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To: Dr. Paxton, Instructor - CS536

Subj: PROPOSAL FOR CS536 PROJECT

1. The following is our project proposal for work we intend to complete for CS536. Our project title is: **Intelligent Power Management of a Microgrid.**

Significance Section

Steadily increasing needs for electrical power, progress in power deregulation, tight construction constraints on new high voltage lines for long distance power transmission, and global environmental concerns have created increased interest in alternative energy (AE) generation. Wind, photovoltaic (PV), fuel cell (FC), and microturbine (MT) AE devices are attractive primarily because of low or zero emissions, high efficiency, and/or adaptability to remote implementation. Hybrid combination of AE sources, networked within a microgrid framework, can significantly improve their reliability and better deliver power to customer loads. Although ideally adaptable to islanded off-grid applications, it is expected that alternative energy distributed generation (AEDG) microgrids that capitalize on diverse energy sources, are controlled in a decentralized way, and reduce the burden on the utility grid by generating power close to the consumer will penetrate the existing infrastructure network in the near future [1]. In fact, DoE expects upwards of 20% of new generation capacity added by 2010 will be in the form of distributed energy resources [2].

Problem Statement Section

Our proposed work seeks to address the problem of power management when integrating multiple AEDGs into a microgrid. The conventional implementation of up to a medium-sized generator onto a distribution system may not have a significant impact on power quality at the feeder level. Additionally, with only one generator operating, the power management problem reduces to a trivial one. However, coupling multiple distributed generators (DG) and dispatchable loads, within a microgrid framework, to a distribution system is a new concept and

creates a daunting challenge for safe and efficient operation of the microgrid and the components themselves. The novelty of this work is in the use of an artificially intelligent power management supervisor to optimize AEDG dispatch based on local load demand and additional realistic constraints such as: emissions concerns, fuel availability and cost, the spot-market price of electricity, and local history information. By using an artificially intelligent supervisor, we hope to demonstrate a means of finding a rapid *Pareto* optimum to what is by definition multi-objective linear programming problem. In short, we intend to address the complicated engineering problem of how multiple AEDGs and dispatchable loads can be successfully controlled on a microgrid in a near-optimal manner using artificial intelligence concepts studied in class.

For typical multi-objective linear programming problems, the goal is to seek an optimal solution for numerous competing objectives, simultaneously. In such problems, the satisfaction of the linear objective functions becomes a combination of vector “maximizations” or “minimizations”. However, in most cases, a global maximum of any particular individual objective function may not be a satisfactory solution for the remaining objectives [3]. Because of this, we need to alter our concept of optimality for such problems. With similarity to economic systems, a *Pareto* optimum can be reached where the solution represents a state of “satisfaction” for one objective that cannot be raised further without lowering another objective’s “satisfaction”. Multi-objective linear programming problems of this type clearly fit into a broad field of problems that are of interest to Computer Scientists. Today, such problems have not been proven to be solvable in strongly polynomial-time. Therefore, algorithms such as ant colony optimization (ACO) may yield excellent near-optimum results in short periods of time which is critical for good power management and dispatch [4].

Background Section

A literature search for research publications regarding ant colony metaheuristic applications to the constraint satisfaction problem (CSPs) yielded a total of only 14 academic works; the oldest of which was published in 1997. Most of the theoretical work on ant applications to CSPs has been conducted by Christine Solnon (France) and Tarrant & Bridge (Ireland) [5, 6]. Additionally, on the *CiteSeer* on-line collection of Computer Science bibliographies, the vast majority of titles that address CSPs utilized evolutionary algorithms,

such as genetic algorithms, not ant metaheuristics. This is a curious result for two reasons. First, it presents the obvious question as why ant algorithms are not used for CSPs. Secondly, and more interesting to us, is that: ant algorithms seem to be ideally suited to CSPs that are the primary class of problems of interest to engineers seeking solutions to practical applications. Ant algorithms, such as MMAS, ACS, and ACO, can find good, near-optimal solutions to CSPs, but cannot prove that a satisfactory *Pareto* optimum *does not* exist if conditions demonstrate a lack of an optimum [4]. Clearly, for engineers seeking practical implementations, the proof of existence for an optimum (or no optimum) is irrelevant. What the engineer wants is a rapid convergence to a solution that is presumably near optimal. Ant algorithms can achieve this, and possibly because less is known about their theoretical expression, this is why they are of less interest to Computer Scientists. An example of a purely engineering application for ant algorithms is described in [7]. In this publication, an ant metaheuristic framework is applied to a relatively straightforward engineering design problem, specifically how to route storm water drainage piping given constraints. We see [7] as a published example of an engineering application that we can build upon and ultimately apply to an electrical engineering CSP for improved implementation.

