Project Description

1. Introduction

Virtually every crucial social and economic function of our society depends on the secure and reliable operation of the electric power network [1]. As demand for digital goods and services has increased, the demand for reliable and disturbance-free electricity has increased as well. Failures in the power system can have significant economical effects due to the interaction of the power network with other critical infrastructure systems such as finance and communications. Because of this interaction, power outages and disturbances cost the US economy more than $100 billion annually [1].

Existing Power Delivery Systems are designed with redundant power generators and delivery lines to make the system tolerant to failures on these elements. However, the control and coordination of the process to generate and distribute power still occurs in a centralized manner, with only a few sites (or even one site!) managing mission-critical tasks for power generation and delivery. This scheme has a clear drawback: a failure in one of these *control centers* might result in the total collapse of the system. Therefore, it is highly desirable that future Power Delivery Systems has the capability of distributing the task of coordination and control of power generation and distribution when contingencies or emergency situations occur.

Here we propose to develop a model for the next generation power network using a distributed concept based on scalable coordination by an *Intelligent Power Router* (IPR). Our goal is to show that by distributing network intelligence and control functions using the IPR, we will be capable of achieving improved survivability, security, reliability, and re-configurability. Our approach builds on our knowledge from power engineering, systems, control, distributed computing, and computer networks to propose a power network concept that will meet the proposed objectives.

We propose a system in which control can be detached from central control sites, and delegated to intelligent power routers (IPRs) that are strategically distributed over the entire Electric Energy Processing Network. Each power router has embedded intelligence into them allowing the power router to switch power lines, shed load based on a priority scheme, activate auxiliary or distributed generation, isolate power region of the energy delivery network to prevent system cascade failures and receive/broadcast local state variable information to and from other routers. The information exchange capability of the routers provides coordination among **themselves** to reconfigure the network, even when the designated principal control center of the system has collapsed due to a natural or man-made disaster. The IPRs may achieve their task using direct monitoring, area-limited on-line security assessment and adaptive controls to establish a coordinated and local set of control actions to either apply preventive countermeasures prior to a potential disturbance or corrective countermeasures following a disturbance.

Our proposed approach borrows from computer networks, where data can be moved over geographically distant nodes via *data routers* (or simply routers) [4-6]. When a flow of data needs to be established between two end points, the routers cooperate by moving pieces of data over the network until the data reaches the desired destination(s). At each step of this process, a router that receives a packet of data determines the **next** router that shall forward that fragment of data. Notice that there might be many candidate routers, but the one that can do the best forwarding job is the one that is selected. In our view, a Power Delivery System could operate in similar fashion with due consideration of the physical differences between data exchange and energy exchange. In the event of a component or system failure, the IPRs will make local decisions and coordinate with other routers to bring the system, or part of it, back into an operational state. We envision energy delivery systems where power will be generated and injected into the delivery network to reach the loads as it does today. The proposed scheme will not substitute current control protocols if there are no contingencies. However, under normal operating conditions, the IPRs would provide additional information on system status to the central energy management system. The IPR will allow the system to operate in degraded operation during major contingencies.

Here we propose a concept (components of the architecture), algorithms, policies, and other methods to realize a next-generation of reliable Power Delivery Systems featuring a distributed and well-coordinated control structure. This proposal is organized as follows: section 2.0 presents our objectives, section 3.0 shows the relation of the proposed work to the present state of the art in the field and work in progress (Literature review), section 4.0 describes our risk assessment method, section 5.0 presents the work plan including a summary of activities to be undertaken, a plan for preservation, documentation and general dissemination of research, section 7.0 shows new curricula and pedagogy development and section 8.0 explains the proposed benchmarking.

