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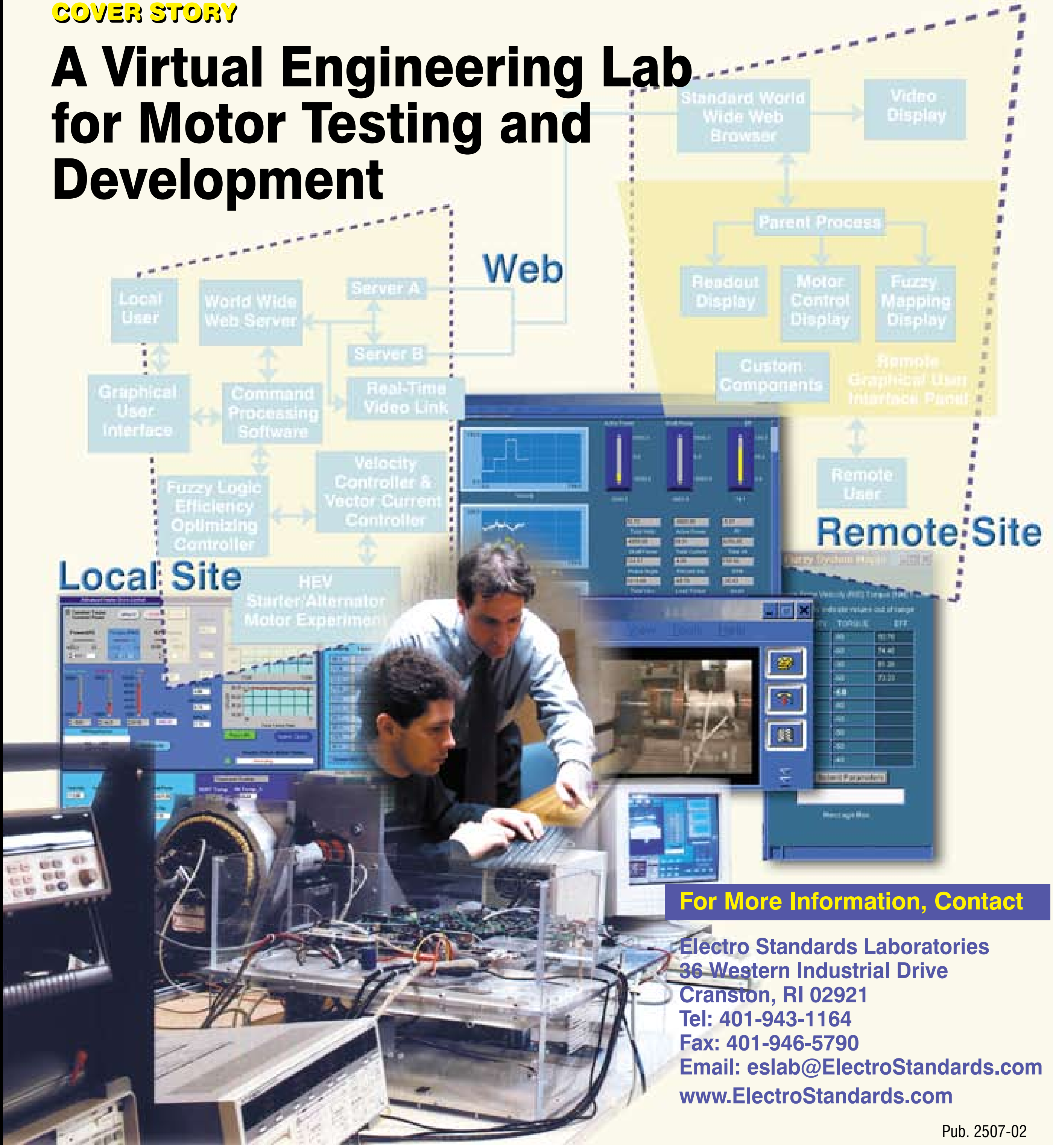
COVER STORY

A Virtual Engineering Lab for Motor Testing and Development



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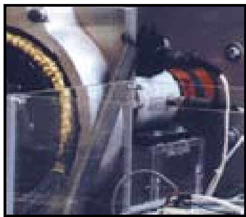


Real-Time Motor Testing and Development— Over the Internet

Raymond B. Sepe Jr., Electro Standards Laboratories

With this Web-based platform, you and your colleagues can collaborate on real-time experiments—wherever you are.

