The Smart Grid, A Scale Demonstration Model Incorporating Electrified Vehicles

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DESCRIPTION AND OBJECTIVE OF RESEARCH

The current electrical grid cannot maintain the rising energy demand of the digital age without the construction of new power plants. In addition, this increasing demand requires upgrading a large number of components within the aging energy infrastructure. Furthermore, with the advent and commercialization of electrified vehicles, energy demand has the capability to increase dramatically. A sustainable solution via renewable energy technologies can act to offset this increased demand; however, transformers and meters across the country do not currently account for this option. As a result, a wholesale revision of the electrical grid into an intelligent communication pathway (energy and information) is required to ensure the energy security of the United States.

Supported by the EPA P3 initiative, the current small-scale stage of the EcoHawks design project involves creation of a smart energy infrastructure that integrates solar and wind renewable energy, electrified vehicle technologies, and information transmission in order to optimize energy resources and maximize overall system efficiency. The smart grid system focuses on accomplishing the two main objectives of the Department of Energy's requirements for an intelligently designed electric grid:

- Decentralization of energy production and storage
- Two-way communication from end users or appliances and the energy network.

It decentralizes energy production through deploying multiple renewable energy resources that can generate and manage power locally, leading to precision control of the electrical grid. Renewable energy is captured using both a student-built 45W solar panel and a 50W wind turbine to charge two separate battery banks, modeled by two deep cycle lead-acid batteries. Storing this energy within the system ensures that even when solar and wind systems are not actively producing power, there is still renewable power available for consumption. Moreover, further decentralization occurs by employing the $LiFeYPO_4$ battery pack of a PHEV/BEV as a reserve or dynamic storage bank. Use of a commercial vehicle in this manner can lower greenhouse-gas emissions, improve urban air quality, save consumers money, bolster power-grid reliability and reduce oil imports.

The application of a smart grid allows for simple additions to the grid in terms of both energy production and storage, but this energy must be controlled in order for it to be used effectively. Thus, two-way communication between energy producers and consumers has been established using a LabVIEW program in which users can track and record all energy and efficiencies. Moreover, this program can control the flow of energy throughout the different subsections of the smart grid in order to maximize efficiency. It monitors power production and the reserve capacity available in the different decentralized storage mediums. Effectively, this system minimizes the usage of fossil-fuel power generation by prioritizing renewable energy and only using fossilized or petroleum power (modeled in the system with a gasoline generator) when the renewable power supply is insufficient to meet demand. Currently, the system employs manual switches in order to facilitate testing; however, the upgrade to digital switching is immediately available and plans are underway to implement its usage.

In order to facilitate this control, the system is outfitted with numerous sensors connected to National Instruments (NI) hardware. With these sensors in place, the user can be updated with information regarding the use of the system through the LabVIEW program. This allows the user the ability to fine-tune the system to their needs, or troubleshoot a malfunctioning system. Additionally, the sensors allow the LabVIEW program to calculate efficiency losses, both within individual parts of the system, as well as over entire subsections of the smart grid.

One final aspect of the system is the inherent need for power conversion within the sources, storage units, and sinks. While the modern electrical grid uses AC power, many components within the smart grid do not, namely the battery and renewable energy generation systems. For maximum functionality, inverters convert DC power from the batteries into AC power useable by the control system, appliances, and the battery management systems. The inclusion of multiple inverters adds a degree of freedom to the system's ability to control the flow of energy between sources and sinks at any one time.

PHEV and BEV technology creates another opportunity for the smart grid to store and use renewable energy. Through enabling energy and communication flow in both Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) systems, the smart grid utilizes the battery systems of these vehicles as auxiliary storage in order to help buffer the supply and demand of energy at peak hours, such as the evening work rush hour. For example, this can be accomplished by charging the car's battery pack at night when energy demand on the grid is low, with subsequent selling back of any excess energy at peak hours for a profit. The smart grid control system would be able to buy back energy from the electric vehicle owner in order to supplement the power supply. Moreover, this promotes efficiency of conventional power plants by limiting cyclical operation and wasting of resources at night by dumping energy.

The scale grid includes a popcorn maker as a model appliance demonstrating the end of the energy flow line. This allows for testing and sizing of the battery systems in order to ensure sufficient capacity for storage of renewable sources. Moreover, smart appliances in the future will be able to interact with the grid demonstrating a future objective of the system to integrate new technologies in the home, business or industry. Finally, the choice of popcorn maker demonstrates the insight of the students to include a sustainable solution in all areas. Little waste is generated in running the appliance, as hungry EcoHawks always need to eat.

SUMMARY OF FINDINGS (OUTPUTS/OUTCOMES)

After assembly of the scale grid, the EcoHawks tested all of the components allowing for a systematic methodology in debugging and troubleshooting the system. Both of the renewable sources of energy were successfully implemented with the solar panel proving to be a reliable source of energy, even under less than favorable weather conditions. In hazy weather, the panel produced 18VDC at a range of 1.5 to 2.5A, and successfully charged one lead-acid battery by 0.1VDC in 2 minutes and 30 seconds while charging the other lead-acid battery by 0.18VDC in just under 5 minutes. The wind turbine has an effective efficiency of 16% in 20 mph winds, after applying Betz's Law, which provides sufficient charge in order to maintain battery capacity through float charging.