2.0 Objectives

Our long-term goal is to architect a new type of scalable and decentralized power distribution infrastructure based on the concept of the Intelligent Power Router. The architecture should provide sustained operation in the presence of partial failures to power sources and communication lines. Such sustained operation demands automatic reconfiguration of the system in response to at least the most frequently occurring failure modes. The fundamental engineering design principle behind the IPR system is *modular decentralized control*. An IPR can be used as a simple yet fundamental building block upon which complex power distribution networks can be engineered in a disciplined fashion. Table 1 describes these and other specific engineering design objectives and summarizes the design choices driven by each objective.

Table 1. IPR System Design Objectives and Corresponding Design Choices

Design Objective	Design Approach
Survivability and Fault Tolerance	Decentralized IPR modules control power routing based on local information. IPRs capable of isolating failures.
Scalability	IPRs can be composed with other IPRs to create complex distribution networks. The system can grow incrementally. Architecture admits graceful profile-based reengineering.
Cost-effectiveness	Decentralized IPR modules avoid having to connect very producer to every consumer directly. Economies of scale reduce the cost of IPRs.
Unattended 24/7 Operation	IPRs are equipped with programmable computing capabilities. IPRs will incorporate algorithms that will make at least the most frequently occurring reconfiguration decisions without human intervention.

3.0 Relation to the present state of the art in the field and work in progress (Literature review)

Amin [1] quoting the July 2001 issue of Wired Magazine stated "The best minds in electricity R&D have a plan: Every node in the power network of the future will be awake, responsive, adaptive, price-smart, eco-sensitive, real-time, flexible, humming and interconnected with everything else." We propose a new approach to achieve this vision. The problem of re-configuration of an Electric Processing Networks is considerable and most of the previous work focuses on radial distribution networks [8, 9, 10 11]. The Electric Processing Network is modeled as a network flow problem [8], in which the goal is to optimize the amount of power that can flow from the generators ("the sources") to the consumers ("the sinks"). These approaches assume centralized control and coordination of the system. In case of a failure in the power network, it is assumed that a central authority will determine the elements (i.e. generators, feeders, lines, etc.) that has failed, and will re-design the graph that models the network. This new graph is then used as input for a program that solves the network flow problem.

Other researchers propose a communication network of agents attempting to solve a local optimization problem, in this case the network flow problem, work sequentially [12] and share their results. The idea is to build a global solution to the optimization problem from the local solutions. Our approach differs from these attempts since we formulate the problem in terms of finding paths that can carry enough power from the generator to the consumers as quickly as possible. Our goal is to make the system survivable to a major failure. Thus, the priority is to find power for the critical loads as soon as possible rather than find an optimal solution, which might take too long to compute. Moreover, we do not presume any central control authority that operates the system in case of major emergency. Instead, we have a totally asynchronous **Peer-to-Peer** system or **mesh [13-16]** that enables distributed control of the bulk electric power system (generation and delivery network). The Electric Power Network has many points of intelligence that can quickly react to failures and repair the network as soon as possible. Thus, in the case of a major failure, the system attempts to "heal itself" rather than waiting for outside help. Our goal is to have a more *reliable* system that can withstand multiple failures, including those that render the control centers inoperable.

Taylor [2,3] states that the future in on-line security assessment and wide-area control is the merging of information and control. Although Taylor's idea focuses on direct monitoring, on-line security assessment and adaptive controls to be used by a centralized control center, these very same tools may be used to establish a coordinated and local set of control actions to either apply preventive countermeasures prior to a potential disturbance or corrective countermeasures following a disturbance. We seek to develop algorithms, and policies that efficiently use local information to make local decision that have a positive effect on larger portions of the power system.

4.0 Risk Assessment

The mere act of living involves risk. It is the responsibility of engineers to design, build, and operate systems that benefit society without significantly increasing risk above the inherent everyday risks of life. We propose the use of IPRs to assess and maintain or improve the reliability of an energy delivery network. Reliability is the probability of a device or system performing its purpose adequately for the period of time intended under the operating conditions encountered [17]. We propose to achieve this while balancing 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]. This method measures reliability indirectly since we calculate the probability of failure rather than the probability of successful operation and use the economic impact of this failure to appraise the cost of unreliability.