Many companies choose technical specialists for their skills instead of their proximity, employing product development teams that are not all on site. During system experiments and testing, however, this distributed expertise must all have access to the hardware laboratory. To answer this need, Electro Standards Laboratories (ESL) has developed a collaborative testing and experimentation platform for electric motor and power systems that can be operated in real time over the Internet using standard Web browsers. This platform operates as a virtual engineering laboratory (VE-Lab) that allows for fully interactive control of actual system hardware.

VE-LAB in Action

To understand the potential benefits of the VE-LAB, consider one example application: the development of a high-efficiency starter/generator for hybrid electric vehicles. With an induction motor starter/generator connected into the VE-LAB platform, controller algorithm developers at the ESL laboratory in Cranston, RI, and starter/generator designers at the automobile manufacturers in Detroit, MI, can perform Web-based remote experiments in real time over the Internet

Photo 1 shows both the local experimental motor test system and the corresponding remote video transmitted over the Web and displayed at the remote site during the experiment. Mounted on the computer, the remote display camera is focused on a close-up of the starter/generator motor. The graphical user display is present on the local laboratory computer as well as on the remote Web computer, enabling concurrent collaborative operation of the test hardware.

Figure 1 is a block diagram of the motor experimentation platform configured for testing the starter/generator, a 12-pole, 8kW induction motor. The digital signal processor (DSP) subsystem is responsible for implementing an indirect vector current controller and velocity controller, along with all pulse width modulation (PWM) timing generation. Generated energy is dissipated in ▶

