Intelligent Power Routers for Distributed Coordination in Electric Energy Processing Networks
Proposal No: 0224743

Response to Reviewers' Comments

The authors are encouraged by the interest generated by their proposal. We appreciate the reviewers' comments as well as the opportunity to respond. The issues raised have been grouped under the headings received in Dr. Momoh's June 21, 2002 e-mail message. The symbol ">" marks the original text of the e-mail message and our response follows.

> 1. EDUCATION/PEDAGOGY: Since engineering **economics and ethics** are essential topics in the
>undergraduate engineering curriculum (Per ABET criteria 2000) the PI should provide a plan to develop
> course materials in these areas:
>a. Course materials in this area for non-majors

All engineering students in the electrical engineering undergraduate program at UPRM are required to approve a one-semester, 3-credit-hour macro economics course. They also require a one-semester, 3-credit-hour **engineering economics** course. The engineering economics course provides students with criteria and techniques of economic analysis as related to decision making in engineering projects where time and money are the primary trade-offs. All basic analysis tools of engineering economics are present including: dicounted cash flow; comparison of alternatives using equivalent annual cost, present worth, or rate of return; break-even analysis, replacement, sensitivity and risk analysis. Thus, UPRM electrical engineering students possess a sound background from which more advanced economic topics can be developed. These topics are already being treated in most of our power engineering courses. <u>The task in this proposal is to arrange the topics within those courses into modules that present a clear picture to students of the economical aspects of the operation of current and future energy systems.</u> Table 3 on the proposal presents the plan to develop course materials in this area. The topics covered in power engineering courses regarding engineering economics will be used to create seminars that will be delivered to a larger student audience (non-majors) as part of the Energy Systems Seminar Series (ES^3).

The ethics component will be addressed through **Ethics Across the Curriculum (EAC)** strategies. The investigators in this proposal have been trained in this philosophy, in which ethics topics are integrated into class material of basic and core courses in a curriculum. This training is part of the ECE Department effort to properly address ABET's EC 2000. The process to include the EAC in the electrical engineering curriculum will start on Fall of 2002, thus this proposal will support the EAC effort at UPRM's ECE Department. The EAC philosophy will be implemented at the Departmental level, thus all ECE students will be exposed to the ethical implications of engineering decisions. The ethics topics covered in power engineering courses will be used to create seminars that will be delivered to a larger student audience (non-majors) as part of the ES^3. Table 3 on the proposal presents the plan to develop course materials in this area.

An economist, Dr. Edwin Irizarry, will join the project team to assist with the economic topics in the curriculum as well as with the evaluation of the economic and social impact of the IPR control scheme. Dr. Luis Jiménez, ECE Professor, will also collaborate in the development of seminars and class material for the study of ethics and the social impact of engineering decisions. Dr. Jiménez has advanced studies in philosophy and ethics, and has experience integrating social aspects to engineering courses.

The modules developed for courses, and used in seminars will be arranged into a Power Engineering short course for non-majors. This short course will cover the fundamental aspects of energy systems (three-phase, transformers, transmission lines), energy policy issues, and socio-economic considerations. This short course will be initially available to non-power engineering students at UPRM and may become available to a larger audience if additional resources are obtained to further develop the course.

> b. Assessment and evaluation methods for measuring these outcomes.

An evaluation plan to assess the impact of the educational strategies will be developed. To evaluate the effectiveness of a practice the following tools will be developed:

? An assessment instrument and/or approach to evaluate the product impact in improving student learning
? An instrument to assess students' perception of their learning experience (e.g., students' comments about affected course).

The collaboration of Dr. Eddie Marrero, from UPRM's Social Sciences Department Applied Social Research Center will be a key component in this process. Using as criteria the fundamental aims of the proposal and the indicators described above, the following assessment categories are identified:

? Assessment of the effect of modules in student learning of economic and ethics concepts of the courses
? Assessment of students' perceptions about how the modules affect their learning; and assessment of students' awareness of social implications in engineering

The first category describes an *objective* assessment of two main goals of the project: actual learning from the implementation of the educational modules. The second category describes a *subjective* assessment: student perception of their learning, and student awareness.

