

# Decision Support Independence in a Smart Grid

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**Abstract**—We describe a novel framework for designing and implementing agent based simulations of the smart electrical grid. The framework is based on two primary concepts. First, the electrical grid system is separated into semi-autonomous microgrids, each with their own set of hierarchically organized agents. Second, models for automating decision-making in the grid during crisis situations are independently supported. Advantages of this framework are scalability, modularity, coordinated local and global decision making, and the ability to easily implement and test a large variety of decision models. We believe that simulators based on this kind of framework will be valuable for evaluating the effectiveness and reliability of alternative methodologies for configuring automated self-healing in the grid with little human intervention. The primary achievement of work is the software design for directly supporting decision model independence.

**Keywords**—Multi-agent System; SmartGrid; Distributed Computing; Intelligent Systems; Self-healing.

## I. INTRODUCTION

A primary objective of smart grid software architectures is to provide intelligence and communications technology to support powerful and efficient automation. A power system is exposed to faults created by natural calamity, terrorism and equipment or operator failures. Once a fault occurs in a power system, it is necessary to quickly isolate the malfunctioning components from the rest of the network to minimize outages. A power failure can range in magnitude and impact from a relatively modest curtailment to a catastrophic regional blackout. Because most power failures cannot be prevented [6], it is desirable for the Smart Grid to have self-healing capabilities that respond appropriately to disruptions when they occur, restore the power system to a healthy state, minimize consumer outages, and involve little or no manual intervention.

Due to the large scale and complexity of the Smart Grid, anticipating all possible scenarios that lead to performance lapses is difficult [7]. There is a high degree of uncertainty in accurately estimating the impact of disruptions on the reliability, availability and efficiency of the power delivery system. These uncertainties result in hesitation on the part of decision makers in committing to smart systems for grid management. We report here on research that is focused on the use of simulation models to promote trust in Smart Grid solutions in safe and cost effective ways.

Recently developed Smart Grid simulators and analysis tools include GridLAB-D and the Graphical Contingency

Analysis (GCA). Both are projects developed at the U.S. Department of Energy's (DOE) Pacific Northwest National Laboratory (PNNL). GridLAB-D is a sophisticated simulator that provides detailed information of the power grid's state, including power flow, end-use loads, and market functions and interactions. The GCA is a visual analytic software tool that aids power grid operators in making complex decisions. By using human friendly visualizations and classifications of critical areas and by allowing the operators to simulate possible actions and their consequences, the tool helps human operators to analyze large amounts of data and make decisions in a reasonable amount of time. Due to the large amounts of data representing the grid status at any given time, even when aided by simulation and analysis tools, there are still limitations on how quickly human operators can make efficient decisions in near real time.

Because of the limitations of human operators in comparison with automated control, there is considerable research being done on how to fully automate control of the electrical grid by using software agents. A software agent is an encapsulated software system situated in an environment where it can conduct flexible and autonomous actions to meet its design objectives [2]. A Multi Agent System (MAS) is composed of multiple interacting intelligent agents that can sense, act, communicate and collaborate with each other. In our previous work [1], we presented guidelines for an agent-oriented smart grid simulation design. The agents in our MAS exhibit autonomy or partial autonomy, are decentralized, and have local views and knowledge. This design is related to other agent-based simulators that have been developed [4][5][16][17].

A fully automated grid relying on a multi-agent system will also presents some challenges and disadvantages along with its many advantages however. For example, developing agents able to function on par with human experts for the various scenarios that can happen in the smart grid, this will require a significant amount of research and experimentation. Relying on autonomous agents will also introduce a number of security issues. An agent could be hacked and controlled by an attacker who could manipulate the decisions and communications of the agent to perform malicious behavior. The trustworthiness of any particular agent or even the system as a whole could be called into question because of both the security risks and the general difficulty in replicating human expertise. Much must be done in order to overcome these inherent disadvantages of autonomous agent based systems.

