POWER CONDITIONING SYSTEMS FOR RENEWABLES, STORAGE, AND MICROGRIDS

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ABSTRACT

The introduction of variable renewables, storage and microgrids into today's electrical grid requires conversion of electric power from one form to another (AC to/from DC and/or conversion between different voltage levels), and requires conditioning the power quality to what is needed by the subsystems being integrated. These functions are performed by Power Conditioning Systems (PCSs) that are a key enabler to utilizing renewables, storage and microgrids on a large scale. This paper develops measurement methods for PCSs and associated power electronics technologies needed for these applications, and supports PCS performance standards development to provide smart grid-interactive interfaces for these devices. The PCS grid applications supported include smart grid interfaces for individual renewable/clean energy and storage systems including plug-in vehicles used as storage, as well as microgrids, and DC circuits.

1. INTRODUCTION

The term Power Conditioning System (PCS) refers to the general class of devices that use power electronics technologies to convert electric power from one form to another; for example, converting between direct current (DC) and alternating current (AC), and/or converting between different voltage levels, and/or providing specific power qualities required by the subsystems being interfaced by the PCS. Advanced smart grid-interactive PCS-based generator and microgrid functions developed as a result of this paper enable solutions to these and many other issues and will enable distributed generators to provide grid interactive functions that increase their value proposition.

The interagency coordination of PCS, Distributed Energy Resources (DER) and microgrid technology and standards development performed by this paper will aid in more rapid adoption of advanced disaster recovery strategies.

This paper addresses the critical standards, metrology, and technology gaps needed to support the transformation to high penetration levels of PCS-based distributed generators, storage and microgrids. The paper will enable DER to be used by entities, such as utilities and industrial parks, as multi-functional operational assets to manage local and regional grid operations including the ability to island into resilient self-sustainable microgrids. The paper plan has three tasks that address: 1) metrology and standards for advanced interface functionalities of PCS-based generators and microgrids, 2) advanced PCS technologies and metrology needed to support these applications, and 3) application integration through conformity and interoperability testing and demonstration.

2. ELECTRIC STORAGE TECHNOLOGIES

Energy storage is now a prime determinant of how quickly society can shift from its dependency on fossil fuels to more effective use of renewable resources. Battery energy storage systems manage the variability of renewable energy, smooth power and shift energy in a safe, reliable and simple way. Electricity storage, or power storage, is the missing piece of the puzzle in the renewable energy cycle. Effective, efficient and economical storage of energy can make renewable energy dispatchable: that is making it available whenever and wherever it is needed. It is necessary to make a real difference in the transition to renewable energy-based consumption with economical, safe, and environmentally sound energy storage solutions.

A number of electric storage technologies have been developed which serve various electric applications, including:[1]

_ Pumped Hydropower
_ Compressed air energy storage (CAES)
_ Batteries
_ Flywheels
_ Superconducting magnetic energy storage (SMES)
_ Super capacitors
_ Hydrogen Storage

2.1 Pumped Hydropower:

Pumped hydro has been around as an electric storage technology since 1929, making it the oldest used technology.

Operation:

Conventional pumped hydro facilities consist of two reservoirs, each of which is built at two different levels. A body of water at the higher elevation represents potential or "stored" energy. Electrical energy is produced when water is released from this reservoir to the lower reservoir while causing the water to flow through hydraulic turbines which generate electric power as high as 1000 MW. Within last ten years the advanced pumped storage (APS) technology has been introduced to increase efficiency, speed and reliability.

2.2 Compressed Air Energy Storage (CAES):
CAES is an attractive energy storage technology for large, bulk storage.
Operation:
CAES systems store energy by compressing air within an air reservoir using a compressor powered by low cost electric energy. During charging the plant's generator operates in reverse – as a motor – to send compressed air into the reservoir. When the plant discharges, it uses the compressed air to operate the combustion turbine generator. This method is more efficient because natural gas is burned in this process as compared to a conventional turbine plant as the CAES plant uses all of its mechanical energy to generate electricity.
An important performance parameter for a CAES system is the charging ratio, which is defined as the ratio of the electrical energy required to charge the system versus the electrical energy generated during discharge (the number of kilowatt hour (kWh) input in charging to produce 1 kWh output).

2.3 Flywheels:
Operation:
A flywheel storage device consists of a flywheel that spins at a very high velocity and an integrated electrical apparatus that can operate either as a motor to turn the flywheel and store energy or as a generator to produce electrical power on demand using the energy stored in the flywheel. The use of magnetic bearings and a vacuum chamber helps reduce energy losses. Flywheels have been proposed to improve the range, performance and energy efficiency of electric vehicles. Development of flywheels for utilities has been focused on power quality applications.

2.4 Advanced Electrochemical Capacitors:
Operation:
An electrochemical capacitor has components related to both a battery and a capacitor. Consequently, cell voltage is limited to a few volts. