a torque table and there is also an in-line torque sensor seen on the shaft. In the background of Figure 1, a cabinet houses a variable frequency ac drive (rated up to 230 V and 100 Hz) and a dc drive (rated up to 240 V). The contactor panel has circuit breakers for the dynamometer and drives. The output panel supplies 230 V ac, 125 V dc, and 250 Vdc. Also available at the terminals are the drive outputs, a synchronous exciter output, an induction motor starter, and a tie line for connection to other stations. The meter panel includes in-line current and power meters as well as versatile voltage meters which are read by the PC. Hardware-in-

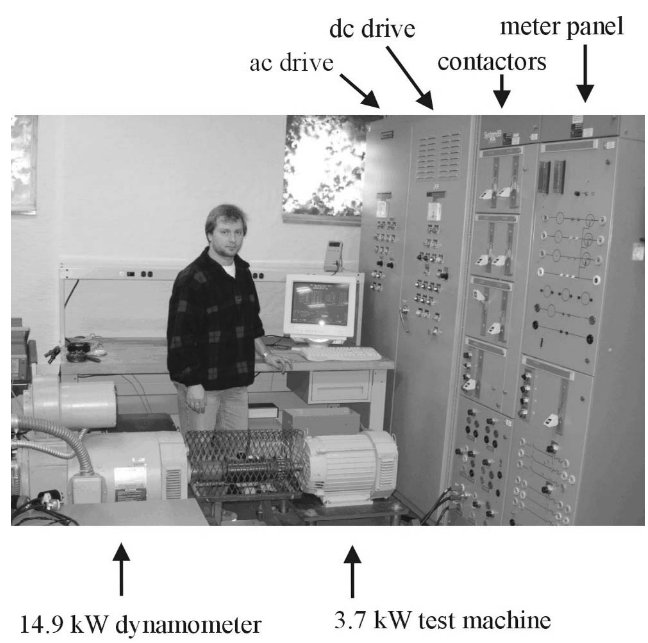

Figure 1. Emerson Electric Company Energy Conversion Laboratory station.

the-loop studies are conducted via dedicated Pentium PCs.

The Emerson Electric Company Energy Conversion Laboratory has played a vial role in several research projects involving a wide range of machines. Examples include synchronous generator modeling [1], induction motor control [2], and brushless dc motor position sensing [3]. The laboratory is also instrumental in setting up system studies using multiple stations for study of stabilizing controls [4]. Furthermore, a small amount of power electronic equipment in the lab allows the study of novel motor drives [5].

B. Ameren Power Electronics Laboratory

This laboratory was developed with a grant from Ameren. The primary focus is modern power electronic converters and their applications. Figure 2 shows one station of the laboratory (there are four stations altogether). The power electronics rack contains sixteen IGBT transistors (rated at 600V 50A), four power diodes, and necessary sensors. By re-configuration of the connectors on the front panel, a wide variety of power converters can be constructed including inverters, dc-dc converters, and rectifiers. The added power diodes help for configuration of unique converters (such as switched reluctance drives). A and a TMS320 based digital signal processor (DSP) is available at each station. The PC contains a GPIB card and a National Instruments data acquisition card with LabView software. Each station also has a Tektronix TDS-460A oscilloscope with a hall-effect current probe system. The source for these experiments is a dc power supply in the power electronics rack and resistive banks (not shown in the photo) are available for loading. The existing equipment is outstanding for carrying out power electronics experiments. The Ameren Power Electronics Laboratory is described in more detail in [7]