The first phase for assessment will involve the construction of a series of instruments for assessing student learning. The content of the instrument deals with the economic and ethics concepts of the courses. This instrument can be administered *prior* and *after* a class or seminar to determine the impact of the contents of the class on learning. The second phase is the assessment of students' perception about their learning. An instrument will be developed to assess students' perception of different aspects related to educational modules on ethics and economy. This instrument will be administered after each educational activity.

Dr. Marrero has collaborated previously with Dr. Efrain O'Neill in the assessment of engineering concepts, results summarized in [FIE 02 PAPER]. Their work will be expanded and adapted for use in this proposal. Table 1 below illustrates a sample assessment tool to be adapted for this proposal.

TABLE 1
SURVEY ON THE IMPACT OF LAB EQUIPMENT ON STUDENT LEARNING.

1= Deficient / absolutely not **3= Average / Regular** **4= Good / Adequate**
2= Poor / not enough **5= Excellent / very much**

Item/scale	1	2	3	4	5
How do you evaluate the operation of the equipment during the lab exercise?					
Was the equipment used suitable to solve the assigned lab exercise?					
Did using the equipment in the process of solving the assigned lab task help you to better understand class concepts?					
Did the use of the equipment help you to acquire new strategies for solving problems similar to the one presented in the lab exercise?					
Did the use of the lab equipment help you to feel able of solving on your own a similar problem in a similar situation using a similar equipment?					
Did using the equipment help you to reduce the probability of making mistakes in similar tasks in the future?					

Did the equipment contribute to increase your capability for troubleshooting in similar situations?					
Did using the equipment during the lab exercise help you feel confident about using this or similar equipment in other situations?					

> c. The graduate course materials should have a tie to undergraduate students and/or the > appropriate industry.

Most of the proposed course material is directed to undergraduate students. Students will be made active participants in the learning process, and will improve their understanding of power engineering principles and applications through undergraduate research, laboratory modules and seminars. The interaction between graduate and undergraduate students is a key element of these activities. Graduate students will act, not only as TAs, but also as originators and mentors of the activities. The interaction between graduate and undergraduate students will be conducted through the affinity research group model [31].

The graduate courses on computational methods, system dynamics and power quality will be revised to include advanced concepts in system security and reliability. Projects and results from graduate course work will be adapted for use as class examples, seminars and demonstrations for undergraduate students. Undergraduate research projects will also be used to integrate research and education.

The Puerto Rico Energy Affairs Administration will collaborate with the researchers in the development of seminars and sharing of data on energy policy issues. The Puerto Rico Electric Power Authority (PREPA), the Island's electric utility, will share with the researchers the experience of coordinating energy flow with co-generators and data related to major contingencies the utility has had. These collaborations will directly benefit the revision of graduate and undergraduate courses by providing examples and topics for class projects.

> d. Developed education modules should be properly documented, assessed and displayed on the > web.

There is already a website assigned to the project (www.ece.uprm.edu/projects/iprs). The Power Engineering Group also has a website that is currently being renovated (http://www.ece.uprm.edu/~power). These instruments will be used to disseminate the work and make it available to a larger audience. Information will include documentation, assessment tools and results, links to submitted publications and other documentation regarding the project.

> 2. TECHNICAL ISSUES:
> a. Relationship of the proposed research to a benchmark system as described in the solicitation is not > addressed.

We propose to use the IEEE Reliability Test System – 1996 (RTS-96) [33] to benchmark the proposed approach on a realistic power system network. The RTS – 96 is an enhanced test system for use in bulk power system reliability evaluation indices. It contains failure rates, maintenance and dynamic data needed for reliability indices calculation and dynamic system simulation. New models for reliability assessment, including the risk assessment method, have been developed since 1996. The values for the parameters required by these methods, will be consistent with the values of parameters, which are tabulated in the RTS – 96.

We will use the Virtual Test Bed (VTB) software for prototyping of large-scale, multi-technical dynamic systems to benchmark the proposed approach on advanced power systems for navy platforms. In both cases software interfaces to interconnect different simulation environments will be developed as needed.