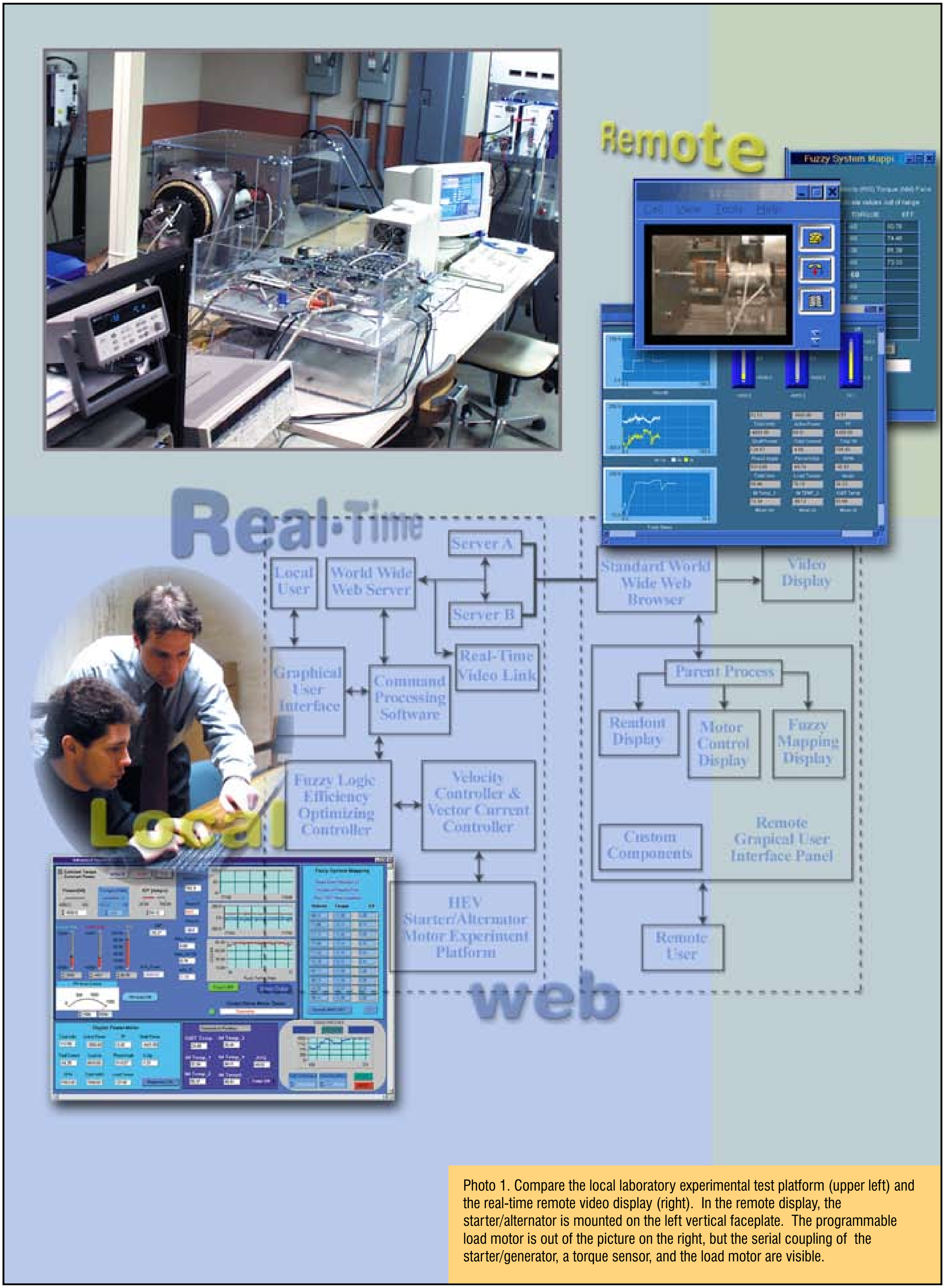


Photo 1. Compare the local laboratory experimental test platform (upper left) and the real-time remote video display (right). In the remote display, the starter/alternator is mounted on the left vertical faceplate. The programmable load motor is out of the picture on the right, but the serial coupling of the starter/generator, a torque sensor, and the load motor are visible.

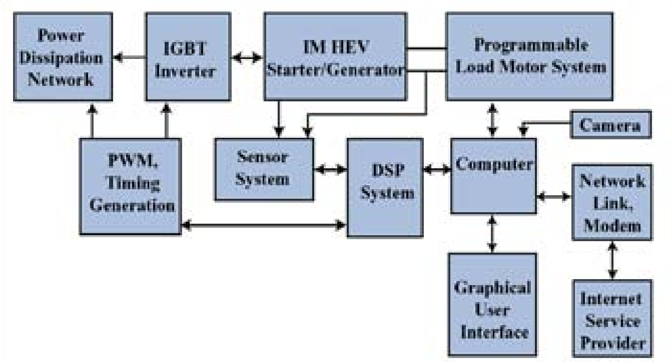
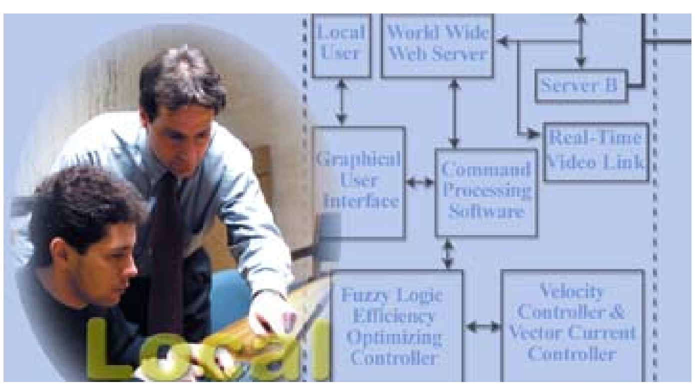


Figure 1. The VE-Lab experimentation plaform is shown here as configured for testing an induction motor hybrid electric vehicle (IM HEV) starter/generator.

width modulation (PWM) timing generation. Generated energy is dissipated in an insulated gate bipolar transistor (IGBT)-switched resistor-braking network. The DC bus voltage applied to the inverter is maintained between 300 and 350 V by a hysteretic voltage controller, which is also implemented in the DSP. The programmable load motor allows the generation of active load profiles that can emulate various load and road conditions, as reflected to the starter/generator. The sensor system conditions and samples starter/generator power, currents, voltages, and speed. It can measure efficiency for any system component or combination of components. The system also can be reconfigured to test other types of motors, power systems, or electronics by replacing the appropriate subsystem blocks in Figure 1.

Data and commands are transferred between the DSP sys-tem and the computer via shared memory. Graphical user interfaces provide both local and remote user control of experiments. Connection to the Internet is made through a local area network, into a dial-up modem, and finally through a commercial Internet service provider. A computer video camera provides remote viewing of the experiment via the Web.

A central issue in the performance of any Internet system is, of course, time delay (see the sidebar "Effects of Delay on Stability,"). In cross-country experiments, the VE- Lab system has time delays of only seconds over a dial-up connection. Use of integrated services digital network (ISDN), cable, digital subscriber loop (DSL), or other high-speed Internet connection will further enhance performance.