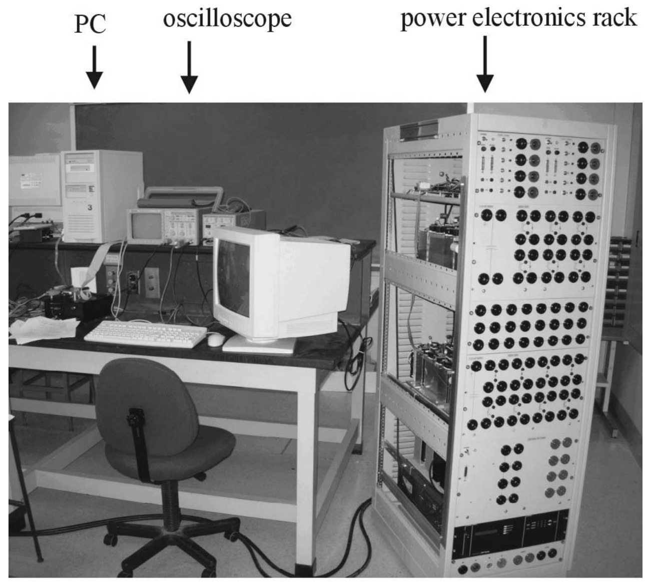

Figure 2. Ameren Power Electronics Laboratory station.

C. High-Frequency Machines and Drives Laboratory

This laboratory has been expanded through recent federal and state equipment grants, and has over $350,000 of dedicated state-of-the-art equipment, including a network analyzer, spectrum analyzer, impedance analyzer, LCR meter, high-speed digital oscilloscope and TDR, and dynamic signal analyzer suitable for EMI measurements and parasitic characterization of systems in the 1 Hz - 100 MHz frequency range. With this facility, electric machinery can be studied in the high-frequency range where ground currents and bearing currents are a major issue. This lab is for several research projects including high-frequency modeling of induction motors [6].

D. The Anechoic Acoustic Chamber

The anechoic acoustic chamber is an 8' × 8' × 8' anechoic room with a cutoff frequency of 300 Hz. An acoustically isolated 14.9 kW four-quadrant dynamometer is located outside the chamber to support the analysis of machines in either motor or generator operation. Acoustic data is obtained using a 3-set microphone array, signal conditioning equipment, a real-time 3rd octave band signal processor, and a real-time narrow band signal processor with order tracking. A machine stand is used to facilitate operation of machines by either direct or in-direct drive. This versatility is utilized in the analysis of machines used in automotive applications. Torque transducers and measurement procedures have been customized to facilitate torque ripple induced noise/ vibration measurements into the 30 kHz range. Figure 3 shows students taking measurements in the anechoic chamber. Note the three microphones that hang from the ceiling of the chamber to record various frequency input from the motor stand.

Figure 3. Students working in the anechoic acoustic chamber.

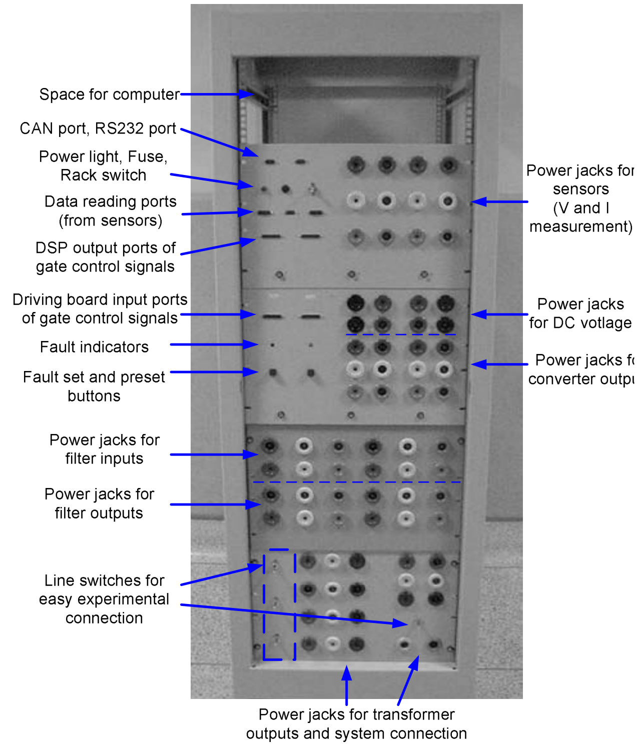

Figure 4. Front panel of the UPFC.