The RTS-96 provides data to be modeled using any standard power system simulator package (examples of these packages for which the proponents have active licenses are PowerWorld, EPRI's PSAPAC and PTI's PSS). The Virtual Test Bed (VTB) software and electric model and data for a ship must be provided by the Navy. In both cases it is necessary to develop a simulation model for the IPR. This can be achieved in two ways: 1) integrating the mathematical model and algorithms that will conform the IPR model into the simulator package or 2) developing the IPR model as an independent software process which exchanges status and control signals with the simulation package via some kind of interprocess communication (IPC). Each approach places a different set of requirements on the simulation package. The first approach requires that the package provides some type of programmatic interface (API). One common approach to providing such an API is to allow additional modules to be linked with the simulator code in a way that allows procedures from the new modules to interact with code from the simulator. The second approach requires that the simulation package provides an IPC mechanism. An common example of an IPC mechanism is the Socket interface often used in the development of networking applications. The approach used will be contingent upon the simulator package selected in each instance.

> b. Research plan as given is at the stage of conceptual discussion. Please provide clarifying details.

Table 2 provides a summary of major research milestones to be completed over the three-year effort.

Table 2. Summary of activities to be undertaken and proposed time frame of completion

Activity	Tentative schedule
Design of first IPR(v1.0) software module Integration of the IPR module into simulation system or development of the programmatic interface Experimentation with IPR(v1.0) Formulation of the risk assessment problem for IPR controled system Development of economics and ethics modules (curriculum improvement)	First year
Disseminate results from iteration 0 Design of alternative IPR control algorithms Simulations and preliminary reliability assessment Design of second IPR (v2.0) software module Evaluation of alternative IPR control algorithms Use of economics and ethics modules in electrical engineering courses (use assessment tools) Development of short course for non-power engineeering majors	Second year
Reliability assessment comparison between IPR controlled system and centrally controled system Deliver short course for non power engineering majors Disseminate economic and ethics modules using WebSite	Third year

> c. Analysis of social impacts of decentralized control of power systems is not given.

Reconfiguring a power network after a major contingency will require the use of "regional" or distributed generation for those areas without a power plant nearby. Most of the technologies being studied nowadays, (e.g., fuel cells, microturbines) have lower emissions than traditional power plant technology. Thus, decentralized control is expected to have a positive social impact regarding the environment.

In a decentralized control mode, the network will allocate available generation to critical loads such as primary services (e.g., hospitals). Other critical loads include economic centers vital to restore/maintain the economy (e.g., airports, financial districts). This contingency mode would have a temporal negative impact on residential and small industrial loads. However, limited resources need to be distributed in a way that the basic functions of society are restored. Thus, decentralized control under this philosophy works towards the greater good of society, and has an overall positive social impact.

Dr. Eddie Marrero will collaborate with the group in further analysis of the social impacts of decentralized control. He will provide assistance on ways to measure public perception and tools to increase public information. Dr. Luis Jiménez will also collaborate in the analysis of the social implications of the proposed work.

> d. PI did not identify appropriate risk assessment tools for analyzing impact of IPRS.

We propose to balance reliability cost and reliability worth by using risk, defined as the product of probability and economic impact of an outcome, summed over all possible outcomes, $R = \sum_{\forall \, outcomes} P_{outcome} \times I_{outcome}$. This approach, previously used by the PI to determine operating limits for dynamic security constrained electric power systems [7], has been further developed to assess a variety of system security problems [18-21]. We propose to use the risk of operating at a given operating point, i.e. the expected cost of operating at a given operating point, to evaluate system reliability cost/reliability worth. We will compare the risk level of operating at a given operating point under the existing system control mechanisms and the control mechanism offered by the IPR. Further discussion of the acceptability of a system operating point based on our risk assessment method follows.

In general, security assessment in an operational planning environment seeks to determine operating limits for a given system situation characterized by:

1. system configuration: network topology and unit commitment
2. operating conditions: generation levels, line flows and voltage levels (observable and controllable) and load levels (observable only)
3. contingency set: a list of outage events
4. performance measure: post-contingency system performance criteria

Because a single study requires an explicit choice of configuration, conditions and contingency, and because the number of each is quite large, the number of possible studies is overwhelming. To reduce the possibilities to a manageable size and still obtain useful results, studies are limited using a credibility criterion: only credible system configurations, operating conditions and outage events are considered. This criterion is not usually applied statistically but rather using rules of thumb and judgment. Second, a severity criterion is applied; here the analyst tries to identify the system configuration, operating conditions, and outage event which result in the most severe system performance. Because this approach generally identifies a single event which drives the resulting decision, it is often called the **deterministic approach**.