Supporting knowledge bases and decision-making capabilities within individual agents is a key challenge in Smart Grid designs. In order to successfully evaluate intelligent systems that allow agents to employ appropriate decision models for self-healing scenarios that can occur in the Smart Grid, intensive testing should be done using simulators. We are carrying out extensive experimentation with our own simulator based on the discussed framework. The following types of questions are being answered through experimentation within the simulator.

- What decision model is most appropriate for handling self-healing in a particular situation in the smart grid?
- What decision model can guarantee that reliability and efficiency is maximized for a given power system?
- How can decisions be made quickly enough to avoid potential cascading failures, yet be deliberate enough to maintain high efficiency in the overall system?

Unfortunately, previous smart grid simulators, despite their valuable contributions, do not provide suitable simulation frameworks for answering these kinds of questions.

In this work, we present a simulator design aimed at directly supporting the research and experimentation required for full automation of distributed decision making in the grid. Our design assumes that the Smart Grid is naturally modularized into microgrids. A microgrid is a regional grouping of electrical generation, storage and consumption units that can be isolated from the centralized grid. microgrids typically have some ability to function autonomously if necessary. The new framework is fundamentally based on Distributed Control and Decision Model Independence. This paper is divided as follows: Section II discusses the previous research works in more details. Section III discusses the Distributed Control aspects of the simulation framework, including its advantages challenges. Section IV discusses Decision Model Independence. In section V we present our conclusions and describe future work.

## II. LITERATURE REVIEW

There have been several attempts to create simulation systems for a smart grid using multi agent systems. In one of the earliest works [3], the authors created an accurate hardware simulation of a simple microgrid using MATLAB and Simulink to model the functionality of low level electrical circuits. Their agent implementation was very simple, with voltage monitoring to activate a circuit breaker and secure critical loads, with no complex decision making. Their focus was on showing that a microgrid can be managed as part of the global grid and is still able to work autonomously in an islanded mode. Their simulation of agent interaction and collaboration was not thoroughly tested, evaluated or analyzed. Their contribution was valuable in showing that the smart grid could be modularized into smaller independent units with their own agents and that those modules could work autonomously and as part of the whole.

In [10], a centralized multi-agent framework for power system restoration was designed. In [11] and [12], improvements were done to the framework while still maintaining a centralized design. Multi-Agent systems that utilize centralized control are typically not able to respond quickly enough to perform global decisions and actions in near real time. Thus, such systems fall short of being able to address critical situations like a cascading failure that could have catastrophic consequences if not dealt with promptly. In

[13] and [14], new multi-agent frameworks for the power grid based on decentralized multi-agent systems are presented. The frameworks presented in [13] and [14] are decentralized multi-agent systems, but have the disadvantage of only allowing nodes to communicate with their neighbors. When nodes only acquire information from their neighbors, it greatly limits the quality of the decisions that the nodes can make, due to insufficient data. In [15], a hybrid multi agent framework that combined centralized and decentralized architectures was proposed. All of these approaches are topology dependent, with the exception of [14] and [15], which used a topology independent framework. By allowing the framework to work irrespective of the physical structure of the grid, a high level of flexibility and scalability can be obtained. Other agent-oriented Smart Grid designs are described in [4] and [5].

In [8] and [1], we describe our MAS simulator, including innovations in supporting power grid topology, dynamic agent generation, and scalability. The simulator is based on a topology independent framework that places the physical aspects of the power grid and the actual agents in separate independent layers.

A major goal of our simulator is to support the appropriate decision models for the various self-healing scenarios that can occur. This addresses the previously unmet need to allow researchers to easily configure the type of decision model used by the agents, to compare how agents perform in the same case scenario when using different reasoning processes. More importantly, we also address the need for researchers to develop their own models and easily integrate them in the simulator for testing.

The framework we present in this research work addresses many of the shortcomings of traditional centralized and decentralized schemes by utilizing a hierarchical distributed control scheme. It also supports direct comparisons among different decisions models, by implementing them in a separate independent layer from the agents. We see considerable potential for the simulator to help in the building of smarter electrical grid architecture.