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. IPRs could act based on information locally available or exchanged with nearby IRPs to prevent slower dynamic security violations, such as voltage violations and thermal overloads, as well as act with local knowledge and "prior state" information obtained from other IRPs to prevent faster dynamic security violations, such as underfrequency or generator angle instability. The combination of the IRPs and reliability assessment using risk should lead to superior survivability and robustness of the entire energy delivery network. In fact, determining IRPs location based on a minimum risk approach may prove to be instrumental in enhancing overall system security

Risk Assessment was the principal method used by the PI in his Ph.D. Dissertation [7] and continues to be one of his principal research interests. The IRPs control scheme proposed here constitute a significant addition to the Risk Assessment method because it provides a defense plan against very low probability events with very severe impact.

Risk assessment methods will be used by the PI to enhance previously funded research work in the area of Energy Storage [23] to mitigate rapid response spinning reserve insufficiency under generation deficiency conditions. A complete economic comparison of energy storage alternatives shall include the effect on system reliability of the alternative energy storage solutions. This comparative appraisal can be obtained using Risk determination methods since the method provides a concise and quantitative assessment of the security versus economy tradeoff.

5.0 Research plan

Figure 1 presents the architecture of the proposed system. Generation units $P_1, P_2, ..., P_n$ are connected via the power network with consumers $C_1, C_2, ..., C_m$ .. The producers and the consumers are connected via a series of power lines and intelligent power routers (**IPRs**). The network will have a group of intelligent power routers $R_{1,} R_2, ..., R_k$, which take on the role of controlling the routing of power over their lines. These routers are the intelligence of the network, capable of adjusting controllable system variables to meet unexpected system disturbances. More importantly, the routers will re-configure the network in the event of a high risk operating condition or a component or system failure. For example, IPRs will shed load according to a predefined priority scheme.

As we can see from Figure 1, each IPR controls a series of input lines that bring power from either a power generator or another source possibly under the control of a different router. In addition, each router controls a series of output lines transporting power to a consumer or serving as power sources to another power node that again may be controlled by a different router. Thus, the routers are organized in a **network** providing multiple redundant power paths between producers and consumers. . Key to our design is the fact that to a given IPR, it should be irrelevant whether its inputs come from power producers or other IPRs. In other words the control protocol between two adjacent IPRs is no different from that between IPRs and producers. In Distributed Systems terminology, this hierarchy is often called a **Peer-to-Peer** system (P2P) or a **mesh**.

Each IPR maintains information on the power flowing through each of its connecting power lines This information is used to make **local decisions** on how to re-route power in the event of changes in the amount of power moving along the lines, which might be caused by failures, changes in power generation or demand. These routers may also signal that emergency power sources are needed on-line to meet the power demands of the network in the event of a failure or unexpected demands. Finally, the routers might implement policies to gracefully bring down portions of the system in order to avoid further damage and maintain service to critical loads.

