# Combined Studies of Power Electronics and Communication Networks for the Smart Grid

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***Abstract*--The modernization of the current power grid has brought forward many requirements in order to make possible the vision of a smarter grid. This paper presents these challenges and the current achievements in order to aid in its transformation. It identifies developing applications within the power network; from centralized generation to distribution in terms of power electronics, power systems, and communications. A summary of the current undergoing studies in a lab setting geared towards solving the needs of the smart grid is described. Furthermore, a case study which emphasizes the communication, control, and simulation aspects for the smart grid is expressed and results are displayed in detail.**

***Index Terms*-- Smart grids, real time systems, solar energy, communication networks, power grids.**

## I. INTRODUCTION

THE rejuvenation of the current power grid has brought forward many ideas for which power electronics, and communications play a fundamental role. In different levels of the power grid, such as centralized generation or distribution, solutions and research is needed in order to make possible this vision of a smarter grid [1], [2]. In [3], these challenges were categorized into four aspects; environmental challenges, market/customer needs, infrastructural challenges, and innovative technologies.

In Figure 1, an overall description of the applications/needs within power grid is introduced in terms of innovative technologies in power electronics. The system could be divided into three areas:

a) *Generation:* At this level, new emerging types of energy such as Nuclear Fusion, large Scale Photovoltaic (PV) systems, and wind generation (WG) are amongst the most promising. In nuclear fusion, one of the main challenges for power electronics is the need for reliable power supplies (ac-dc or dc-ac) for neutral beam injection, plasma stabilization, etc. [4]. As for PV and WG systems, efficiency, costs, and reliability of power electronics converters are some of the main aspects for future development.

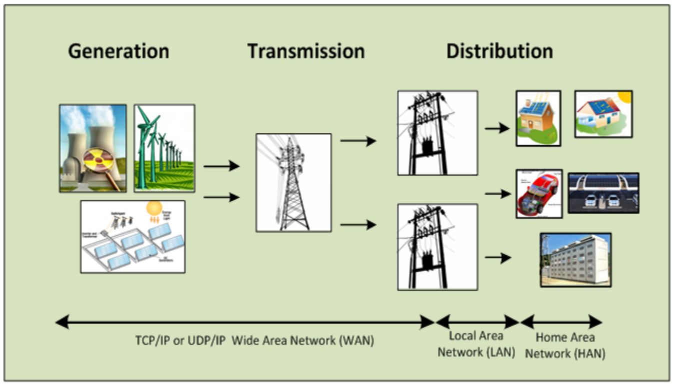

Fig. 1. Advancements in Power Electronics within Power Systems

b) *Transmission:* Flexible AC Transmission Systems (FACTs) devices are used to control the power transfer of interconnected AC systems [5]. They allow for a change in the system voltage and line impedance. Other applications to transmission systems include line monitoring and energy harvesting. With the demand for a smart grid, the new transmission lines planned for the next two decades have made real time monitoring of the lines more meaningful [6].

c) *Distribution:* This is perhaps one of the top levels of development in recent years as concerns to the smart grid. With the introduction of Advance Metering Infrastructure (AMI), distributed energy resources, PHEVs, and energy storage, the future at the distribution level seems very promising. Moreover, communications will play a major role in control and management of Distributed Energy Resources (DER) within the distribution level [7].

In general, a combination of power electronics, communications, and controls play an important role for new developments and realizations within an intelligent grid.

This paper is organized as follows: Section II presents a further step in categorizing recent research needs in terms of physical and simulation layers. In addition, it introduces the current research at The Ohio State University (OSU) in these two layers. Section III discusses a case study for simulation which integrates power and communication networks. Finally, a conclusion and future work is presented.

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## II. Summary of Current Research

Present power systems research could be further subdivided into two areas: physical layer, which includes power electronics circuits, switching devices, etc. and the simulation layer, which combines the physical layer with control and communications as a research platform. The following describes the current research performed on these two sections.