VE-Lab Architecture

Figure 2 shows the VE-Lab architecture. Accepting input from a mouse or keyboard, the local graphical user interface presents data output from the experiment. Real-time video from a mini camera mounted on the computer is also simultaneously displayed. The web server is coded on the local computer and acts as a host for Web communications. A command processor:

- Responds to incoming commands from both the graphical user interface and the Web server
- Passes the appropriate commands on to the fuzzy logic control system
- Updates both local and remote graphical interface panels

The remote graphical user interface panel enables the remote users to:

- Monitor commands initiated by the local user
- Operate and interact with the motor platform
- Receive real-time experimental data

The remote-side video display also simultaneously adds a visual confirmation to the operator's commands.

At the conclusion of a series of tests, remote users are prompted to receive a data file containing relevant parameters from the experiment such as efficiency, power, and motor temperatures. If accepted, the file is transferred to the remote site and saved on that computer, and a Microsoft Excel spreadsheet is automatically launched to display the saved data for further analysis.

The local site software contains all the code required to run and perform diagnostics on the starter/generator, as well as the code necessary to read from and write to any remote user who requests control of the starter/alternator and access to the data readouts. As shown in Figure 2, remote communication is accomplished via two data servers, A and B. A monitors a logical port on the local machine for incoming data from remote users. Once read, these data are passed to utility functions for decoding. Numerical data are entered on the local interface panel, or logical buttons are depressed in accordance with the interpreted command. After the action has been completed, an acknowledgment is sent back to the remote site for confirmation.Data server B sits idle on its logical port. When local commands are initiated, B and its utility functions communicate these commands to any remote site that is registered to receive them.

At the remote site, a parent process controls Internet communications and communicates with three important child processes.

- Readout display
- Motor control display
- Fuzzy mapping control

Data transmitted from the local site and received by the parent are directed to the correct child process for proper execution. ▶

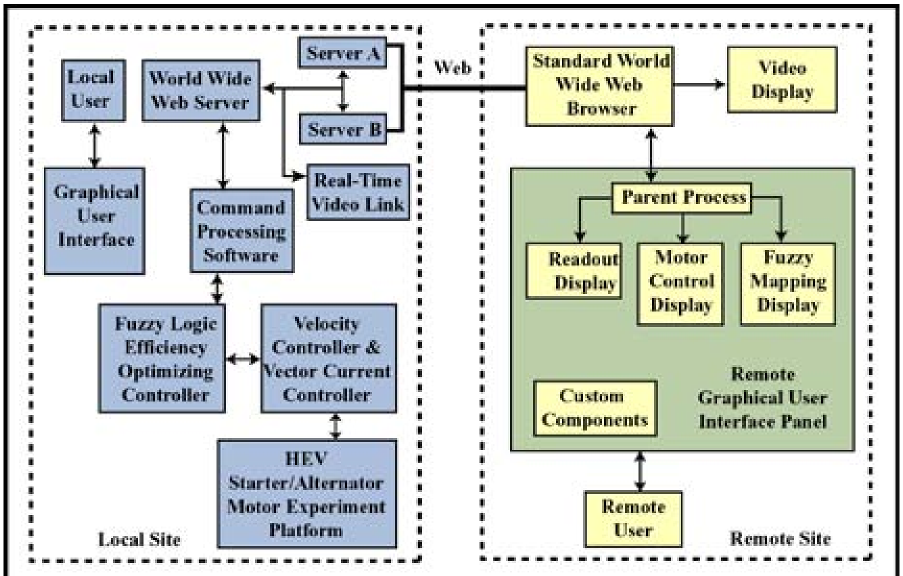
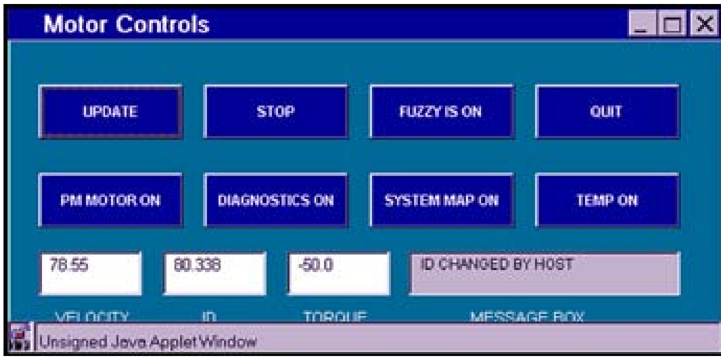


Figure 2. Compare the VE-Lab's system architecture for the local and remote sites.