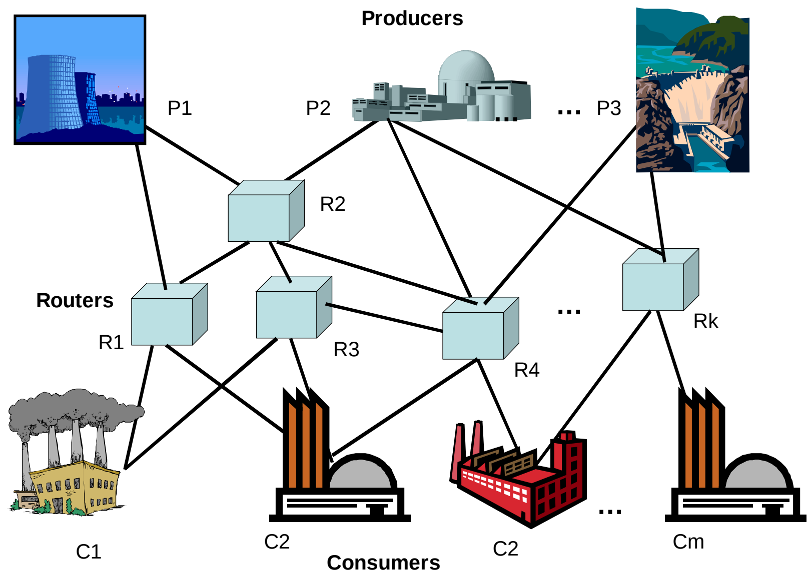

Figure 1: Electrical Energy Network featuring intelligent power routers.

Notice that this approach is a departure from state-of-the-art schemes since the power network has the infrastructure to react to changes in a decentralized and autonomous fashion. The power network has enough redundancy and intelligence to find alternate paths to deliver power to the loads. The goal of the network is to **survive** failures, and returns critical loads to an acceptable level of operation. To achieve this, our approach reduces the risk associated with single-points of failures by using the IPRs a mechanism to operate the system following a distributed control scheme.

Intelligent power routers are fundamental building blocks for the control scheme of the power distribution system that we are proposing. We envision these routers to be strategically distributed over power delivery networks, possibly at key substations or transmission centers, managing existing redundant paths used to carry power from one of more producers to a given consumer. For example, a metropolitan area can be divided into several sectors, each one served by at least two routers. These routers can then be connected to a second layer of routers that are in charge of controlling power delivery on the scale of regions formed by two or more sectors. These, routers can in turn connect to a group of backbone routers that are directly connected to the power generators. The same principle could apply to a naval ship, in which each compartment is connected to the energy sources by a reliable mesh of intelligent power routers.

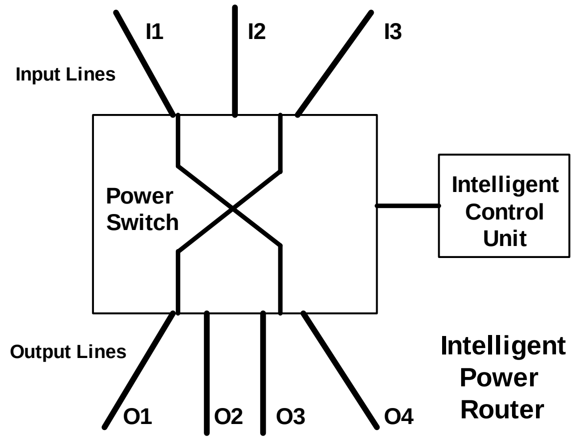

Figure 2: Organization of an Intelligent Power Router

The architecture of an intelligent power router is shown in Figure 2. The router consists of a power switch that moves power between input and output lines. The power switch operates under the control an Intelligent Control and Communication Unit (ICCU), which has the necessary logic to determine how to route power from the input lines into the output lines.

As we can see from Figure 2, there are several lines that arrive and leave from the power switch in each IPR. Each input line connects an IPR to either a power source (i.e. a power plant or an emergency backup) or to another IPR. Similarly, each output line connects a router to either a power consumer or another IPR. To a router, it does not matter whether the other end of an input (output) power line connects to an IPR or to a power source (drain). All the router needs to know is that it must send messages requesting power changes to devices connected to input lines, and it must send messages informing about granted or denied power requests to devices connected to the output lines. Thus, our approach exhibits an important closure property, in which the input of one power router can become the output to another power router. This property will enhance the reliability of the system, because routers can be composed into groups that distribute power in a very efficient manner. These groups or regions can be subdivided as the need for increased reliability arises.

5.1 Operation of the Intelligent Power Router

Normally, an intelligent power router operates on a state of *equilibrium*, where the total amount of power arriving from the input lines is sufficient to satisfy the minimal amount of power that must be supplied to each output line. In this case, the Intelligent Control and Communication Unit (ICCU) in the power routers only needs to send periodic message to the neighboring routers to advertise the state of each line. The state of each line can be read by the ICCU from sensors that are attached to each line in the power switch.