E. The Flexible AC Transmission Systems (FACTS) Laboratory

This facility is a portion of the Emerson Electric Energy Conversion Lab and is dedicated to research in power electronics applied to bulk power systems. Several FACTS devices have been constructed including the StatCom, SSSC, and UPFC. Figure 4 shows the front panel of the UPFC. With funding from the Sandia National Laboratories Energy Storage Systems Department, the experimental FACTS devices are capable of interfacing with a battery set that consists of 34 VLRA super-gel batteries in two strings supplying 204 V dc. The IGBT driver boards converts the TTL level switching signals into isolated ±15V levels to trigger the IGBTs. The signal interface board plays an important role in interfacing the power converter and controller. Firstly, it decodes and latches the switching signals generated by the DSP and feeds them to the IGBT driver board. Secondly, it multiplexes the 16 channels of sampled signals to 8 channels and sends them to the data acquisition DSP board. The signal interface board also generates a shaped synchronizing signal.

Two DSP boards (M5000, TMS320C51 core) are hosted in a PC via an EISA bus and operate concurrently as two slaves of the PC. The TMS320C51 DSP is chosen because of its ideal features: it has a 25 ns instruction cycle, 1056-word dual access RAM on chip, and 16 dedicated I/O ports. In addition, the M5000 board integrates ample hardware resources besides the DSP: 128K words of data SRAM and 64K words of program SRAM with 0 wait state; on-board timer (up to 4 MHz); interface with EISA bus; 12-bit 500Ksps A/D converter (MAX120) and a dual 12-bit D/A converter.

The data acquisition DSP collects data from the on-board A/D and implements real-time computational tasks such as low-pass filtering, Park's transformation and ac phasor calculation. Additionally, it measures the system frequency and monitors for any possible system errors. The switching signal DSP generates switching signals for the power converter according to the voltage phasor commands sent by host PC. The host PC provides supervisory control and an indirect communication link between the DSP boards via interrupts and data storage. The PC collects the processed field data such as system voltage and current from the data acquisition DSP whenever its 11th interrupt is requested. After applying control algorithms, the PC writes the new inverter output voltage commands to the RAM on the switching signal DSP board and then sends an interrupt signal to it. In this way, the host PC receives interrupts from the data acquisition DSP and send interrupts to switching signal DSP to form a closed loop control system and a communication link between the two DSP boards.

Common system-level control algorithms such as PI and fuzzy logic can be rapidly implemented via the PC by simply changing the software. Additionally, the host PC provides a user interface and data logger based on a DOS operating system and a C++ development environment.

The FACTS laboratory has been used to conduct a number of research projects. Recent examples include battery energy storage FACTS [8] and multilevel FACTS devices [9]. The FACTS laboratory is also described in detail in [10].

III. Future Developments

A. The Emerson Electric Company Energy Conversion Laboratory

Many of the recent additions to the Emerson Electric Company Energy Conversion Laboratory have come from research grants. Presently, the U.S. Navy is supporting research in ac system impedance measurement. Laboratory validation of this project will require the use of multiple stations to set up the system as well as power electronic equipment. The specific system involves an active rectifier and a converter for injecting current signals into the system. Figure 5 shows an outline drawing of one (of two) power electronic carts to be constructed for this project. The design of these carts will be unique and involves a wall of power electronic components on one side and a computer station with a digital signal processor (DSP) on the other side. With this design the path for analog sensor signals can be minimized and at the same time, the researcher is somewhat removed from the power section (for safety reasons). The power section will include a large number of transistors and energy storage components on one plane which can be easily re-wired so that a variety of power converters can be realized.

