EXPERIENCE FROM CONSTRUCTION OF A SMART GRID RESEARCH, DEVELOPMENT AND DEMONSTRATION PLATFORM

Nicholas ETHERDEN
STRI AB – SWEDEN
nicholas.etherden@stri.se

Michael GUDMUNDSSON
STRI AB – SWEDEN
michael.gudmundsson@stri.se

Mats HÄGER
STRI AB – SWEDEN
mats.hager@stri.se

Henrik STOMBERG
STRI AB – SWEDEN
henrik.stomberg@stri.se

ABSTRACT

This paper presents experience from the construction of a Smart Grid Research, Development and Demonstration (RD^2) platform. The first stage of the platform consists of a small solar, wind and fuel cell-plant with battery, super capacitor and hydrogen energy storage systems. Emphasis during the development of the platform has been on construction of an up-scalable control system and the AC/DC network infrastructure.

INTRODUCTION

The integration of large amounts of small scale intermittent energy resources like solar, wind and small scale hydro power can be facilitated with coordinated control of local production and consumption. Small scale energy sources will produce electricity with various voltages, including DC. The difference in frequencies is an additional challenge when combining them into one source that behaves as a single generator.

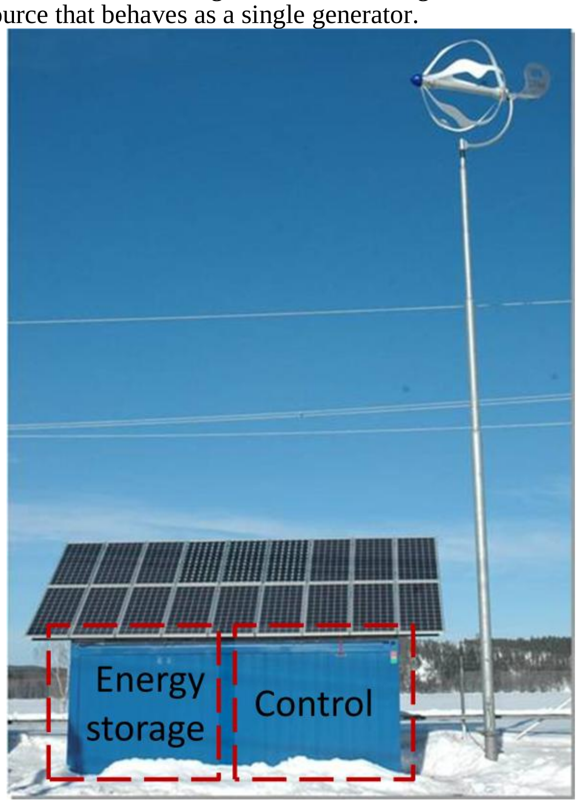

Figure 1. The Smart Grid Research, Development and Demonstration (RD^2) platform is a modular container solution with solar, wind and fuel cell production. Energy storage is with batteries and hydrogen gas.

To be able to compensate for the varying production from intermittent power sources improved methods of energy storage need to be developed. The energy storage may consist of storing electricity in battery packs or conversion to other energy forms such as hydrogen gas. Energy storage can also consist of the management of loads to shift consumption in time and thereby create a "virtual storage" of the energy in the loads until times of high energy production or low energy price.

STRI decided to develop a research, development and demonstration platform to gain practical experience from such power quality phenomena as well as to test novel energy storage technologies and different control algorithms and communications protocols for microgrids and virtual power plants. From the beginning, two criteria were basic in the building of the platform: it should be realistic and it should be flexible. The platform is enclosed in a container (Figure 1). Some internal views of the RD^2 platform are given in Figure 2.