The deterministic approach is widely accepted in industry. It should be noted that the basic underpinnings of the approach are probability (credibility) and consequence (severity), if only in a qualitative way. Therefore, the philosophy behind the deterministic approach is to appraise the system situation using qualitative risk. In [7] we developed the means of determining operating limits using quantitative risk, where we measure the credibility of events using probability and assess its severity via its economic impact.

The risk-based approach described in [7] builds from the deterministic approach in that steps 1, 2 and 3 are retained. However, the risk-based approach departs from the deterministic approach in the following fundamental way. Whereas the deterministic approach develops limits based on the most severe contingencies, the risk-based approach develops limits based on a composite measure computed from a risk contribution from all contingencies in the list, where risk is the product of probability and consequence. Therefore, in the risk-based approach, analysis is required for all contingencies in the credible contigencies list and not just the most severe. Although this requirement could result in additional labor, this is a reasonable price to pay to gain the benefits associated with a more quantitative assessment of the security versus economy tradeoff.

The main difference between the two approaches resides not in the methods used to obtain results regarding system performance following a specific contingency; indeed the same methods are required in both approaches. Instead, the main difference between the two approaches resides in the criterion used to judge operating point acceptability. Whereas one uses a deterministic criterion (secure or insecure for most severe contingency under worst-case disturbance scenario), the other uses a criterion based on probability and consequence (composite risk level from all contingencies). Therefore the risk-based approach does not necessarily replace the deterministic approach; it extends it.

We propose to use the risk-based security assessment techniques developed by the PI to compare the risk associated with a given operating point under the current power system control scheme and the proposed IPR control scheme. In fact we will extend the risk-based operating limits calculation to account for local control based on local data and the impact of affecting a reduced portion of the system under the IRP control scheme.

A drawback of the risk assessment method is that it lacks the inherent capability of adequately taking into account events of extremely low probability of occurrence but very severe consequences. For this reason a risk averse decision maker may doubt the results of an economic analysis produced using this risk assessment method. To account for such events we will need a defense plan [22].

We believe that the proposed IRP control scheme can act as the defense plan for an energy delivery network. The IRP could be located defining regions of the energy delivery network that include distributed or auxiliary generation capable of sustaining all or most loads within each region. IPRs could take preventive countermeasures against high risk operating conditions that may result in adverse system responses to disturbances.

> e. The panel would like to see more discussion of how an IPR would actually be built; provide a
>discussion of what problems might be encountered.

A potential architecture for an Intelligent Power Router is shown in Figure 1. The router consists of Interfacing Circuits (ICKT) that operates existing Energy Flow Control and Sensing Devices (EFCD) and Intelligent Control and Communication Unit (ICCU). Example of EFCD's are: circuit breakers, phase shifting transformers, series compensation capacitors or their combination as Flexible AC Transmission (FACTS). The ICKT is the hardware component that interacts with the energy transfer portions of the electric power system. These already existing devices will control the power flow, opening and closing lines as needed, or regulating the amount of power that flows through a given interface. The Interfacing Circuits sends commands to the EFCD to dynamically change the behavior of the power system. Also, the ICKT receives information already being collected by sensors (CTc, PTs) and Dynamic System Monitors (DSM) on the system state (phase currents, bus voltages, system frequency, generation levels …) to assess the current status of the system.