## III. DISTRIBUTED CONTROL

To address the large size and complexity of the smart grid, we break the problems that were handled by a centralized controller into smaller problems handled by multiple distributed controllers. It is critical to utilize a granularity that allows the units to work independently and autonomously as well as to integrate and coordinate with each other in order to guarantee that the system works efficiently as a whole.

Our design is inspired by the concept of an Intelligent Autonomous Distributed Power System (IDAPS) that was proposed by the Advanced Research Institute of Virginia Tech. [9]. An IDAPS is essentially a microgrid that contains sufficient intelligence and resources to be fully autonomous, yet function within the global grid. We specifically design microgrids so that they are capable of disconnecting themselves from the rest of the grid under certain situations and work autonomously in islanded mode [3]. The intelligence in the microgrid handled by the multi-agent system associated with the microgrid and its quality depends directly on the multi-agent design employed.

### A. Multi-Agent Design

In our design, we establish hierarchical relationships among the agents, where the agents on higher levels supervise

those in the levels below. With this arrangement, an agent can either be entirely autonomous (acts on its own) or semi-autonomous (works under direction from a supervisor) [18]. In our framework, we implement a three level hierarchical system of agents, in which the agents in the second level are supervised by the agents in the first level and agents in the third level are supervised by those in the second. In general, this means that the agents in the first level exhibit full autonomy in that they act of their own accord without direct instruction, while the agents on the second and third layer act semi-autonomously in that they receive instructions from their supervisory agents.

In our modeling of autonomous micro-grids, we use a three layered design, the two upper layers of which consist of the two hierarchical agent levels as described above. The bottom layer is a simple hardware simulation called the physical layer. The purpose of this bottom layer is to mimic the behavior of the electrical components themselves. This layer simulates devices such as relays, transformers, capacitors, power lines, consumers and generators that run on their own, with no intervention or added intelligence. This separation between the intelligent agent layers and the physical simulation allows researchers to run two basic scenarios in the simulator, one, at the base hardware level without autonomous actions like the grid would normally operate, and another, using intelligent autonomous agent support.

The top layer, called the management layer, hosts the management agents that make the high level decisions. These agents are continuously sending data that represents the status of the microgrid at a given point in time. A management agent organizes, analyzes, and parameterizes models with the data, in order to detect situations in the grid that require healing. If such a situation is detected, it creates a strategy to handle the disruption and heal the system. This strategy is expressed as a set of different roles to be performed by the middle layer agents, known as corrective behaviors. The management agent is the main decision maker in our simulation framework, but the agents in the middle layer do have a certain amount of autonomy in how they carry out the high level decisions generated by the management agent.

We refer to agents in the middle layer as distributed energy resource (DER) agents, user agents, device agents, and control agents. These agents collaborate with each other as well as report to and follow the instructions of the management agents. We describe each in turn.

1) *User agents*: act on behalf of consumers to ensure that businesses, organizations, homes, or other electricity consumers have the power they need.

2) *DER agents*: act on behalf of the DERs within the microgrid. DERs are generation sources that are independent from the main power distribution circuit. These generators are typically small companies or special consumers that also participate in the power market, such as a wind power unit or geothermal generator. DER agents act on behalf of their generators by engaging in power supply negotiations with users.

3) *Device Agents*: act on behalf of the individual electrical grid components (such as switches and transformers). The device agent reports the device's sensor and meter readings to the control agents. It also has the ability to perform actions such as using a relay to reroute power, or closing a circuit breaker.

4) *Control agents*: are in charge of monitoring a section of the grid by collecting data from all of the agents in that area. These agents carry out data fusion and are sent on to the management agent as the representation of the current status of the system.

In order for the agents in the middle layer to communicate with simulated physical components in the first layer, it is fundamental to have middleware to facilitate the communication. This is achieved by encapsulating the bottom layer within an environment agent. An environment agent contains all information about the grid topology and all device status information at any given time. Middle layer agents can query the environment agents to gain information about the physical grid. They also communicate with the environment agent when they seek to alter the behavior of the physical grid. This simulates, at an abstract level, how the agents can be integrated with smart meters and other sensors in a real grid.