Figure 2. Battery and hydrogen storage system (top left) are separated from the various controllers, converters and other electrical equipment (top right). The RD2 is connected to a medium voltage substation refurbished with a multi-vendor IEC 61850 (bottom left and right)

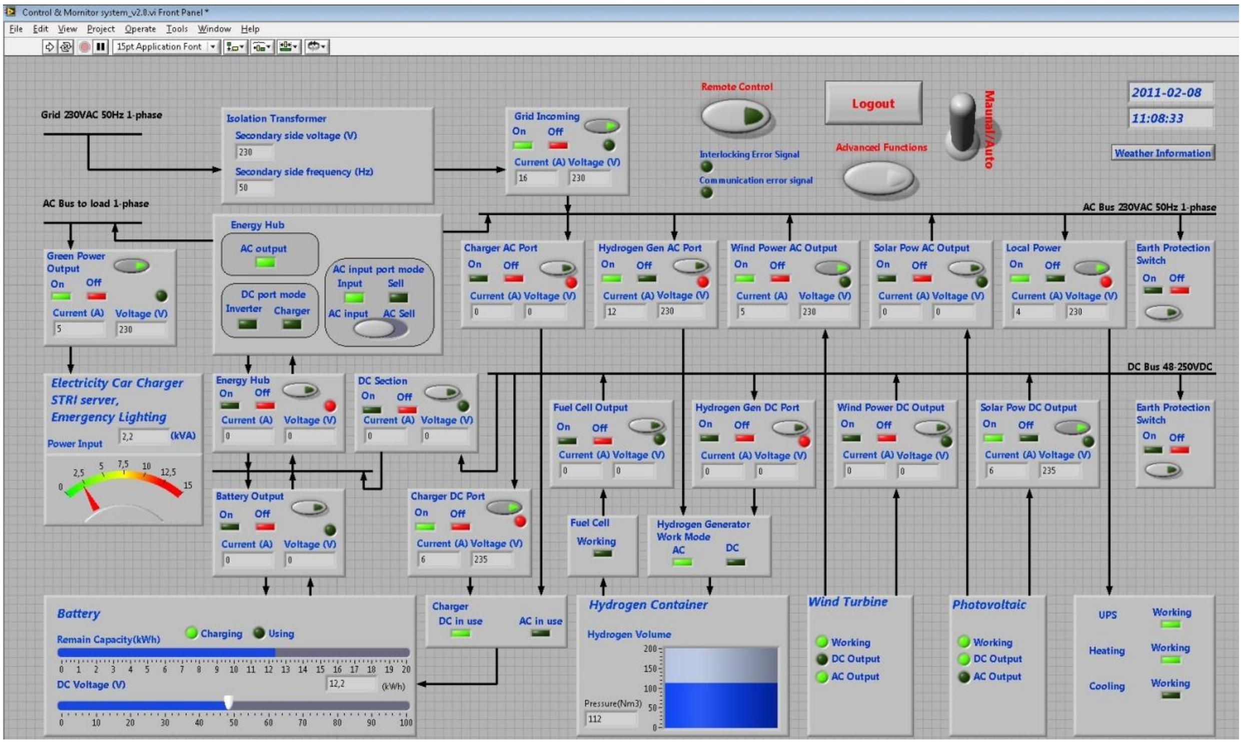

Figure 3. Operator interface with single line diagram of the Research Development and Demonstration (RD^2) platform.

THE STRI RD^2

The aim of the STRI Smart Grid Research, Development and Demonstration (RD^2) platform is to provide a modular, scalable and flexible infrastructure where different aspects of local distributed generation can be studied. Aspects that can be studied include the AC/DC conversion, performance of individual sources or any combination of sources, demand control, and various power-quality issues. Communication can be tested between the grid and the different sources, between sources, as well as between sources and load.

The platform is enclosed in a container (Figure 1) and enables absorption of energy from a multitude of energy sources and storage devices with various voltages and frequencies. The RD^2 shall be able to control the local production and consumption and can among others be used to test different control algorithms.

System Design

The RD^2 platform is grid-connected through a single phase low-voltage system connected to a 10 kV/380V multi-vendor IEC 61850 station. This will allow standardized communication and control of the RD^2 and the end-user equipment in STRIs high voltage laboratory.

The systems backbone consists of a parallel AC and DC bus with converters as shown in Figure 3. The control and operation was implemented with a PLC system that can connect or disconnect all individual production sources and loads. The RD^2's flexibility supports integration of further distributed energy resources (DER) and other storage devices like electrical vehicles in research projects.