An important feature of the power router is ability to *advertise* [4, 24,] its current state, that is, the values of the variables that describes the current operational state for each input and output line. This is similar to Link-State-Protocols [25] used in computer networks, and Service Advertisement Protocols used in Distributed Databases, which enable interested nodes in the system to learn about services, current conditions, and other state information about other nodes in the network. In our scheme, each IPR periodically sends neighboring routers a message indicating its current state *S*. This information can be used by the neighboring IPRs to understand the state of another IPR at a given time *t*. This information is essential to make decisions when failures or other conditions alter the flow of power on the delivery network. For example, if a router cannot supply its demand for power, it might access the information banks in its ICCU to determine which parent nodes can be requested to increase their supplies. The parent node will sense this as an increase in demand from its outputs. Therefore, a change in demands from a node has the potential of triggering a chain reaction with further requests from that originating node until it reaches the power generators. This scheme is designed to mimic the behavior of the routers used in computer networks, which advertise the best link they know can be used to move a packet from one computer to another. In our case, each power router can advertise the state of each line, which can be used to determine **alternative** power routes to meet existing demands.

When the ICCU detects a value coming from a sensor that deviates from the normal operation parameters, the ICCU brings the router into an *adaptation* mode in which it goes through several states that are designed to bring the power router back into equilibrium.

If additional power is required the IRP sends a message to all candidate power routers that can provide power so they increase the flow that is arriving over the given input power lines. This process will trigger requests from the candidate power routers to other power routers that are adjacent to them, and the process continues recursively until the power request reaches the power generators. It is at this point that the generators are required to increase the generation of power to meet the demands of the system.

Clearly, the communications time and the time to make decisions must lie with within a time horizon that is feasible and obeys the physical constrains in the system. We seek to develop protocols and algorithms that use state information from the neighbors to incrementally pre-computes many alternative contingencies plans, and then choose one based on the current conditions at the moment of failure. This is similar to schemes used in Distributed Data Processing schemes where multiple plans to run a query are maintained. Then, current system conditions are used to select and complete the actual plan to be used. This illustrates another important feature of approach: the ability to foresee and adapt to changes.

5.2 Summary of activities to be undertaken

Table 2 summarizes the activities to be undertaken over the three-year effort.

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

Activity	Tentative schedule
Study of unrestricted energy transfer problem Test bed and benchmarking development Design of alternative IPR control algorithms	First year
Study of constrained energy transfer problem Simulations and preliminary reliability assessment Evaluation of alternative IPR control algorithms	Second year
Reliability assessment	Third year

A web site has already been constructed to disseminate all research products to the general public. Interim reports and a Final Report documenting all research activities and results will be written. We will also publish our work in reputable refereed conferences and journals.

6.0 New Curricula and Pedagogy

The future energy course, wherever it may lead, will require a new kind of energy professional. Today's energy challenges require qualified professionals knowledgeable not only in classic power systems topics, but also in areas such as power electronics, socio-economic issues, environmental constraints and policy issues. Furthermore, the restructured electric energy business, new energy challenges in reliability and security, declining workforce development and scarcity of prepared professionals threaten to aggravate current and future energy woes. A change is needed in the educational paradigm that guides power engineering programs. This is further supported by the crisis in power engineering education faced at many universities worldwide, where traditional power programs have been reduced or eliminated [26], [27], [28].

Contrary to the national trend, the University of Puerto Rico-Mayagüez (UPRM) has a strong power engineering program, which is divided into power systems and power electronics. Eight professors teach energy courses to an average of 200 students each semester. More than 100 students specialize in power engineering. Over 30 students graduate each year with a power engineering minor (at least 19 credit-hours). The strength of the program has been preserved through an ambitious curriculum renovation that includes revision of course contents, integration of laboratory practices to courses, and a more prominent role of undergraduate research and power electronics in the power engineering curriculum [29]. Courses are being updated to include contemporary topics while keeping fundamental engineering principles. Recent NSF grants and participation in CPES has given UPRM the opportunity to expand course offerings and undergraduate research in power engineering.

In order to stimulate active learning and critical thinking, it is important to realize that the teaching/learning process also goes on outside the traditional classroom setting. The proposed education objectives will make students active participants in the learning process, and will improve their understanding of power engineering principles and applications [29, 30]. Dr. Efraín O'Neill-Carrillo will coordinate education activities in this proposal. The Energy Systems Instrumentation Laboratory (ESIL), composed of an Electromechanical Energy Conversion Laboratory and a new Power Engineering Design Laboratory, will provide resources needed to carry out the following activities:

? Undergraduate research projects
? Laboratory modules
? Seminars
? Revision of graduate and undergraduate courses in power engineering
? Demonstrations to the community, special emphasis on pre-college students

The integration of research and education will be achieved through undergraduate research and also by adapting research results for class examples, seminars and demonstrations. The structure of undergraduate research will be improved by using the affinity research group model [31]. This model integrates the knowledge and skills required for research to the knowledge and skills required for cooperative work. Membership is dynamic, new members join in when other members graduate. Dr. O'Neill-Carrillo will transform small groups of graduate and undergraduate students into cohesive entities which will maximize student understanding of energy principles while strengthening their communication, social and research skills. Emphasis will be given to multidisciplinary research issues. For example, the Puerto Rico Electric Power Authority has interest in considering environmental constraints in their optimal dispatch problem. This is a potential undergraduate project in which students would work on an actual situation in which they have to ponder system operation and security while minimizing environmental impact.

Efforts to integrate laboratories to undergraduate courses will continue. Practices and demonstrations will be developed for the power system analysis course and the transmission and distribution course. As part of the on-going curriculum renovation, activities proposed in this work will transform power engineering into an innovative program that integrates multi-disciplinary knowledge such that students obtain a broader perspective of today's energy challenges. It will merge technical, social, economical and environmental topics within graduate and undergraduate courses. Such a multi-disciplinary perspective is vital to ensure a pool of qualified energy professionals. This revised curriculum, both in contents and structure, will spark student interest in attending energy-related courses and participate in research. Table 3 presents proposed changes in the courses. In addition the graduate courses on computational methods, dynamics and power quality will be revised to include advanced concepts in system security and reliability. In order to better integrate researchers and students from other disciplines to proposed research, a short course on energy principles will be developed for non-power engineers. Such a course will enable students from other disciplines, e.g., social sciences, to apply their areas of expertise to research on power system operation.

Table 3: Proposed changes to include ethical, social and environmental issues in our courses

Issues to be included	Courses	Examples of topics within the course that may be used to address the issues
Economic	All courses	Cost models, economic comparison of alternative designs
Environmental	4407, 4408, 4409, 5406, 5407, 5408, 6025, 6028	Hazardous materials, snakes/bird control, aesthetics, emissions, regulatory bodies, alternate energy sources, energy efficiency (demand side management, motor selection and sizing, alternate transformer options)
Health and Safety	4407, 4408, 4409, 5406, 5407, 5408	Existing codes (NEC, NESC, Complementary Rules, PREPA requirements, OSHA) electric shock hazard, hazardous materials
Social & Ethical	5406, 5407, 6025, 6028	Load shedding scheme priorities, economic vs. environmental dispatch of generators, lobbying, public perceptions and education
Political	5407,5408, 6025, 6028	Policy makers, regulatory agencies and bodies

Dr. Eddie Marrero, researcher and instructor from the Social Sciences Department, will collaborate in the education plan. He will develop instruments to assess student learning and perception about the integrated multi-disciplinary curriculum. Dr. Marrero will also provide assistance on ways to measure public perception and tools to increase public information. The Puerto Rico Energy Affairs Administration will also collaborate with the researchers. This government agency, in charge of the Island's energy policy, will support activities such as seminars, proposals to DOE, and development of informative brochures for the public. They can also provide assistance in projects that need action from the Department of Natural and Environmental Resources. Dr. Luis Jiménez, UPRM ECE Professor, will collaborate in the development of seminars and class material for the study of ethics and social impact of engineering decisions. He has advanced studies in philosophy and ethics.

