Progress report: fourth quarter of 2011

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The effort at the University of Rochester has two main goals: (i) development of a set of laboratory exercises (two to three) to be conducted in ECE227/427[1], *Electric Power: Conversion, Transmission, & Consumption*, an existing course that previously had no laboratory component and (ii) a wireless power monitor for buildings. This monitor will be developed as a series of special studies and senior design projects for ECE majors. Because the instrumentation to be developed for the ECE227/427 labs will serve as the basis of the power monitors, the work will be closely coordinated.

ECE227/427 lab development

Description: Build, test, and use a scaled (single-phase) AC power distribution network to demonstrate basic, grid-related delivery issues, such as capacitive power factor correction for reduction of line losses and series capacitive compensation for system voltage regulation. Combining laboratory convenience with a degree of realism, this system is being designed to operate at 120 V-rms. The network will be based on a standardized load module. Each of these modules will consume ~100 W at a power factor (before correction) of ~0.7 (lagging).

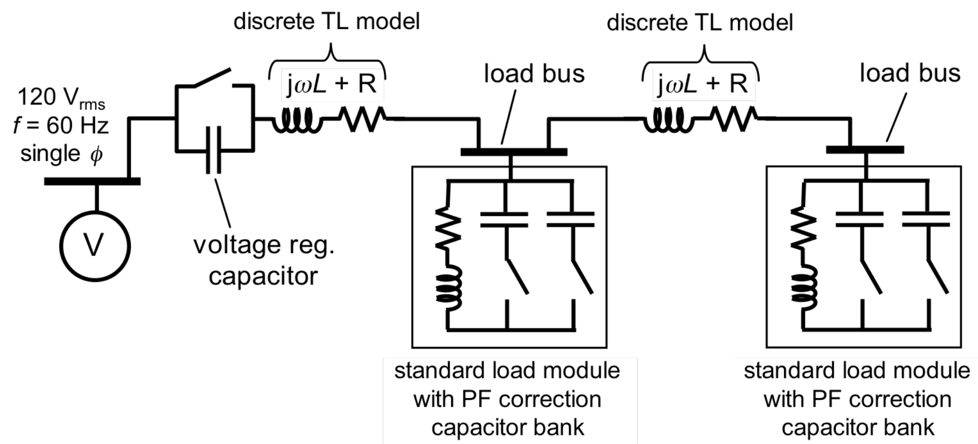
Progress: The standard load module has been designed and a prototype has been built and tested successfully. These modules contain resistors in series with an inductive choke to emulate a load, but also they are equipped with a built-in capacitive PF correction network controlled by a set of switches. The switches make it possible to adjust power factor from ~0.7 up to ~1.0. For design compactness, thick-film power resistors fitted with heat sinks and high-voltage multilayer ceramic capacitors are used. A second module is now being assembled and a third will be added later.

Near-term plan: The next phase of the work is to assemble the scaled power transmission/distribution network. This network will use two (ultimately three) of the load modules described above to represent load centers. Refer to the figure. The modules will be interconnected to 120 V line power via “transmission lines” represented by series-connected resistors and inductors. For the resistance and inductance values of the TL model, we will implement a scaling rule to emulate typical load-related voltage regulation concerns. The switchable capacitor,

[1] …ECE227/427 is a senior/first-year grad. level course taken primarily by ECE students, but also by a few undergraduate Chemical Engrg. majors and students from the Master of Science in Technical Entrepreneurship and management (TEAM) program of the Simon School.

shown series-connected to the line impedances in the figure, provides a simple means to model the voltage regulation function as load variations occur.

During the Spring 2012 offering of ECE227/427, this apparatus will be utilized in a set of two or three laboratory exercises. Approximately fifteen students are expected to enroll in this course; they will be divided into small groups to conduct the laboratories, taking data and then later presenting their analyses in reports. Initially, low-cost electronic power meters will be used to measure voltage, current, and power factor. The overall goal of these labs is to demonstrate that line losses can be reduced by power factor correction and that series line capacitance can improve voltage regulation as load is varied.



Line diagram of basic AC power distribution network with capacitive line regulation and PF correction for ECE227/427 laboratory implementation. Measurement instrumentation is not shown in this diagram.

Longer-term plan: Because the electronic power meters are of limited accuracy and reliability, they will be replaced with more accurate instruments including current transformers, voltmeters, power meter chips, and an A/D board. Work on this new instrumentation will start immediately, but probably will not be ready until the Spring Semester is over. Output from these sensors will be collected and displayed using the virtual instrument capabilities of the LabView® programming environment. With this enhanced instrumentation, it will be possible to monitor voltage, current, and power flow in real time under steady-state conditions. In this way, students will be able to get a feeling for the way power flow is monitored and controlled in regional dispatch centers.

This new instrumentation will also serve as a critical building block for the wireless building monitor project detailed below.

<u>Wireless building monitor</u>

Description: The objective of this task is to develop a self-contained wireless network that monitors a single three-phase circuit in the Hopeman Engineering

Building on the University of Rochester campus, processes this critical power flow data, and then transmits it using WiFi to a local “cloudlet” server for analysis and archiving using cloud resources. We have an active wireless sensor-networking group in the ECE Department at the University of Rochester and plan to exploit this expertise. Once the system is working, data will be collected, analyzed, and compared to expectations for a building of this type.

Progress: Monitoring a three-phase circuit involves nine quantities: three voltages, three currents, and three phases. From these, all the important measures such as average AC power, power factor, and phase balance can be derived. Because phase is defined relative to the voltage and current waveforms, these latter quantities must be sampled at a rate sufficient to extract phase difference values. Presumably, the power monitor will have the capability to process the current and voltage data for each circuit to extract phase data. We are investigating available off-the-shelf chips to find one that best meets the specifications for obtaining phase information. Despite the fact that the wireless system will be called on to transmit a minimum of nine parameters from each of a possibly large number of monitors, the demands on bandwidth are not expected to be especially challenging.

Longer-term: More challenging than routine monitoring of voltage and current magnitudes and phase is the matter of harmonics. Harmonic content in AC power, which arises from load nonlinearities and power electronic devices, is a growing concern in the power industry. At present, energy suppliers have no means in place to measure harmonic power. Without means to measure it, harmonic power constitutes an operating loss. Further, harmonics can create serious, unanticipated operational problems in over-current and over-voltage protection gear. The power industry needs the ability to collect harmonic content data in real time. One way to meet this need involves deploying large numbers of remote power monitors with wireless connectivity.

As the first step in building a harmonic sensing capability into the power monitor, we have begun gathering information about several classes of power measuring chips, including the MAXQ3183 series made by MAXIM and the MSP430 series from TI.

Perhaps the greatest challenge to the implementation of a wireless sensor network for building power monitors is how to collect, process, analyze, and archive such masses of incoming data. We plan to use Arduino boards[2] with WiFly attachments[3] to gather the data from the monitors and transmit the data using WiFi to a local server called a “cloudlet.” A cloudlet is a device that can accelerate the computation between mobile devices and the cloud. Made up of commodity hardware such as a Graphics Processing Unit and Gigabit network cards, the processing power and storage capacity in the cloudlet will not be as

[2] …http://www.arduino.cc
[3] …http://www.sparkfun.com/products/9954

abundant as that in a commercial cloud, but it will be far more than that of the MSP430 and the Arduino board. The cloudlet will thus serve as the central authority that receives the power data, performs data pre-processing, and sends data and any required computing tasks to the cloud for further processing and data storage. This approach will enable us to store massive amount of data for later analysis and comparisons.