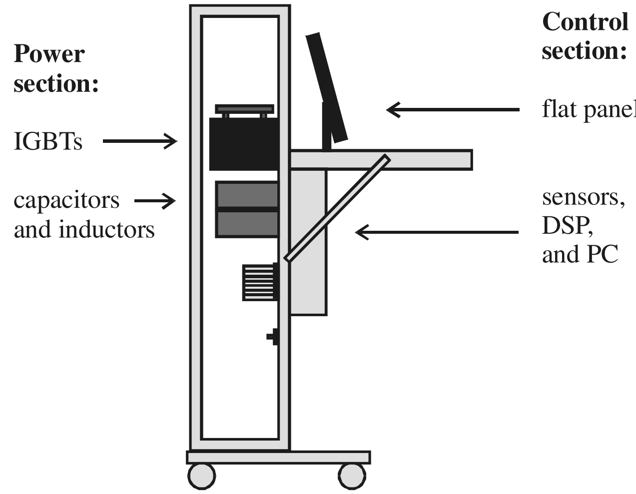

Figure 5. Power electronic carts (under development).

Emerson Electric Company has recently committed to a three-year grant to update the laboratory. The first step involves removal of the dynamometer controller and the dc and ac drives. The dynamometer control will be replaced with a modern 19.5 kW dc motor drive and the ac and dc drives will be replaced with a cabinet of modern power electronics. This will greatly reduce the size and increase the functionality of each station. Other planned improvements include placement of a DSP and oscilloscope at each station.

B. Ameren Power Electronics Laboratory

One limitation of this laboratory is the lack of machinery. Figure 6 shows one potential upgrade. Therein, the non-shaded equipment is the existing power electronics, PC, and oscilloscope. The shaded equipment is devices to be added to the lab. A simple 2.2 kW motor-generator set could be custom made for this station. An additional source, meter panel, and load can be imbedded in the laboratory bench. With the addition of this equipment, classic machines experiments can be carried out. Furthermore, the power electronics can be interfaced with the motor-generator set to perform a variety of drives experiments.

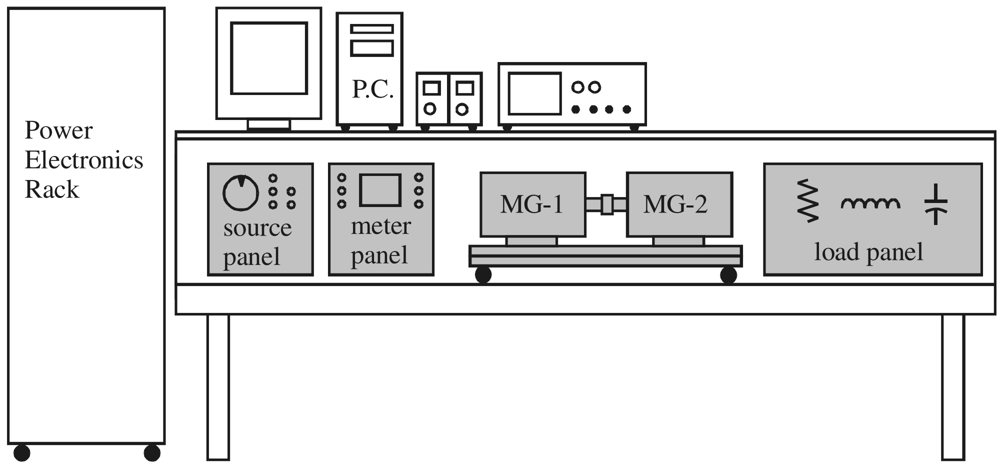

Figure 6. The Ameren Power Electronics Laboratory with added machinery and equipment.

IV. CONCLUSION

One of the significant niche areas at UMR is the area of Electric Power. For this reason UMR has invested in its power program over the years. The extent of this program ranges from power systems, motor drives, high-frequency effects in electric machines, acoustic noise of electric machines, FACTS devices for electric utility applications, and Naval propulsion power systems. The various laboratory facilities at UMR which support these activities have been described in detail in this paper.

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