Dr. O'Neill-Carrillo created the *Energy Systems Seminar Series* (ES^3) during the spring of 2001. Over ten seminars have been delivered by Industry, Faculty, graduate and undergraduate students. The seminar series will be expanded, and will present topics that are not usually covered in traditional courses. Pre-seminar and post-seminar surveys will be administered to assess impact on learning and perception of learning. Examples of proposed topics include:

"Energy policy and engineering decision making"
"Power and the Environment: Social, economical and ethical implications"
"New Power Generation Technologies: Minimizing Environmental Impact"
"Efficient Utilization of Energy: Getting the most out of limited resources"
"Distributed Generation"
"Power electronics applications in power systems"

Proposed education activities will impact at the department, campus and national level. This project will further UPRM's ECE departmental goal for ABET accreditation renovation. Over 95% of students at UPRM are Hispanic. UPRM is on the top ten universities in terms of number of engineering graduates. The proposed activities can also be adapted to meet particular characteristics of other institutions and may contribute to the national debate on engineering education reform [32].

7.0 Benchmark Test Systems

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.

8.0 Results from Prior NSF Support

The proposed work is the continuation and extension of previous NSF projects that have enhanced educational and research infrastructure at UPRM, and have contributed to advance research and education in energy processing systems, and implement strategies to further energy research and education. This proposal will build upon and expand current education and research NSF projects at UPRM.

Dr. Vélez-Reyes is the principal investigator and Co-PI in two NSF supported projects of direct relevance to the proposed project. The first under the Presidential Early Career Award for Scientists and Engineers (PECASE), ECS-9702860, entitled "Parameter Estimation for Ill-Conditioned Systems with Application to Electric Drives and Power Systems." The second is a subcontract under prime award number ECS-9731677 between Virginia Tech and NSF for the project "Center for Power Electronic Systems."

Grant ECS-9702860 involves the development of methodologies for conditioning assessment and parameter estimation in ill-conditioned systems. It has been shown how sensitivity analysis tools developed by Dr. Vélez-Reyes can be used to assess conditioning of estimation problems associated with induction motor drives and synchronous generators, and how the results can be used to develop robust estimation algorithms [34-39]. His approach has been to use matrix analysis and multivariable statistical techniques to study the conditioning of parameter estimates using sensitivity functions that assess the conditioning of parameters in estimation problems. That information is used to determine how many and which parameters can be identified from the available data. Once this information is available we develop formulations of the parameter estimation optimization problem by incorporation of prior information that result in well-conditioned problems. In this process, we trade bias versus sensitivity. Sensitivity is reduced at the price of introducing bias on the estimate. Numerical algorithms perform significantly better when computing the parameter estimates for the well-conditioned problem versus the ill-conditioned problem. For instance, iterative algorithms for nonlinear least square estimation converge in fewer iterations, one to two orders of magnitude, than ill-conditioned versions. We have developed active collaboration with Prof. Alexandar Stankovic from Northeastern University in applications of the sensitivity analysis techniques to PM electric drive as documented in [39]. Also, we are jointly conducting a research project in using this methodology to develop robust algorithms for tuning of Field Oriented Controllers for induction machine drives used in electric vehicle applications. The Electric Energy Processing Systems Laboratory (EEPSL) has been established as part of the grant. The laboratory has two principal areas one for experimental and prototyping work and a computer center. A description of the instrumentation currently available at EEPSL is presented later.