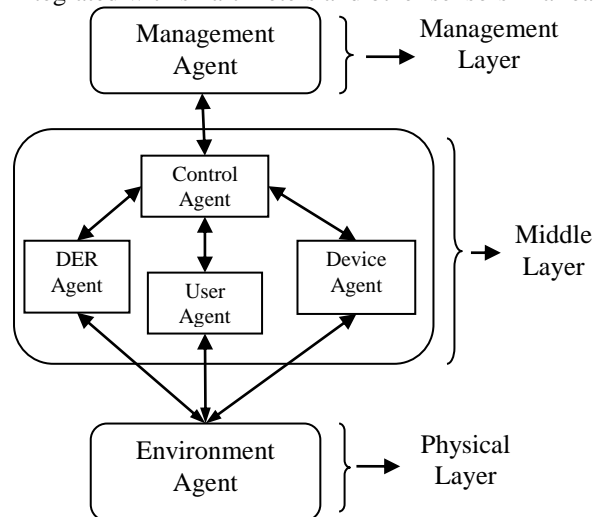


Figure 2. Graphical representation of communication between layers

Figure 1 shows a graphic representation of the communication flow between the layers, illustrating the kinds of intelligence that is integrated into each layer. High level decisions are carried out by a management agent, and the physical components with no intelligence reside at the bottom. The middle layer agents have limited intelligence.

#### IV. THE PRIMARY ADVANTAGES OF THIS FRAMEWORK USING DISTRIBUTED CONTROL ARE MODULARITY, SCALABILITY AND EFFECTIVE LOCAL AND GLOBAL DECISION MAKING

##### A. Modularity

The complexity of large systems such as the smart grid can be managed with a divide and conquer approach. As much as possible, each autonomous unit is responsible for managing and solving local problems that pertain to the unit itself. When a critical situation occurs in the unit it is simple to isolate that unit from the global grid to prevent the crisis from propagating to other sections of the grid, which happens easily for cascading failures. Modularity also allows the different agents within the microgrid to tune themselves and adapt to use the decision models and strategies that optimize resource usage and maximize efficiency for that particular microgrid, with its own topology, organization and operation.

### B. Scalability

Separation into well-defined independent autonomous units simplifies the process of testing at the unit level. Integration testing, referring to testing how the modules coordinate and integrate together, is also facilitated. The design supports the scalability of the system, because every microgrid enjoys autonomy in that all the subordinate agents in the microgrid report to their management agents and communication is done exclusively between elected management agents in each microgrid. This means that if we verify that a number of units work properly when tested independently and also work properly together when tested through integration testing, that is good evidence that adding more units would also scale well. The main purpose of our design is to allow for easy scaling of the system. With our approach we can create a larger macrogrid by connecting several microgrids together. It is convenient for a user to create a simulation of a large grid by developing several different microgrids in the simulator, followed by connecting them together.

Once a user has generated several microgrids and established connections between them, the simulator should give him/her some flexibility on how to run those microgrids. Many microgrids could be set to run on the same computer or one microgrid per computer. Therefore, the only limits to the scalability of the system are the resources available to the user. The simulator itself shouldn't have specific limits, since different instances of it can be run to support each microgrid, and the microgrids if connected can communicate and interact with each other.

### C. Local and Global Decision Making

In designing a distributed control system, it is often very difficult to coordinate effective local and global decision making. For example, in distributed systems, if agents are only able to communicate with neighboring agents, there is a severe restriction on the quality and quantity of the data that can be collected. For local decisions this restriction of data is acceptable for the decisions that are correspondingly limited in scope, but for global decisions this data restriction can easily result in ineffective and potentially harmful decisions. However, centralizing decision making and forcing the nodes to report to and be controlled by a single entity is also problematic due to excessive communication requirements. Our design combines the two extreme approaches by allowing local microgrid-based decisions to be handled locally, while still supporting certain global interactions.

Separating the extremely large and complex electrical grid system into small independent microgrids facilitates effective local decision making. These decisions are handled by the management agents contained in every microgrid. These agents constantly receive data reflecting the status of the local microgrid in near real time, and therefore are enabled to make decisions that optimize the local performance of the microgrid. However, there are circumstances under which it is desirable for microgrids to adjust their level of autonomy. This tuning of autonomy levels depends greatly on the specific decision model in effect in the management agents. We describe this in more detail in the next section.

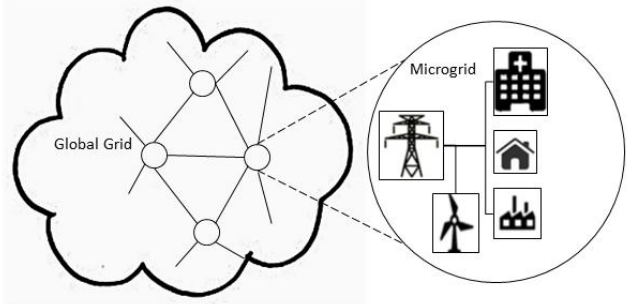


Figure 3. Local and Global Control Interactions

In the electrical grid, it is highly desirable to distribute decision-making. Our design allows each microgrid to essentially act as a single node in the larger grid. For example, If an individual microgrid requires electrical power from outside, it can communicate and negotiate with its connected neighbors establish a contract for that power. Under outage conditions, a microgrid node can island itself from its neighbors to avoid propagation of the disruption. Islanding to avoid cascading failures is described in [19]. A key advantage of a Smart Grid is the ability to access an open market for power with speed and agility [20]. This means that a microgrid node that requires additional power can access the power market, select its preferred provider based on attributes such as price or location, and then negotiate an automated contract with the provider in near real time. This ability can make significant advances in removing inefficiencies that are pervasive in the standard grid.

### V. DECISION MODEL INDEPENDENCE

We envision that the true promise of the Smart Grid lies in the development of multiple types of decision models that carry out their calculations automatically and trigger actions that are appropriate to the situation with little or no human intervention. The following types of decisions are candidates for automation:

- Power rerouting. When devices or power lines fail, models that are equipped with details of the network topology and distribution costs and parameters can be charged with rerouting power along alternative pathways. The decisions must avoid exceeding the capacities of the available lines and devices, honor reliability requirements, and head off possibilities for cascading failures.
- Resource allocation. When it is critical to rapidly access new or reserve power supply sources, the decisions must consider many available combinations and prioritize them in terms of their advantages and disadvantages. Cost, transmission distance and routing options, risks and reliability, and contract terms are all factors that must be included in parameterizing these models.
- Dynamic pricing. When it is advantageous to shift power sources or limit power consumption at prescribed times to achieve cost savings, dynamic pricing models can negotiate and establish new power supply schedules at reduced cost.

An important new innovation of our simulation framework is that of supporting the decision models independently within the design. By placing the decision model agents on an independent layer, the monitoring and action-oriented agents can carry out their functions with no encumbrance from extensive special interactions and communications. This is

accomplished through middleware that adheres to communication standards between the decision support agents and the others.

A. Decision\_Process

The management agents play a central role in the decision-making process. Management agents receive extensive near-real time data that characterizes the state of the system. The management agents are equipped with meta-level reasoning capabilities that determine if the current state of the grid is acceptable or in need of healing. In the latter case, it generates a strategy that is evaluated by calling upon decision model agents that carry out and return results aimed at corrective actions.