Preliminary and Future Work Section

Research plan: We intend to capitalize on the strengths that each of us bring to this project. Kristie has strong experience with programming and data structures. Chris has good modeling experience and is well versed in control system theory. Together, we will collaborate on the core of the project (the artificially intelligent algorithms to be used) and draw upon our knowledge of electrical engineering to implement it.

An overview of the intelligently-controlled microgrid system is displayed in Fig. 1. Our research will consist of three primary tasks and one optional task, delineated below.

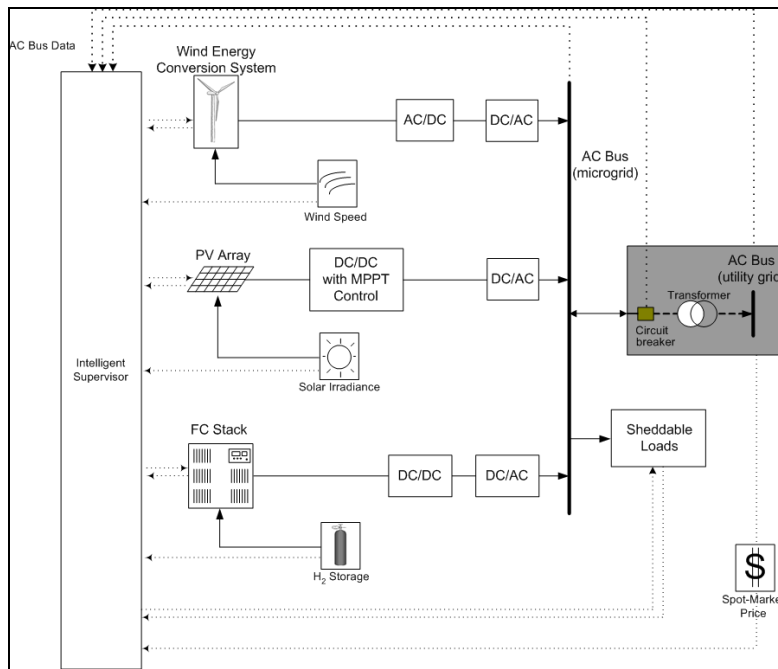


Fig. 1: System Block Diagram

Task #1: Establish a simulated microgrid test-bed. Integrate the dynamic mathematical models of three simulated AEDG sources in a microgrid architecture (MATLAB/SIMULINK). Design and attach a representative 5-tier load center to the microgrid that varies over a 24-hour (simulated) period. Derive the time-domain state equations of the electrical components.

Task #2: Design the ACO-based control supervisor. Design an artificially intelligent controller that will search the possible solution sets for a *Pareto* optimal solution for generator dispatch and appropriate load-shedding. The ultimate goal of the supervisor is to satisfactorily maintain microgrid bus voltage within a pre-set deadband. Fig. 2 lays out the proposed logic flow for the controller. This will be the most involved task specified by this proposal.

Task #3: Analyze the performance of the intelligent supervisor compared with conventional control methods. Design and implement a conventional excitation controller and a conventional threshold load-shedding controller (see explanatory note below). Simulate each of the three methods and compare their performance on the basis of speed to solution, optimality of solution, and transient response on generators, loads, and bus voltage.

(Explanatory note: In most power system cases, excitation control of the generation source is implemented when voltage stability is a concern. In rarer instances, threshold voltage load shedding is implemented for the same purpose, but controlling the load-end rather than the generator-end (see Fig. 3). These voltage control strategies are never implemented together because of the concern over “fighting” controllers and unstable conditions.)