### *A. Physical Layer*

Within the physical layer, emerging devices such as AlGaN/GaN exhibit interesting characteristics such as higher electron mobility, greater electrical field, higher sheet carrier concentration, and larger saturation velocity when compared to silicon devices [8]-[10]. In addition, a feature of study is the third quadrant operation of these devices which up to date, very little research has been discussed in this topic.

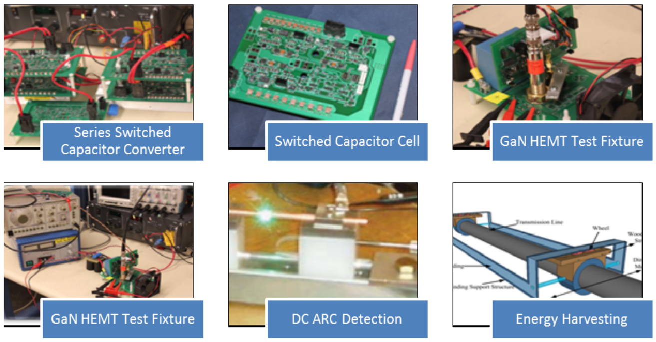

Fig. 2. Power Electronics Projects under Development.

With concerns to power electronics converters, switched capacitor circuits are gaining popularity due to their smaller size in comparison to more conventional dc-dc/dc-ac converters. Achieving a higher power rating switched capacitor converter is of present interest in order to apply them to applications such as electric vehicles or power grid [11], [12].

Other topics of research include dc arc detection, and energy harvesting. Due to the growing numbers of high voltage dc networks in applications such as electric vehicles, naval vessels, PV panels, etc. DC arc detection is of importance for the protection of these devices. Lastly, a method for harvesting energy in high voltage transmission lines has been studied for its use on power sensors and communication devices. Ideally, as strategic assets, transmission lines need to be monitored and maintained closely to ensure safe and reliable operation. The related monitoring and maintenance aspects include line temperature, line sag, icing, broken strand, corona, etc. [13], [14]. Figure 2, provides a brief description of the physical layer topics presently under work.

### *B. Simulation Layer*

The simulation layer works to combine physical layer together with control and communication. Although there is highly advanced technology in areas such as communication and power electronics, sufficient research and validation of these tools is necessary prior to large scale implementation [15]. Furthermore, newly developed real time hardware in-the-loop (HIL) machines provide a test platform for power electronics devices such as the ones discussed in the previous section. Figure 3 displays the current real time HIL system used for these goals.

Fig. 3. Real Time HIL System for Simulation of Power Systems.

An example of real time HIL simulation for testing different characteristics of micro grids was proposed in [16], where a model containing two renewable energy sources and two inverters was run in real time with a switching frequency of 1 kHz. Another illustration is given in [17], where a real time model of a power network was combined with a physical remote control center to provide a link to assess cyber vulnerabilities when testing fault detection, breaker control, etc. Although real time HIL simulation platforms have been discussed in academia, most focus on one aspect in modeling, either continuous (power electronics, power systems) or discrete (communication networks). The project currently under work is incorporating these two elements into one test platform in order to model more closely the characteristics of the smart grid. This project is explained in more detail in the following section.

## III. Case Study

A case study is performed in this section to show the current simulation platform and its contribution on the combined study of power electronics and communication networks in the smart grid.

### *A. Platform Introduction*

A description of the current setup for real time Hardware in the Loop modeling is presented in Figure 4. It consists of 4 target machines with a total of 6 CPUs, 32 cores, 4 FPGA chips, and more than 500 analogue and digital inputs/outputs. Each target machine is connected together through a high speed, low latency Dolphin link [18]. This system can run a complex power system model with a maximum of 32 subsystems, with each subsystem capable of separate local real DSP controller for hardware-in-the-loop operation. With the technology of parallel computation and switch event interpolation [19], the switching frequency in a real time simulation can achieve up to 10 kHz even with a large number of switching devices.

The current configuration permits multiple users to connect simultaneously to the system to perform collaborative simulations. One master simulation contains the main grid model and multiple clients can attach simulation components to the grid such as FACTs devices, renewable energy sources, etc. Distributed control with real controllers can then be tested at the same time to study the behavior of a fully integrated power grid.

