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NSF CAREER: Scalable Learning and Adaptation with Intelligent Techniques and Neural Networks for Reconfiguration and Survivability of Complex Systems

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***Abstract*--The NSF CAREER program is a premier program that emphasizes the importance the Foundation places on the early development of academic careers solely dedicated to stimulating the discovery process in which the excitement of research enriched by inspired teaching and enthusiastic learning. This paper describes the research and education experiences gained by the principal investigator and his research collaborators and students as a result of a NSF CAREER proposal been awarded by the Power, Control and Adaptive Networks (PCAN) program of the Electrical, Communications and Cyber Systems Division, effective June 1, 2004. In addition, suggestions on writing a winning NSF CAREER proposal are presented.**

***Index Terms*—adaptive control, adaptive critic designs, computational intelligence, evolvable hardware, FACTS, nonlinear control, power systems stability, wide area control.**

I. Introduction

THE NSF CAREER proposal of the principal investigator (PI) [1] focuses on the development of advanced computational intelligence techniques for identification, control and optimization of complex systems. Recently, intelligent techniques and adaptive critic designs have received increasing attention. The dynamic stochastic optimization (DSO) of complex systems such as the electric power grid and its parts can be formulated as minimization and/or maximization of certain quantities. The electric power grid is faced with deregulation and an increased demand for high-quality and reliable electricity for our digital economy, and coupled with interdependencies with other critical infrastructures, it is becoming more and more stressed. Intelligent systems technology will play an important role in carrying out DSO to improve the network efficiency and eliminate congestion problems without seriously diminishing reliability and security. This project investigates ways in which the power grid can be dynamically optimized using brain-like stochastic identifiers and controllers.

A creative, integrative and effective research and education plans at all levels generates a synergy in which the process of discovery stimulates learning and assures that the findings and methods of research are quickly and effectively communicated in a broader context and to a larger audience. The PI's career goal is to promote best practices in engineering, science and education by effective integrating of research and teaching in power and intelligent systems. This paper describes briefly how a successful integrated research and education plan has been proposed and implemented by the PI at the Missouri University of Science and Technology (Missouri S & T) in the field of Power and Intelligent Systems.

A NSF CAREER proposal in the PI's opinion should include international collaboration today to enrich the research and rapidly make an impact. NSF strongly encourages PIs to include international dimensions where appropriate (e.g., visits to foreign research facilities, collaborations with foreign research partners, and development of international educational activities) [2]. The education and research activities proposed may also include collaborations with partners from other sectors (for example, partnerships with industry, national laboratories, or schools and school districts). The PI describes in this paper the several new collaborations he has established and other existing collaborations which have been enhanced as a result of the CAREER award.

NSF especially encourages the inclusion of women, members of underrepresented minority groups, and persons with disabilities in research and educational activities of a CAREER proposal. This paper briefly describes how this dimension was incorporated in the PI's CAREER proposal.

II. Research Experience

The research activities of this proposal include advancement of knowledge and understanding in a number of disciplines including:

- Computational intelligence (CI).
- Modeling, control and optimization of power system generation and transmission networks.

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- Digital hardware design.

Computational intelligence is the study of adaptive mechanisms to enable or facilitate intelligent behavior in complex, uncertain and changing environments. These adaptive mechanisms include those artificial intelligence paradigms that exhibit an ability to learn or adapt to new situations, to generalize, abstract, discover and associate [3]. The typical paradigms of CI are illustrated in Fig. 1. These paradigms can be combined to form hybrids as shown in Fig. 1 resulting in Neuro-Fuzzy systems, Neuro-Swarm systems, Fuzzy-PSO systems, Fuzzy-GA systems, Neuro-Genetic systems, etc. Other advanced CI techniques not depicted below include adaptive critic designs [4, 5], reinforcement learning and approximate dynamic programming [5].

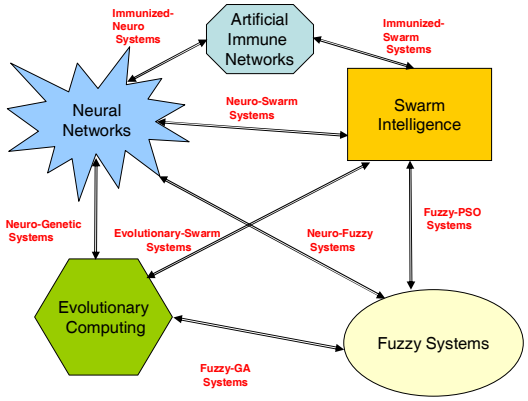

Fig. 1. Five main paradigms of CI and some possible hybrids.

The PI's research in CI focuses on developing robust and fast search algorithms, less complex neural network structures, and hybrid CI paradigms for solving system identification, modeling, control and optimization problems effectively.

A number of papers have been published in improving the performance of swarm and evolutionary algorithms for solving problems involving search and optimization. The performance of particle swarm optimization (PSO) was improved by removing the constraints that are normally applied on the velocities of particles and modifying the position update equation. Results were presented on the standard benchmark functions [6]. Adaptive critics was applied to improve the performance of PSO by changing dynamically the inertia weight, w and cognitive and social acceleration constants, c_1 and c_2, respectively [7].

Hybrid algorithms were developed for solving a number of complex problems. Training recurrent neural networks and simultaneous recurrent neural networks (SRNs) is a much harder problem than training feedforward multilayered perceptron neural networks. A hybrid PSO-EA (evolutionary algorithm) algorithm was developed to predict the missing data in the CATS time series competition posed at the 2004 IEEE International Conference on Neural Networks [8]. A quantum inspired evolutionary algorithm was developed and compared with PSO for training SRNs and shown to perform better on this difficult neural network training [9]. Hybrids of fuzzy logic and PSO (swarm intelligence) paradigms were used in the design of controllers for grid photovoltaic systems [10] and mobile sensor navigation [11]. Hybrid algorithms between PSO and quantum evolution/differential evolution (DE) were developed and shown to have better performance than PSO or DE for evolving digital circuits [12, 13].

A dual function neuron (DFN), trained with PSO, has been shown to perform well for approximation, estimation and classification problems [14, 15, 16]. DFN is a compact structure and has tremendous potential for replacing complex neural network structures for a number of applications. DFN is attractive for applications that require learning to be carried in a short period of time and with less hardware implementation resource requirements. Several other developments were made to CI algorithms for applications in power systems, digital systems and collective robotic search and the entire list of publications is provided in [17, 18].

The PI established the Real-Time Power and Intelligent Systems (RTPIS) Laboratory at Missouri S & T on the award of the CAREER grant. The laboratory's primary emphasis is the development of computational intelligence techniques for the modeling, control and optimization of power systems and power electronic devices. The current activities of the RTPIS laboratory are depicted in Fig. 2. The different projects are currently supported by a number of grants from NSF, Industry and US Office of Naval Research including a Young Investigator Program award [19].

The PI's website [17] list the papers published on a number of power and energy system issues. Most recent and relevant research to the CAREER proposal includes the following:

- Development of identification and control ObjectNets for a power system with multiple generators and transmission devices using SRN neural network architectures [20]. Controller parameters are dynamically adjusted using an adaptive critic whose objective is to minimize voltage deviations at buses and speed deviations of generators during dynamic and transient conditions.
- Development of echo state networks (ESNs) fast online identification of wide area generator dynamics [21]. Results have been presented to show that ESNs are 50 times faster than time delayed neural networks with identification of an order better.
- Development of intelligent wide area controllers for providing auxiliary signals to excitation controller input of respective generators in multiple area power network. The wide area controller design is based on a SRN which has the capability to predict multiple time steps ahead the states of the network. Thus, the controller is able to provide just-in-time control signals to the different areas of the power system compensating for any communication delays under 1.4s [22]. A real-time implementation of the wide area controller on a digital signal processor interfaced to the real time digital simulator (RTDS) has been implemented to illustrate the merits of such a design.
- Development of intelligent wide area controllers for different flexible AC transmission systems (FACTS) including the unified power flow controller (UPFC) [23], gate controlled series capacitor (GCSC) [24] and STATCOM [25].