An important component of ECS-9702860 is the education plan. As part of the grant, we have given six workshops to high school students in electric energy conversion as part of the UPRM pre-engineering program during the summers of 1998-2000. We have revised the manual for the energy conversion laboratory offered to EE and ME students. The new manual was first used in fall 1999 and the last revision is being used in spring 2002. We obtained funds from UPR administration for the amount of $109k to remodel laboratory facilities. Most of UPRM funds were used for the acquisition of computers and data acquisition equipment to enable studies of different electrical phenomena at finer scales, and introduction of time and frequency domain signal-analysis capability. Our current educational work has changed its focus from the one proposed in the original proposal that had a strong component of high school and teachers outreach to one mainly on curriculum and laboratory improvement some of our ideas are documented in [29]. We are taking advantage of curricular revision motivated by ABET 2000 criteria.

As part of the NSF Center for Power Electronic Systems (CPES) Engineering Research Center, a subcontract under grant ECS-9731677, UPRM principal role has focused in enhancing its research and education infrastructure in power electronics and research work in modeling and simulation of power electronic modules and systems. Over 45 undergraduate students and 20 graduate students have participated in undergraduate and graduate research projects in power electronics and electric drives sponsored by CPES. Results of the educational efforts are documented in [29, 40]. The research program has focused in gray box modeling of electric drives as a way to improve drive performance under uncertain mechanical loads [42, 43]. This approach can potentially be used in self-commissioning and self-tuning of drive controllers. Another component of the work is multidisciplinary modeling of power electronic systems and drives. There are two areas of focus electro thermal and EMI. Electro thermal modeling of power electronic modules this is a key component of the system integration effort at CPES. Models being developed as part of the research work can be used for virtual power module prototyping. New packaging concepts being explored at CPES require different models as it is shown in [44]. We have developed implementations for existing power electronic modules that will be used by NIST researchers [45-47]. EMI work has focused on modeling of induction motors to take into consideration PWM effects. The results of current work are documented in [48]-[51]. Cost modeling of power electronic modules is an important component for CPES to be able to quantify cost improvement an extensive model has been developed and is presented in [52, 53]. Current work deals with implementation using data base tools. Participation in CPES enabled an expansion of the scope of EEPSL activities.

Project “Integrating Laboratory Practices and Undergraduate Research to the Power Engineering Curriculum at UPRM,” (DUE 0088619) is the cornerstone for the renovation of power engineering curriculum at UPRM. During year 1 (May 2001 – April 2002) equipment was acquired and used jointly with existing instrumentation in the Electric Machines Laboratory to constitute the Energy Systems Instrumentation Laboratory (ESIL). The establishment of ESIL provides both students and professors an environment to explore engineering ideas and concepts, fundamental principles as well as current issues and new research areas in power engineering. Test practices were conducted on the Introductory Course on Power Systems. Students reacted with enthusiasm to the laboratory practice since it helped them better understand class theory. Two education projects were linked to the CCLI project by providing twelve practices that can be used for the power electronics courses. Four papers that include discussions on proposed activities and the development of initial tools were accepted/submitted [39], [40], [53], [54].

Project “Acquisition of Instrumentation for the Electric Energy Processing Systems Laboratory at UPRM” (ECS 0116314) started on January 2002. This project provided the Power Engineering group with research infrastructure support. It allowed an expansion of experimental facilities and acquisition of equipment close to industrial applications. EEPSL increased to 1,400 sq. ft and was divided into the following areas: Energy systems component testing and prototyping; power system component modeling and simulation; and power quality and energy conversion.

Project "Career- Power Quality Research and Education: A New Power Engineer for Today's Energy Challenges" (ECS 0134021) has a five-year duration beginning on May 2002. This project combines power electronics, power systems and contemporary energy issues through power quality. T he topics of this CAREER award are very related to the proposed work. Dr. O'Neill-Carrillo is very interested in collaborating in the development of new operation schemes in power systems, and how power quality is degraded due to different system conditions.