When combined with a discrete network emulator, the system can provide advantages to simulating the influence of communication in a power network in a cost effective manner. The communication and control units are linked with the real time targets by an Ethernet connection. Relevant information (e.g. voltage, current, breaker status) is packaged and transferred between control units through a virtual communication network, in which the effects of latency, bandwidth, package losses, etc., can be introduced and studied.

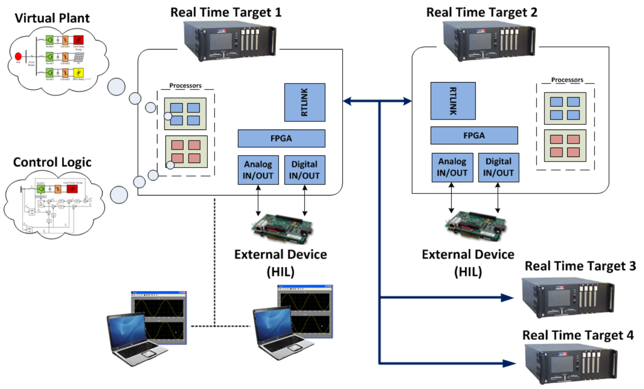

Fig. 4. Research platform structure.

Several software packages were considered for the network emulator. NS2 [20] is an open-source network simulation package which has the capability to operate as a network emulator, accepting real-time network traffic and simulate either wired or wireless networks. The live traffic can be interpreted as either opaque or protocol data packets. Since NS2 was mainly developed in the academic and open-source community, there is no corporate support available; however, a large community of support exists online. DummyNet [21] is another open-source tool which has been used for real time emulation; however, it is not as well developed and it is mainly programmed to serve as a static emulator.

When considering commercial network emulators, Exata [22] and OPNET [23] are two important options. Exata is a network emulator developed by Scalable Network Technologies (SNT) based on the popular QualNet network simulator. It has the ability to simulate parameters such as terrain, cyber attacks, and static parameters. Although Exata can be used for system in the loop applications, it is mainly focused for simulation in the military industry. OPNET is a well-developed network simulator used extensively in research. The university license for OPNET allows for significant flexibility in terms of network development, this combined with the integrated support of many well-known communication protocols, makes OPNET an excellent option for this case study.

The system in the loop (SITL) models from OPNET allows the communication and power simulation network to run jointly in real time. Each key power network device will be assigned its own IP subnet; and therefore, will require the simulated network to route packets between the power network devices. In addition, different types of virtual networks such as wired (e.g. Ethernet, fiber optic) or wireless (e.g. Wi-MAX, satellite) can be simulated depending on the application required.

### B. Model Description

An example of a micro grid consisting of a PHEV charging station, Local Energy Storage (LES), and a renewable energy resource (photovoltaic) is built with the proposed system. Intentional islanding, and load shedding operation scenarios are implemented in the model. The influence of communication between controllers and sensors will be tested. In addition, control has been implemented from the dc side Distributed Energy Resources (DER) in order to achieve a smooth transition during islanding.

In grid connected mode, a multi-loop controller is used for all utility interactive inverters shown in Figure 5. The objective of this controller is to keep the dc-link voltage constant. The outer loop consists of a voltage loop with dc-link voltage as feedback. The inner loop is a grid current control loop, with the active current reference generated by the outer voltage loop and reactive current reference set to 0.

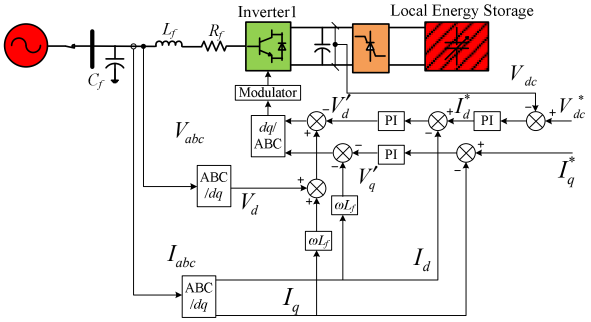

Fig. 5. The control strategy of utility interactive inverter during grid-connected mode.