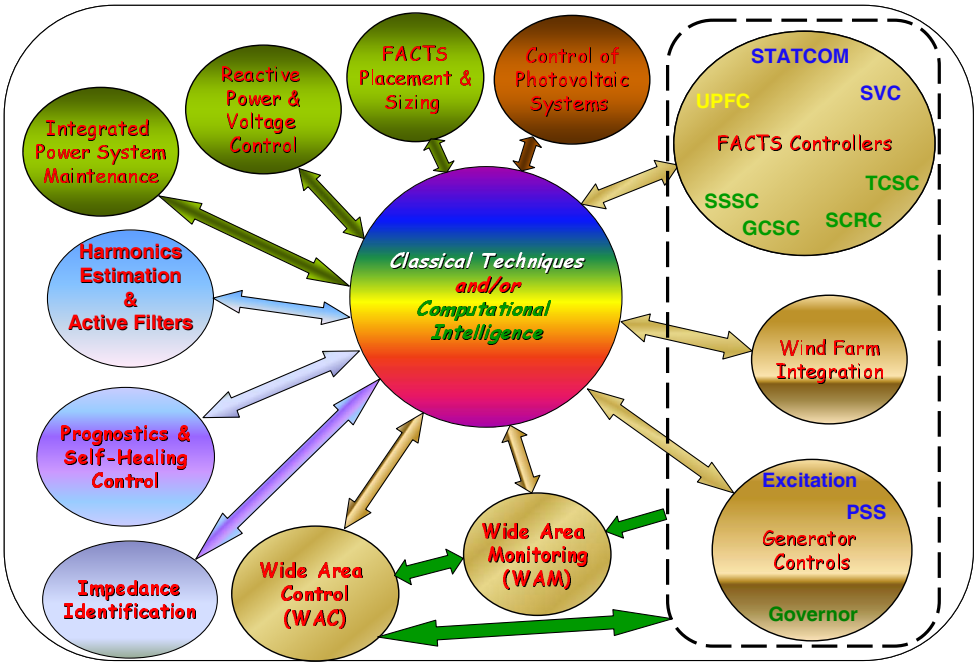

Fig. 2 Research in power and energy systems at the RTPIS laboratory at Missouri S & T (http://rtpis.mst.edu).

- Development of an intelligent wide area controller and state predictor for coordinating generators and FACTS devices have been successfully carried out [26].
- A computationally less intensive dual function neuron is used for the development of an external static var compensator (SVC). The DFN based controller provides damping to the power system oscillations by modulating the SVC reference voltage during transients using remote speed deviation measurements of generators [16].
- Development of an advanced adaptive critic design based optimal neurocontroller for coordinating the controls between a large wind farm and FACTS devices. Results that the wide area coordinating controller provides better stabilizing control especially for the wind farm during transient conditions [27].
- A survey paper has been carried out on the origins of PSO, its basic concepts, variants and applications in power systems [28].
- A small population based PSO (SPPSO) has been developed and compared with a bacteria foraging algorithm (BFA) for the simultaneous design of multiple power system stabilizers [29]. SPPSO is shown to be a better algorithm than BFA computationally and in terms of fast convergence.
- Fault tolerant control systems for FACTS devices have been developed with missing sensor measurements. The missing data can be restored using neural networks and particle swarm [30].

PSO, DE, DEPSO and other hybrid algorithms have been shown to be effective in the evolution of digital circuits given some specification in form of truth tables [12, 13]. As the desired specifications are changed, different circuits can be evolved immediately using the above algorithms.

III. Education Experience

As mentioned in the Introduction section of this paper, a CAREER proposal requires at its core an educational plan in addition to a research plan. As part of the PI's educational objectives, the development of new courses at Missouri S & T was outlined. These courses include:

- Computational intelligence: As mentioned under research experience section, this course deals with introducing the five CI paradigms depicted in Fig. 1. The PI introduced this course for the first time at Missouri S &T in 2004. The PI's website [17] provides a course description. Papers on teaching neural networks [31] and the CI course development [32] were published at the American Society for Engineering Education (ASEE) Midwest Symposium and at the national ASEE meeting respectively.
- Adaptive critic designs (ACDs): This course deals with combining the concepts of reinforcement learning and approximate dynamic programming to develop dynamic optimization and optimal control tools. ACDs use neural networks as tools for its implementation. The PI's website [17] provides a course description.
- Adaptive devices, circuits and systems (ADCS): This course deals with how CI paradigms can be applied to make devices, circuits and systems robust during dynamic reconfiguration, estimation and, self-healing and restoration mechanisms.

The PI has presented 12 tutorials nationally and internationally (8 countries) as an outreach program to a larger audience based on findings of the research carried out in the CAREER proposal. The PI's website [17] provides a detail list of the tutorials presented, where and when.

Several students, from US and other countries of different races and gender, have been involved in the different aspects

of the research activities in this CAREER proposal. The PI has advised 3 PhDs students who had their dissertations in the field of power and intelligent systems. The PI has also advised 8 MS thesis students in areas including power systems, signal processing and robotics.

As a result of the experiences gained from writing the education plan for the CAREER proposal and its implementation, the PI was successful in winning two other major educational proposals. One was from the NSF Course, Curriculum and Laboratory Improvement program targeted at undergraduate students [33] and the other was from the US Department of Education GAANN (Graduate Assistance in Areas of National Need) program [34].

IV. International Collaboration

The PI has established several new and enhanced existing international collaborations in addition to those within USA through the CAREER proposal research and educational activities. Several workshops and invited presentations have been presented in Australia, Brazil, Cyprus, India, Germany, Ghana, Mexico, Nigeria, South Africa and South Korea. A complete of list of workshops and invited presentations given is available on the PI's webpage [17].

In addition, the PI secured additional funding the NSF International Experience and Education in Engineering (IREE) program to visit with the ABB Corporate Research Center in Vasteras, Sweden and the Royal Institute of Technology, Stockholm, Sweden. The PI and a PhD student spent the summer of 2007 in Sweden. The objectives of the IREE visit is gain understanding of the state of the art industrial controls in power systems and introduce the benefits of CI techniques to the ABB researchers. Recently, the PI has been selected by the British Council Researcher Exchange program to visit with Imperial College, London, UK.