Screen 1. You can view the remote site starter/generator control panel using Netscape, as shown here, or any other browser.

Screen 2. The remote site data readout interface panel monitors VE-Lab experiments in real-time.

Fuzzy Efficiency Optimization

Induction machines normally operate at rated flux to achieve their best dynamic response, but under less than rated load conditions, operation at rated flux can cause excessive core losses that lower efficiency. If you can reduce the flux, theoretically the system can regain optimum efficiency. The fuzzy logic controller is used to automatically determine the proper flux level for optimum efficiency operation under varying load and temperature. The reduction of flux, however, also decreases the transient response of the motor. The tradeoff between dynamic response and efficiency is application dependent.

The fuzzy logic efficiency-optimizing controller adjusts the motor's flux using the flux-producing component of current, I_d. Its objective is to maximize the starter/generator electrical output power for constant mechanical input power. The fuzzy optimizing controller accomplishes this by perturbing I_d and reacting to the resulting change in electrical output power. If the power output increases, it continues to perturb I_d in the same direction.

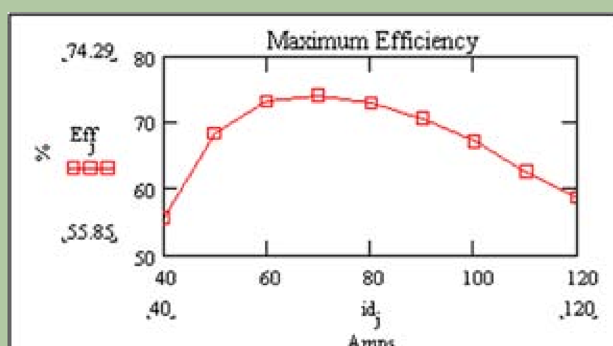
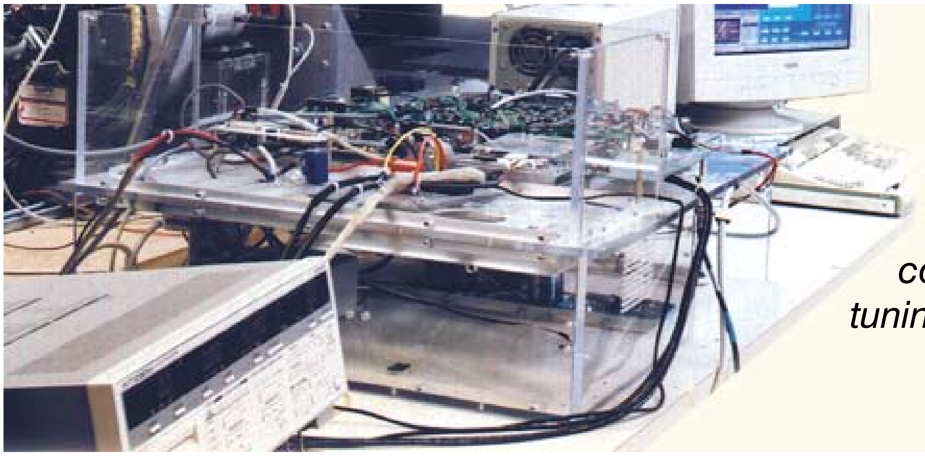


Figure 3. Plotting the measured starter/generator efficiency as a funcition of I_d reveals the point of maximun efficiency.

Figure 3 plots the measured starter/generator efficiency as a function of I_d, illustrating the objective of the fuzzy controller. At a constant 2kW operating point, notice that the efficiency curve is a bell shape with a maximum point of ~75% at an I_d of 70 A. The fuzzy controller must tune I_d to reach this maximum, and continue to track subsequent maximum efficiency points as they change with time and operating point. □



After each change in velocity, the efficiency plateaus indicate the fuzzy logic controller's effectiveness in tuning the system for optimum efficiency of operation.

A Closer Look at Remote Operation

After all connections between the local and remote site have been established, the motor controls display panel, readout display panel, and fuzzy mapping display panel appear. The motor controls display (see Screen 1) is used to operate the starter/generator control hardware, including the load motor system, system diagnostics, fuzzy efficiency mapping, temperature monitoring, and velocity torque, and flux control.