During islanding, the controller is very similar to the one in grid connected mode, with the main difference that for the LES inverter, the ac bus voltage is used as feedback in the outer loop. The reason is that during loss of the grid source, the objective of this controller is to keep the ac bus voltage constant. The inverters and converters of the PV, noncritical load, and batteries keep the same strategy as in grid connected mode. Figure 6 provides an illustration for the island mode converter control.

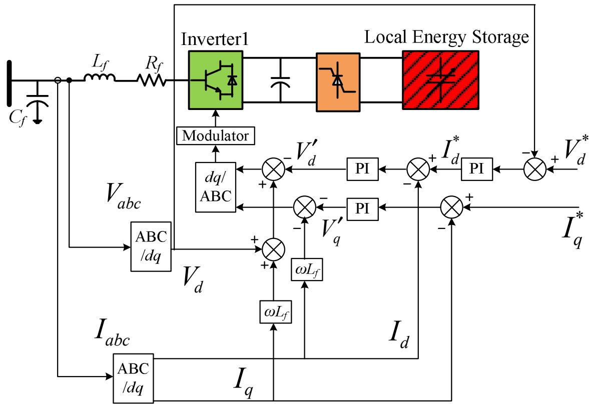

Fig. 6. The control strategy of LES-connected inverter during islanding mode.

The model is split into two targets as shown in Figure 7. RT1 contains the grid source along with the DERs, while RT2 contains the critical and noncritical loads. The noncritical load is simulated as a PHEV charging station, composed of three batteries. The communication network is composed of four nodes; the sensing unit from the LES, main CB signal, PHEV load controller, and the server which could function as an external control center. The communication is achieved through a virtual Ethernet network and each node is placed at different distances, obtaining dissimilar delay values for different communication paths and applications (e.g. control, protection, etc.).

When a three phase fault occurs from the grid side, the main circuit breaker will open and send a signal to the load controller which will disconnect the noncritical loads. Then, the PHEV batteries will be connected back to the system one by one. As this process occurs, the dc bus voltage on the LES is measured and sent to the switch controller of the loads periodically through the virtual network for monitoring. Within the network, parameters such as latency, bandwidth limitation, and packet losses are introduced. A drop on the dc bus voltage signifies that there are more loads than the LES and PV can sustain, thus, the last load added to the system will be disconnected and the process of reconnecting loads is stopped.

## C. *Simulation Results*

Real time simulation results are presented which tests the influence of the communication network on the model described previously. The details of the power capacity of each unit within the system are shown in Figure 7. The LES and PV can supply a total of 11.5kW, while the PHEV charging station and the critical load require 12kW (4kW/battery) and 1kW respectively. The normal dc bus voltage is 800V and its threshold level is 700V.

Figure 8 and 9 shows the results for two types of communication. The first situation assumes no delay or instantaneous data transfer between the different nodes in the network. In the second case, delay, bandwidth, and packet losses are introduced in the virtual communication network.

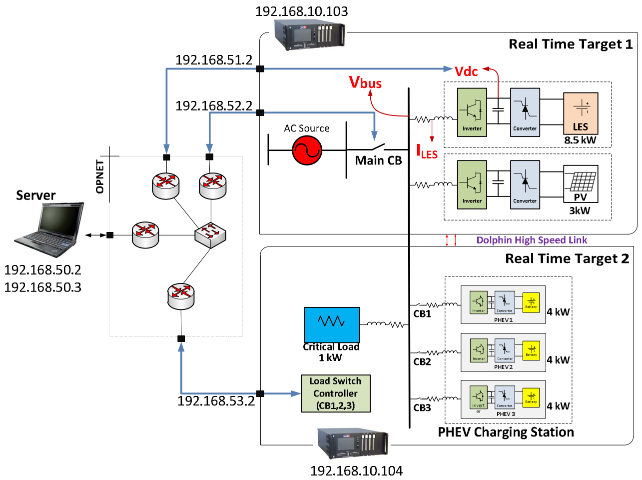

Fig. 7. Simulation Model.