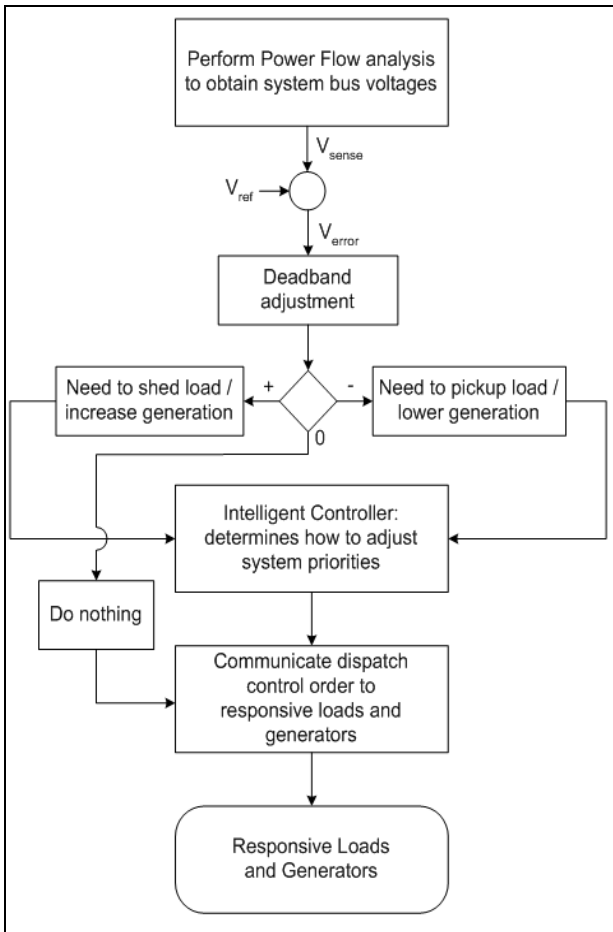


Fig. 2: Control algorithm

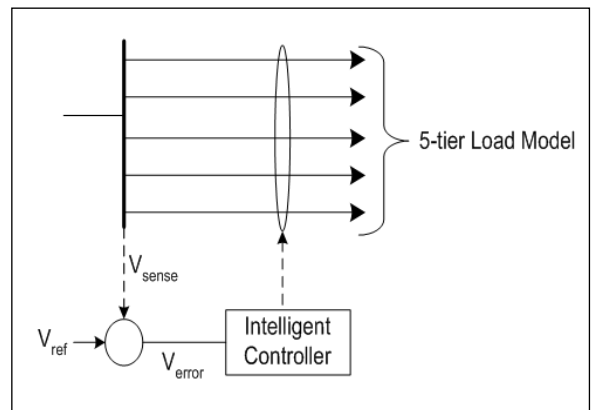


Fig. 3: Simple 5-tier sheddable load control scheme

(Optional, if time permits) Task #4: Analyze microgrid controller performance when interconnected with the utility grid. Use the microgrid architecture established in Task #1 to add in the additional constraint of grid-interconnection. Analyze how the intelligent controller responds to the additional constraints of spot-market pricing and an infinite bus voltage.

Problem definition: For this multi-objective problem:

The intelligent controller can affect two vector quantities: φ and λ . The φ vector represents the commands to the generators as to what voltages to produce. The λ vector represents the binary signal commands to the five-tier load as to which loads to have in operation.

The R quantities represent the available resource for a particular generator (i.e. solar irradiance, wind speed, hydrogen fuel availability/cost). In order to simulate realistic conditions, each R quantity varies with time and is based on real-world data. These quantities are sensed by the intelligent controller for the purpose of evaluating dispatch.

The Γ function represents the dispatch of a particular generator. The individual characteristic function of each generator ($\Gamma_x\{\varphi_x, R_x\}$) takes the φ_x command and R_x available and produces a voltage (V_x) in the generator.

The η quantity represents the environmental impact factor assigned to the operation of a given generator. For simulation purposes the environmental impact factors are non-time varying, i.e. CO₂ emissions from a fuel cell are always bad. In future studies, these quantities could be time-varying, i.e. wind power is not desirable during periods of avian migration. Environmental impact is viewed as a negative characteristic in this study.

The Ψ function represents the environmental impact of a particular generator operating at a given voltage. The vector of individual environmental impact characteristic functions for all generators is $\Psi_x\{\eta_x, \Gamma_x\}$, where η_x are the environmental impact factors and Γ_x are the dispatches to the generators.

The primary constraints for this problem are:

- a. Generator voltages
- b. Microgrid bus deadband voltage range

The primary objectives are:

- a. Maximize the number of loads on-line

- b. Minimize resource consumption
- c. Minimize environmental impact factor
- d. (Optional) Maximize power delivered to grid interconnection (i.e. results in revenue)