With an up-scalable Research-Development-Demonstration concept in mind, flexible configuration of operating modes as well as measurements of important parameters is essential. A combined switching and measuring control module (CM) was developed, consisting of a remote operated AC/DC switch and measurement sensors for AC/DC current and voltage. The installation of the CMs and control system computer are shown in figure 4.

Figure 4. Combined switching, measuring and control modules (CM) developed for the RD^2 platform (left) and communication and control equipment (right).

A dedicated control and measurement system manages a palette of possible operating modes supporting necessary safety functions and connecting generating and storage devices. The control system is operated via Ethernet communication. The first control system was implemented on a propriety system from National Instruments. Work is currently ongoing to add an IEC 61850 application programming interface.

PRACTICAL IMPLEMENTATION ISSUES

The emission of disturbances like waveform distortion and flicker has changed character with new power electronics. One fundamental difference compared to traditional power electronics is the asynchronous behaviour of interharmonics and harmonics, as the new converters operate without being synchronized to the main supply system.

The DC Bus voltage was selected to 48 V since the numbers of options of available inverters was large. However a higher voltage will lead to corresponding smaller DC currents which will be considered in the expansion of the RD^2 platform.

Dimensioning considerations

The challenge was to build a system that is flexible while still storing and using energy in an optimal way. A time consuming task during the design of the system was to find suitable power levels for inverters, battery chargers, fuel cell and electrolyser.

The various inverters had to operate together while handling both AC and DC voltage and have an appropriate surge protector. The ability to operate in both grid connection and in island operation made it still harder to find suitable inverters. This is because island operation requires frequency control not available in most inverters developed for grid connected applications. Also it was demanding to fulfil national safety regulations for electrical installations in both island and grid operation modes due to e.g. varying short circuit currents.

Handling of hydrogen requires a separate ventilated gas-tight space and a security system that governed the layout of the container. During the construction the need for heating was exposed as the electrolyser uses water to produce hydrogen in which there is a risk of freezing at low temperatures. At other times the large amount of electronic equipment caused heating and a water cooling system was installed for the container.

Finding the most cost-effective mix of the energy sources and storage is a complex task influenced by local wind, sun availability available subsidies for grid expert as well as local building regulations regarding height of wind turbine. Simulations where made with an energy modeling software (see Figure 5) to dimension the RD^2 and estimate the per kWh cost of energy production.

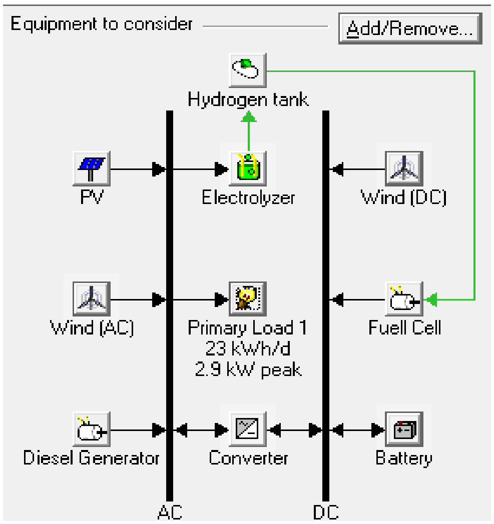

Figure 5. Simulation in HOMER energy modeling software used to dimension energy sources and storage as well as estimate capital and per kWh costs.

INTENDED USE OF SMART GRID RD^2 PLATFORM

Power quality studies

In the RD^2 Power Quality (PQ) meters from two manufacturers record parameters according to IEC 61000-4-30 in parallel with the raw data obtained from the RD^2 platform. The measurement results for different phenomena from the two meters will be compared

The effects will be studied arising from the extensive implementation of power electronic interfaces from generation, storage equipment and loads in combination with both relatively high network impedance and low damping during operation of the RD^2. Characterisation of voltage variations in a time scale of seconds, flicker and harmonic/ interharmonic levels in both voltage and current are of interest with the RD^2 synchronized with the main grid and during island operation.

A new kind of event that is introduced with the RD^2 is the transition to/from islanded operation. Of special interest here is a rapid voltage- and frequency change as well as changes in various harmonic emission levels and flicker. Also the aggregation of such emission from different sources can be studied with data from the RD^2.