A readout display panel (see Screen 2) provides real-time starter/generator diagnostics data in text as well as graphic format. Notice that velocity (top graph); flux-producing current, I_d and torque producing I_q (middle graph); and efficiency (bottom Graph) are plotted in real-time. The velocity is periodically changed to create new operating points. The efficiency plateaus after each transient indicate the effectiveness of the fuzzy logic controller in tuning the system for optimum-efficiency operation.

Output from various sensors, including a digital power meter and temperature sensors, allows additional online monitoring of the experiment. A fuzzy mapping display panel is activated whenever remote users engage the starter/alternator mapping function. The user enters a series of velocity-torque pairs in tabular form, then initiates the experiment. When the fuzzy optimizer is activated, the experimental system is automatically adjusted to an optimum efficiency point for each table entry. (For more on this process, see the sidebar "Fuzzy Efficiency Optimization,") Efficiency results are communicated back to the remote site and automatically entered into the remaining column in the table. In this way, user-specific, optimum-efficiency contours can be remotely mapped. Figure 4 plots the maximum efficiency mapping across constant power contours of 1, 2, 4, 6, and 8kW. Notice that starter/generator efficiency is ~85% at 1400 rpm, but is as low as 35% at speeds below 300 rpm. ▶

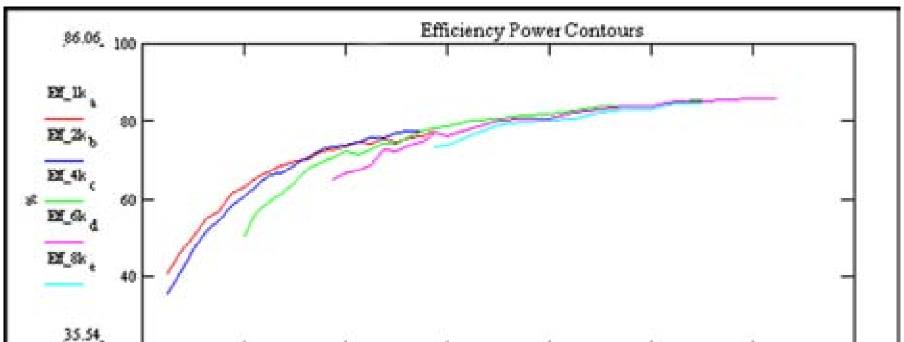


Figure 4. The starter/alternator efficiency changes depending on the power contour. Here it is mapped for 1, 2, 4, and 8kW.

Effect of Delay on Stability

Time delay will affect the performance and stability of feedback control system. Figure 5 shows a motor current step response when a closed-loop current controller is subjected to varying time delays within the feedback loop. Without any delay, the sampled current response has about a 1 ms rise time. As the delay is increased, the performance is degradedand an underdamped response is observed. Further delays results in instability. The significance of the time delay depends on the time constant of the dynamic system being controlled, and whether or not it is located within the closed-loop system. □

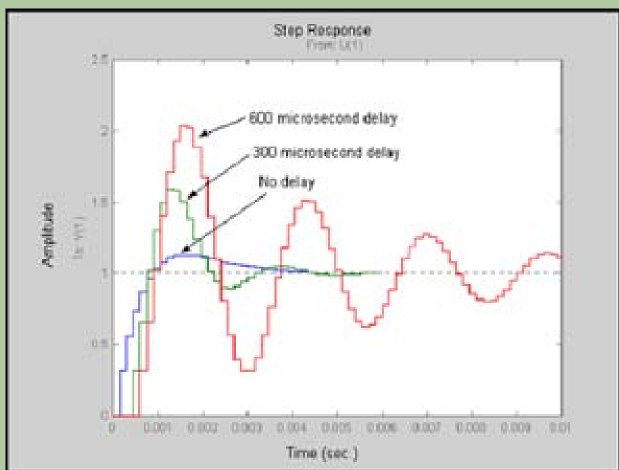


Figure 5. In this plot of proportional-integral (PI) controller step response with varying delays, notice how increasing the delay degrades performance.

Location Independence

By projecting a virtual presence into a working laboratory, the VE-Lab system enables far-flung members of a development team to perform experiments remotely on actual hardware. This can help reduce travel costs and the number of development iterations needed. In addition, the use of standard Web browsers ensures easy accessibility and eliminates additional software maintenance and distribution costs. Although the system described here was applied to a starter/generator, it can be adapted to a wide variety of application areas including remote monitoring, distance learning, and other electromechanical or dynamic systems. ■