Multiple decision models have been designed and prototyped and are at some stage of maturity. These include the following:

- Integer linear programming. These models are capable of identifying optimal rerouting options and resource allocations. They are designed for decomposition so that local management agents can invoke only the portions of the global model that pertains to their microgrid.
- Fuzzy logic. These models are based on fuzzy set membership functions that capture degrees of fit with key resource allocation parameters, such as cost, distance, risk and reliability. The fuzzy sets drive a rule-based expert system that produces the suggested allocations. Although heuristic in nature, this type of decision model can function very quickly and easily in near-real time decision making.
- Bayesian Belief Networks. These models are based on probabilities associated with system states. These models are capable of polling the grid for additional information that forms the basis for producing posterior probabilities with enhanced accuracy.
- Market-driven pricing models. These models work within a market economy in which energy resources are traded. This type of model includes dynamic pricing based on smart building and smart meter infrastructure, and provides an area of great promise in improving grid performance and efficiency.

In general, state variable data is made available via middleware in an Application Programming Interface (API). A key advantage of this approach is that researchers are free to readily test the models above as well as any other developed decision model. The model builder must convert data from the API to match the data types of the decision model. This method is analogous to the presentation layer in the OSI networking model.

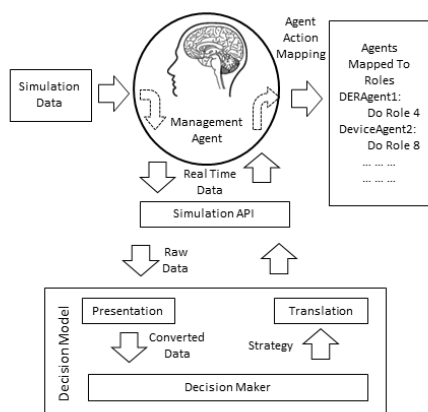


Figure 4. Decision Model Design & Decision Process in our Framework

After a decision model is invoked, it has defined a set of actions and corrective behaviors that can ultimately be carried out middle layer agents.

B. Adjustable\_Agent\_Autonomy

In some cases it is desirable for certain agents to be only semi-autonomous in that they make decisions only in a context controlled by a management agent. For example, a semi-autonomous user agent may have preferences and configurations that can be compromised by a decision model for the betterment of the microgrid. Fully autonomous agents must adhere to their settings regardless of decision model recommendations. Semi-autonomous agents have a “wait” state in which they take actions to deal with a problem only upon a directive from a management agent.

Management agents can strategically choose to elevate the autonomy level of a semi-autonomous agent, based on the current decision model and system state. For example, a component of a management agent strategy to heal the system could be to promote some semi-autonomous agents to fully autonomous status either temporarily or permanently. The inherent flexibility of adjustable autonomy is a powerful capability that allows an agent-oriented system to respond to events that cannot be foreseen. It is critical that an agent-based system for a large complex system such as the Smart Grid support only agents with a high level of trust, to alleviate suspicions expressed by people that agent decisions could go awry. Adjustable, situated autonomy increases the level of trust. Thus, we believe that adjustable autonomy is an important element of decision making in the Smart Grid.

The key advantage of Decision Model Independence is the ease in experimenting with and evaluating alternative decision models. Any single scenario can be evaluated with multiple models for side-by-side comparisons.

VI. CONCLUSIONS

Distributed multi-agent control accomplishes modularity, scalability, and a balance between locally and globally effective decisions. We have discussed the advantages of an agent-based framework as a methodology for fully automating the electrical grid. By supporting decision models separate from the monitoring and action agents, alternative models can be easily evaluated. Adjustable and situated agent autonomy adds further depth and power to the design.