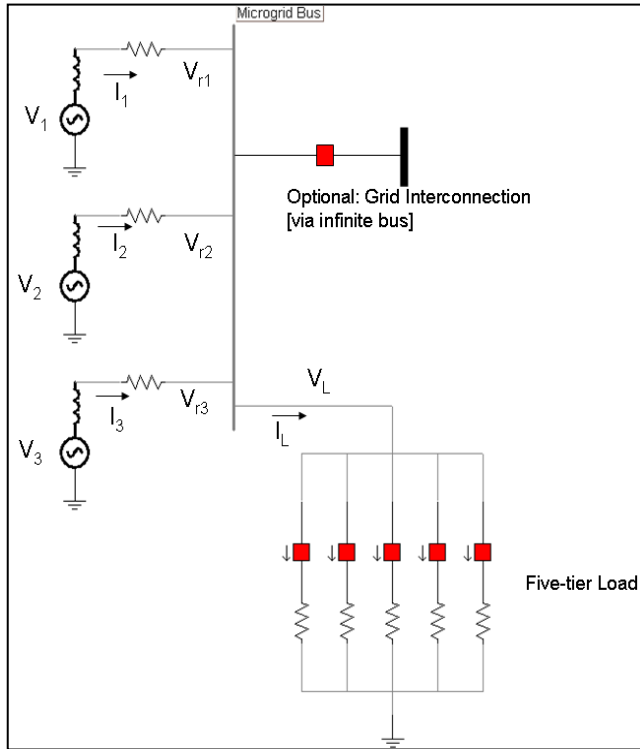


Fig. 4: Power flow diagram

Problem definition equations:

$$\begin{aligned}
 I_1 + I_2 + I_3 + I_L &= 0 \\
 V_{ref}^{low} \leq V_{r1} = V_{r2} = V_{r3} = Z_L I_L \leq V_{ref}^{high} \\
 V_1 - V_{r1} &= Z_1 I_1 \\
 V_2 - V_{r2} &= Z_2 I_2 \\
 V_3 - V_{r3} &= Z_3 I_3 \\
 \Gamma_1 \{ \varphi_1, R_1 \} &= V_1 \\
 \Gamma_2 \{ \varphi_2, R_2 \} &= V_2 \\
 \Gamma_3 \{ \varphi_3, R_3 \} &= V_3 \\
 \Psi_1 \{ \eta_1, \Gamma_1 \} &= E_1 \\
 \Psi_2 \{ \eta_2, \Gamma_2 \} &= E_2 \\
 \Psi_3 \{ \eta_3, \Gamma_3 \} &= E_3 \\
 \varphi_1, \varphi_2, \varphi_3, R_1, R_2, R_3, \eta_1, \eta_2, \eta_3 &\geq 0 \\
 Z_L &= (\lambda_1 Z_{L1} + \lambda_2 Z_{L2} + \lambda_3 Z_{L3} + \lambda_4 Z_{L4} + \lambda_5 Z_{L5}) \\
 \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5 &= [1 \vee 0]
 \end{aligned}$$

Anticipated results or findings: This is a proof-of-concept project. We intend to determine whether an artificially intelligent controller demonstrates any benefit over the conventional means of generator/load control. Results will be presented in a final paper and class presentation.

Conclusion: The worldwide interest in distributed and scalable microgrid architectures that capitalize on diverse energy sources is growing. This growth is aided by the global interest in environmental security and the desire to reduce dependency on fossil fuels. This project specifically addresses a small, but fundamental portion of the challenge to coordinate and control multiple AEDG sources connected to a microgrid. The design of the proposed intelligent

decision-making strategy is an important step toward autonomous operation (power management) of microgrids that achieve energy sustainability while minimizing operational costs and environmental emissions.

Bibliography Section

Literature citations:

[1] Hatziargyriou, Asano, Iravani, & Marnay, “Microgrids,” *IEEE P&E Magazine*, vol. 5, issue 4, July, 2007.

[2] “Strategic plan for distributed energy resources”, US Department of Energy, September, 2000. (http://www.eere.energy.gov/de/pdfs/de_program_plan.pdf)

[3] Saul I. Gass, Linear Programming: Methods and Applications - 5th Edition., Dover Publications, Inc. 2003, pgs. 224-250.

[4] Dorigo, M. and Stutzle, T. Ant Colony Optimization. MIT Press, 2004.

[5] Christine Solnon, “Ants Can Solve Constraint Satisfaction Problems”, *IEEE Transactions on Evolutionary Computation*, Vol. 6, No. 4, August 2002.

[6] Finbarr Tarrant & Derek Bridge, “When Ants Attack: Ant Algorithms for Constraint Satisfaction Problems”, *Artificial Intelligence Review*, Vol. 24, 2005.

[7] M.H. Afshar, “Partially constrained ant colony optimization algorithm for the solution of constrained optimization problems: Application to storm water network design”, *Advances in Water Resources*, Vol. 30, 2007.