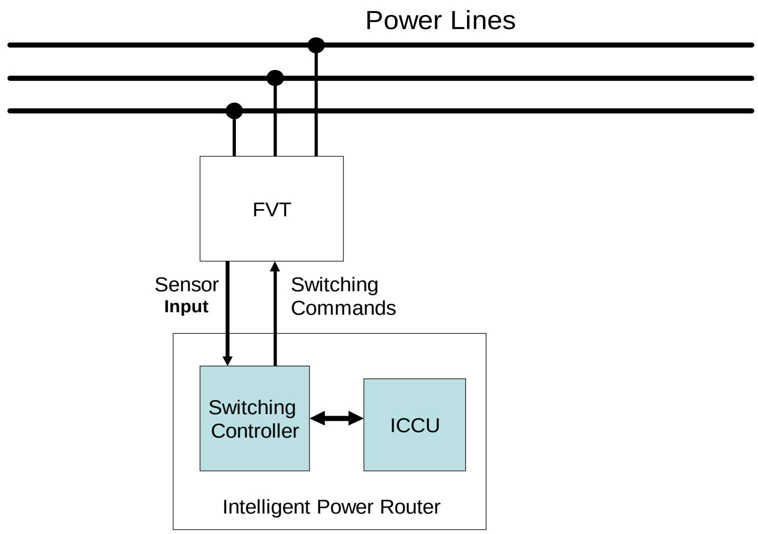

Figure 1: Potential architecture of the Intelligent Power Router

The ICKT will operate under the direct control of the ICCU, which will have the necessary logic to determine how to re-route power, change load set point in generators, shed load or take any other corrective or preventive action to enhance system security. The ICCU can be implemented as an embedded computer located inside the IPR. This scheme is similar to those used in automobiles, and home appliances. The ICCU could feature a RISC-type CPU, high speed RAM, non-volatile data storage and a network interface. The ICCU should be made out of commodity components to keep its cost low, make it easy to fix or replace, and to leverage on the latest advances in the computing technology. For example, the ICCU can run the latest version of the LINUX operating system for embedded systems. This scheme will not only make the IPR fully programmable, but also simpler to upgrade with new version of the system software.

Multiple IPRs should be networked using proven networking technologies. One approach is to leverage of existing phone lines, and adopt the DSL technology to allow the IPRs to exchange data and control commands amongst themselves. In this case, the ICCU on the IPR should feature an Ethernet card and a DSL modem combo as the networking components. The approach has the advantage of being inexpensive, but it makes the system dependent on the phone utility. Alternatively, a dedicated private networking can be built by using fiber optics to implement the communications network between the IPRs. In this case, the network will be more expensive to deploy but the electric utility has total control over it. A third approach is to use wireless technology to built the communications network. In this case, the ICCU can have a wireless network interface (i.e. IEEE 802.11b or 802.11a) that provides access to a fiber optics backbone. This hybrid solution has the advantage of eliminating the network wiring into the ICCU, which makes it easier to redeploy to a different location. Another possibility is using power lines to communicate data among IPR's.

In short, the Intelligent Power Router consists of two distinct elements: the Intelligent Control and Communication Unit (ICCU) and the Interface Circuits (ICKT). Existing energy system controls and sensors will be managed by the IPR. The concept of an IPR is a major leap forward from the currently available power control and delivery schemes. The main function of IPRs will be to reconfigure the network based on local information (The IPR could talk to a finite number of other IPR's depending on accessibility and availability for the purpose of taking a more informed decision.). The proposed work emphasizes on the development of the decentralized control algorithms, the software applications and the components of the architecture needed to implement IPRs. In terms of actual applications, the IPR will rely on the results from research conducted nowadays on alternate generation sources and distributed generation schemes. Interconnection of the sources to the grid is an important aspect that will directly impact IPR implementation. It will rely upon the development of advanced relaying, sensors and fast-acting components (e.g., power electronics switches).

The location of the IPR will vary according to the type of network. Due to the symmetry in a naval ship, IPRs can be located near critical areas. In a civilian power system, the challenge is to locate IPRs such that the critical loads are served even if these loads are geographically dispersed. IPRs may be located in transmission centers and in important distribution substations. The development of "power parks", a concept being studied by EPRI, and some researchers, could be an important step in the implementation of IPRs. Power parks would integrate energy storage, distributed generation and power electronics devices to improve power quality and ensure power availability. IPRs would give power parks the needed intelligence to operate in an autonomous mode. Other challenges for implementation include: impact on protection schemes and philosophy, wireless communications within naval ships (for control and communications signals), re-think the operation of distribution systems to account for bi-directional flows of power.

We envision the IPR becoming a versatile and ubiquitous power distribution device used to control power delivery networks of a varying sizes and complexities and in a variety of scenarios. Although our initial application domain is at the scale of a regional distribution network or a naval ship, IPR's, perhaps built on silicon, may eventually be found controlling power distribution networks inside powerful multiprocessing chips or perhaps inside microscopic medical devices. Reliable power delivery is a pervasive problem of multiple scales.

> 4. BUDGET: Given budgetary limitations, you are to reduce your budget
> so as not to exceed a total of $500,000.
> a. PI should consider reduction of number of graduate students.
> b. NSF cannot pay for academic year salaries for faculty.
> c. The PI should hire a collaborator from economics.
> Please send the revised budget by FASTLANE right away.

The revised budget was submitted via Fast Lane.