In the first case, an interruption from the grid side occurs at t1, the main CB opens, and all the noncritical loads are disconnected. At t2, the first PHEV battery is connected to the system, while the rest are attached every 0.1s afterwards. At t4, switch CB3 is closed and the third PHEV battery is added. Since at this time the DERs do not have enough power to supply the load, the dc bus voltage on the LES side begins to drop. When the voltage drops below 700V, the last load added to the system is re-disconnected, allowing the dc bus voltage to return to its normal value.

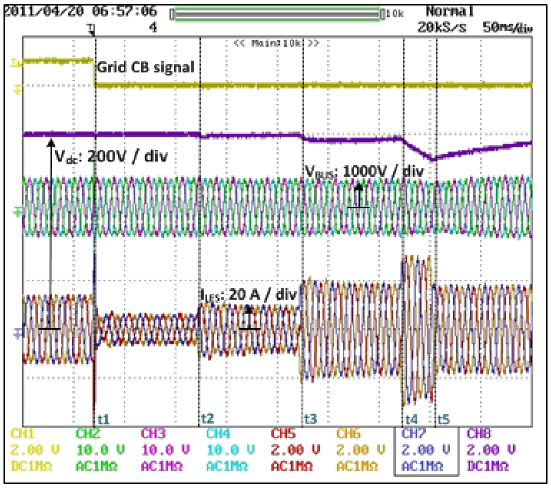

Fig. 8. Simulation result with no delay.

In the second case, the effects introduced by the communication network are more notable. The same scenario is utilized. However, due to the delay introduced by the network, two factors are visible: there is a larger disturbance when the main circuit breaker is disconnected, and the actual voltage measured on the dc bus drops below the threshold voltage.

Typical protection systems require fast response and low latency communications. This type of communication is assumed from the CB to the load controller. Although the delay from the CB signal to the load controller is short (~5ms), there is still a larger disturbance when compared to the case with no delay. Secondly, the drop in voltage below the threshold value is partly caused due to the delay of approximately 30ms in the communication between the LES and the charging station.

These disturbances could cause problems to the LES and the critical load, since it is also shown that there is a bigger disturbance in the ac side voltage. In addition, this scenario displays the importance of a combination of power and communication systems modeling for the smart grid.

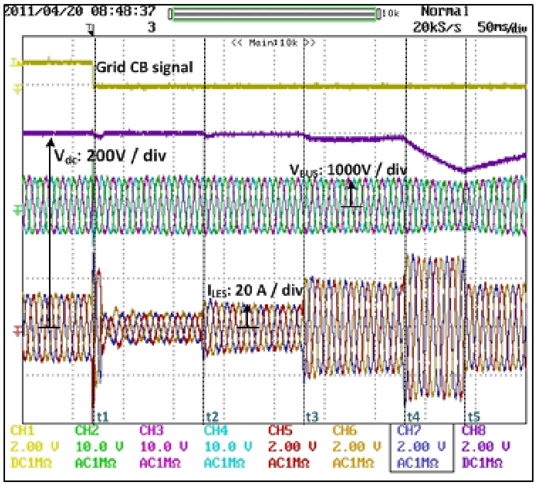

Fig. 9. Simulation result with 30 ms delay.

## IV. CONCLUSION AND FUTURE WORK

A description of the current applications for power electronics with a focus on smart grid is presented in this paper. These applications are categorized in three areas: generation, transmission and distribution. Furthermore, the undergoing research projects which aim to aid in solving challenges related to different levels within power systems are described. These projects are seen from a physical and/or simulation layer perspective.

A case study on real time simulation of a micro grid model is discussed and results are presented in detail. This model showcases the importance of a combined simulation of communication systems and power systems for smart grid research. Without the communication network simulation, the actual system response is not accurately reflected. Future work will continue to provide solutions to the aforementioned challenges and needs in the smart grid.

## V. ACKNOWLEDGMENT

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