For proper usage and lifetime of the PHEV/BEV battery pack, the system employs a Battery Management System (BMS). This device demonstrates proper balancing of individual cells promoting the lifetime of the pack ensuring maximum customer return on investment. Moreover, using a relay it provides the ability to charge a pack safely ensuring over-voltage does not occur. In addition, to prevent excessive discharge of the pack, the BMS controls another relay that cuts the power flow when the pack voltage becomes too low. This demonstrates a proof of concept for the eventual conversion to an automated system in replacing the manual switchboard with a series of computer-controlled relays. It also establishes the methodology of using the PHEV/BEV battery pack as a dynamic storage medium where renewable energy can be stored and used without compromising the ability of the vehicle.

Use of renewable energy to power the appliance was proven by running the popcorn maker off the lead acid batteries individually. Experimental data finds that popping a full batch of popcorn took four minutes for a cool kettle (soaked overnight); whereas, it took two minutes and 30 seconds for a pre-heated kettle. During this experiment, the batteries were drained by approximately 0.10 to 0.15VDC per run, entirely dependent on the time taken to test. Unfortunately, the low capacity of the PHEV/BEV batteries tested (3.6Ah) was not able to provide enough power to make a full batch of popcorn; however, it was able to power the appliance for 35 seconds before being shut down by the BMS. Additional testing using the control computer with a lower power draw demonstrates that the PHEV/BEV batteries could power this device for approximately 8 minutes. Future efforts involve adding more capacity to this pack through a parallel cell arrangement along with testing of a similar 90Ah battery targeted for the current GMC Jimmy BEV conversion. This further illustrates the novelty of the phased approach of the EcoHawks program.

The LabVIEW control program and attached sensors were tested for accuracy against a multimeter, and were found to be operating normally and without significant error. The program was able to generate an output value for any AC current flowing within the system in ten seconds, and can perform the same for a DC current in one second. Because of the sinusoidal nature of AC current, a root mean square averaging is utilized to provide a low standard of deviation of the current value. Efforts are underway at investigating available sensors and calculation methodologies to improve this time frequency. All voltages in the energy grid are being measured and validated using a multimeter. Data collection has begun using the main LabVIEW Graphical User Interface (GUI) on an average value basis with sub-GUIs providing a time-history of the signals.

CONCLUSIONS

The scale smart grid designed and built by the EcoHawks successfully demonstrates the feasibility and potential for intelligent energy management technology in order to enhance traditional power systems. It incorporates electrified vehicle technologies, solar and wind energy as well as two-way communication between power production and consumption. By tying these entities together, better matching of the energy infrastructure with the supply and demand of power can reduce the use of conventional (fossil fuel, petroleum) power production in favor of renewable resources. This smart grid model implements a control system with the capability to manage the flow of energy in order to maximize energy efficiency. A large-scale version of the EcoHawks design can act to meet the increasing energy demand without the need to build new power plant facilities. Systems like these are necessary to reduce greenhouse gas and hazardous emissions while prolonging finite fossil fuel resources.

FUTURE WORK OBJECTIVES AND STRATEGIES (PHASE II)

For Phase II, the insights gained from the scale smart grid constructed in Phase I will be used in order to convert the EcoHawks student design laboratory into a complete smart grid including an electrified vehicle refilling station with attached renewable energy generation. Hence, the building will provide additional power for use with the fleet of electrified vehicles being recycled from older vehicles and tested to replace current petroleum-based vehicles used on campus.

The full-scale smart grid will feature an expansion of an existing solar array through additional solar panels and solar shingles on the facility. In addition, university administration approval is pending on the addition of a wind turbine at the facility. Expanded renewable energy generation will eliminate the need for centralized power generation, such that the design laboratory may become carbon neutral, reduce emissions and improve sustainability. In addition, EcoHawks will add to the control system in order to incorporate additional sources and sinks, automate switching and to optimize efficiency. Further research improvements will come from use of automotive simulation software, particularly AVL Cruise and Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET) from Argonne National Laboratory. These models will aid in improving the applications of V2G and G2V energy transfer. Moreover, their use will foster a macroscopic investigation into the future place of electrified vehicles in the market and their impending stress upon the electrical grid.

In the long term, successive iterations of this research and development program will provide incremental improvements to the efficiency, size, weight, cost, and ease of use of the overall system. Therefore, the system will become more practical over time, with the ultimate goal of appealing to a wide variety of companies, governmental bodies, or individual consumers. Finally, the EcoHawks actively publish their efforts and present at conferences in order to facilitate widespread dissemination of outcomes. This will continue to be a focus throughout Phase II along with the translation of this information onto a K-12 level. The phases indicated and associated efforts of all of the students and interdisciplinary partners illustrate the EcoHawks commitment to sustainability through the five E's of energy, environment, economics, education, and ethics.

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