V. Diversity

Students of different races and gender, from the US and other countries, have been and are involved with the activities of the CAREER proposal. Female and minority undergraduate students have been recruited by PI to take part in the research activities of the CAREER proposal through discussions in a classroom environment. The PI is open to giving tours and demos of the activities in the RTPIS Lab. to the undergraduates. Five undergraduate students were recruited in the last two years including a female and an African student. The undergraduate students contributed to a number of projects, some resulting in conference and journal papers [12, 13, 35-37]. The female student took part in the Missouri S & T undergraduate research conference in 2007 and 2006 and won the first and third prize in the Engineering Oral presentations. Three undergraduate students took part in IEEE IAS Myron Zucker student design competition in 2007 and won the first prize. Most of these undergraduate students have been supported the NSF Research Experience for Undergraduates (REU) programs in 2006 and 2007.

The female is currently enrolled for a PhD degree in field of power and intelligent systems and the PI received a graduate research supplement from NSF to support the female student. Several female graduate students have been advised and are currently enrolled for MS and PhD degrees in the RTPIS laboratory. Two African students are currently pursuing PhD degrees under the guidance of the PI and another undergraduate African student is participating in some research activities of the RTPIS lab.

VI. Conclusion

This paper has outlined briefly the research and educational activities of the PI on his CAREER proposal funded the PCAN program of the ECCS Division of NSF. A successful CAREER proposal should have a solid, creative, integrative and effective research and education plan at their core. There may be different expectations within different disciplinary fields and/or different organizations, a wide range of projects may be appropriate for the CAREER program. It is important and encouraged for potential CAREER awardees to communicate with the CAREER contact in the division closest to their area of research to discuss the expectations and approaches that are most appropriate for that disciplinary field. In summary, applicants to the CAREER program should identify their niche areas, attend NSF CAREER workshops, visit with their respective program directors in their niche areas, read over recent successful CAREER proposals, and seek mentorship and reviews/feedbacks from successful CAREER applicants in their institutions on their CAREER proposals prior submission to NSF.

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VIII. BIOGRAPHY

Ganesh Kumar Venayagamoorthy (S'91, M'97, SM'02) received the B.Eng. degree (with first class honors) in electrical and electronics engineering from Abubakar Tafawa Balewa University, Bauchi, Nigeria, in 1994, and the MScEng and PhD degrees in electrical engineering from the University of Natal, Durban, South Africa, in 1999 and 2002, respectively. He was a Senior Lecturer with Durban Institute of Technology, South Africa, prior to joining the University of Missouri, Rolla (UMR), in May 2002. He is currently an Associate Professor of Electrical and Computer Engineering and the Director of the Real-Time Power and Intelligent Systems Laboratory at UMR. He was a visiting researcher at the ABB, Corporate Research Center, Sweden during summer of 2007. Dr. Venayagamoorthy's research interests are in the development and applications of computational intelligence for real world applications including power systems stability and control, FACTS devices, power electronics, alternative sources of energy, sensor networks, collective robotic search, signal processing and evolvable hardware. He has published 2 edited books, 5 book chapters, 54 refereed journals papers and over 200 refereed international conference proceeding papers. He has attracted close to US $ 4 million in research funding to date.

Dr. Venayagamoorthy is a Senior Member of t the South African Institute of Electrical Engineers (SAIEE). He is also a member of the International Neural Network Society (INNS), The Institution of Engineering and Technology, U.K., and the American Society for Engineering Education. He is currently the IEEE St. Louis Computational Intelligence Society (CIS) and IAS Chapter Chairs, the Chair of the Working Group on Intelligent Control Systems, the Secretary of the Intelligent Systems subcommittee and the Vice-Chair of the Student Meeting Activities subcommittee of the IEEE PES and the Chair of the IEEE CIS Task Force on Power System Applications. He has organized and chaired several panels, invited and regular sessions, and tutorials at international conferences and workshops.

Dr. Venayagamoorthy was a recipient of the 2007 ONR Young Investigator Program Award, the 2004 NSF CAREER Award, the 2006 IEEE Power Engineering Society Walter Fee Outstanding Young Engineer Award, the 2006 IEEE St. Louis Section Outstanding Section Member Award, the 2005 IEEE Industry Applications Society (IAS) Outstanding Young Member Award, the 2005 SAIEE Young Achievers Award, the 2004 IEEE St. Louis Section Outstanding Young Engineer Award, the 2003 INNS Young Investigator Award, the 2001 IEEE CIS Walter Karplus Summer Research Award, five prize papers from the IEEE IAS and IEEE CIS, a 2006 UMR School of Engineering Teaching Excellence Award, and a 2007 and 2005 UMR Faculty Excellence Award. He is listed in the 2007-2008 editions of Who's Who in America, 2008 edition of Who's Who in the World and 2008 edition of Who's Who in Science and Engineering.