VII. REFERENCES

- [1] Boughosn, S., P. Ranganathan, S. Salem, J. Tang, D. Loegering, and K. Nygard, Agent-Oriented Designs for a Self Healing Smart Grid, First IEEE International Conference on Smart Grid Communications, pp. 461-466, 2010.
- [2] Jennings, N. and Wooldridge, M., Agent-Oriented Software Engineering, Artificial Intelligence, vol. 117, pp. 277-296, 2000.
- [3] Pipattanasomporn, M. H., Feroze, and S. Rahman, Multi-Agent Systems in a Distributed Smart Grid: Design and Implementation, IEEE Power Systems Conference and Exposition (PSCE'09), pp. 1-8, 2009.
- [4] Noorian, S., H. Hosseini, and M. Ulieru, “An Autonomous Agent-based Framework for Self-Healing Power Grid,” IEEE Conference on Systems, Man and Cybernetics, pp. 1983-1988, 2009.
- [5] Karnouskos, S. and T. Nass de Holanda, Simulation of a Smart Grid City with Software Agents, Third European Symposium on Computer Modeling and Simulation, pp. 424-429, 2009.
- [6] Solanki, J., S. Khushalani, and N. N. Schulz, “A Multi-agent Solution to Distribution Systems Restoration,” IEEE Transactions on Power Systems, vol. 22, no. 3, pp. 1026–1034, 2007.

- [7] Lemmon, M., G. Venkataramanan, G., and P. Chapman, Using Microgrids as a Path towards Smart Grids. Position Paper, ICEE Workshop, 2009.
- [8] Nygard, K., S. Bou Ghosn, D. Loegering, M. Chowdhury, M. Khan, R. McCulloch, A. Pandey, and P. Rangnathan, Implementing a Flexible Simulation of a Self-Healing Smart Grid, International Conference on Modeling, Simulation and Visualization Methods, pp. 106-111, 2011.
- [9] Rahman, S. M., Pipattanasomporn, and Y. Teklu, Intelligent DistributedAutonomous Power Systems (IDAPS), IEEE PES Annual General Meeting, Tampa, Florida, pp. 1-8, 2007.
- [10] Nagata, T. and H. Sasaki, "A Multi-agent Approach to Power System Restoration," IEEE Trans. on Power Systems, vol. 17, pp. 457-462, 2002.
- [11] Nagata, T., H. Fujita, and H. Sasaki, "Decentralized approach to normal operations for power system network", Proc. 13th International Conf. on Intelligent Systems Application on Power Systems, Cambridge, pp. 407-412, 2005.
- [12] Momoh, J. and O. Diouf, "Optimal Reconfiguration of the Navy Ship Power System Using Agents," Proc. IEEE PES Transmission and Distribution Conf. and Exhibition, Dresden, pp. 562-567, 2006,.
- [13] Nordman, M. and M. Lehtonen, "Distributed Agent-based State Estimation for Electrical Distribution Networks," IEEE Trans. on Power Systems, vol. 20, pp. 52-658, 2005.
- [14] Solanki, J., S. Khushalani, and N. Schulz, "A multi-agent solution to distribution systems restoration," IEEE Trans. on Power Systems, vol. 22, pp. 1026-1034, 2007.
- [15] Sutanto, D, Y. Ye, and M. Zhang, "Design of an Intelligent Self-Healing Smart Grid using a Hybrid Multi-Agent Framework", Journal of Electronic Science and Technology, vol. 9, pp. 17-22, March 2011.
- [16] Hossack, J., S. Mcanhur, J. Mcdonald, J. Stokoe, and T. Cumming, A Multi-agent Approach to Power System Disturbance Diagnosis, In Proc. International Conference on Power System Management and Control,, Vol. 488, pp. 317-322, 2002.
- [17] McArthur, S., E. Davidson, J. Hossack, and R. McDonald, Automating Power System Fault Diagnosis through Multi-agent System Technology, Hawaii International Conference on System Sciences, pp. 947-954, 2004.
- [18] Camponogara, E. and S.N. Talukdar, Agent Cooperation: Distributed Control Applications, International Conference on Intelligent System Application to Power Systems, pp. 1-6, April 1999.
- [19] Pahwa, S., A. Hodges, C. Scoglio, and S.Wood, Topological Analysis of the Power Grid and Mitigation Strategies Against Cascading Failures, IEEE International Systems Conference, 2010.
- [20] Ketter, W., J. Collins, J., and C. Block, "Smart Grid Economics: Policy Guidance Through Competitive Simulation," ERIM Reprot Series, 2010.