Energy storage test bench

To be able to compensate for the varying production from intermittent power sources improved methods of energy storage need to be developed. The energy storage may consist of storing electricity in battery packs or conversion to other energy forms such as hydrogen gas. Energy storage can also consist of the management of loads to shift consumption in time and thereby create a “virtual storage” of the energy in the loads until times of high energy production or low energy price.

The RD^2 is further intended for evaluation of new types of energy storage such as innovative types of batteries, super capacitors and hydride storage of hydrogen gas. Even natural gas will be considered depending on the access of gas.

Last but not least the RD^2 will support research and development projects in which the control and communication algorithms for future power system can be tested and verified. Such algorithms are planned to cover fields as varying as microgrids; virtual power plants; customers with distributed generation; power-system operation involving curtailment of small-scale distributed generation; power-system operation involving demand reduction.

Microgrids and virtual power plants

"Microgrids" and "virtual power plants" are two concepts under development in Europe for allowing more renewable electricity production to be connected to the electricity grid. There are differences between the two concepts, but both ultimately aim at introducing renewable electricity production in such a way that it mimics the behaviour of a conventional power station. Both concepts make use of balancing of production and generation within the customer premises or between different locations belonging to the same market player.

The term "microgrid" is mainly used to refer to a single customer, at one single location, that balances its own production and consumption in such a way that the exchange with the electricity network within certain boundaries. While a virtual power plant has the same aim but the production and consumption are spread over different locations. These microgrids and virtual power plants both require communication: between the different sources of energy but also between those sources and the grid. Finally the communication should enable the control of the sources and the control of any demand reduction that is part of the scheme. For this reason the STRI RD^2 was not limited to the modular container itself but extended to include a newly refurbished multi-vendor IEC 61850 medium voltage substation at its point of grid connection.

Testing of the integration of a microgrid or virtual power plant into the power system and the electricity markets can only be realistic when the communication channels and protocols are realistically modelled. A physical model has many advantages above pure simulation models. Because there is still an absence of real installations based on the concepts of microgrid or virtual power plant is it very difficult to verify any simulation model for communication and control algorithms. Therefore also a limited size installation like the RD^2- while falling short of a full-scale installation- can give valuable results.

Interuniversity cooperation

The STRI RD^2 is part of a joint research project with STRI and three universities in Sweden (Uppsala University, Luleå University of Technology and Royal Institute of Technology). The aim of this cooperation is to develop algorithms and communication for increasing the hosting capacity of the distribution network for renewable sources of energy. Storage will play an important role in the algorithms to be developed. The RD^2 platform will be used to develop and test those control and communication algorithms.

Future platform extensions

In the second stage the RD^2 will be extended with local energy production totaling 90 kW, roughly equivalent to the energy needs of the STRI office building in Ludvika, Sweden.

In a third step supervisory and data acquisition is planned to be added from several tens of MW of existing wind and hydro power in the vicinity of Ludvika. This will enable development of the control algorithms for a fully-flexible virtual power plant including energy storage.

CONCLUSIONS

The electrical integration of small scale intermittent energy resources like solar, wind and small scale hydro power raises a number of practical issues outlined in this paper. Careful dimensioning and selection of components are required to fulfil power quality and national safety regulations.

The integration of large amounts of intermittent energy resources like solar, wind and small scale hydro power can be facilitated with coordinated control of local production and consumption into microgrids and virtual power plants. Testing of the integration of future microgrids or virtual power plants into the power system and the electricity markets can only be realistic when the communication channels and protocols are realistically modelled. Because of the almost complete absence of real installations based on the concepts of microgrid or virtual power plant is it very difficult to verify any simulation model for communication and control algorithms. A full-scale installation would be most appropriate for verifying such models but would by extremely expensive and have other disadvantages. Therefore a limited size installation has been chosen as a compromise.

Acknowledgments

While the Smart Grid Research, Development and Demonstration (RD2) has been funded and constructed by STRI AB of Sweden the interuniversity cooperation project mentioned in this paper is led by the High Voltage Valley consortium and partly funded by the Swedish Government Agency for Innovation Systems (Vinnova).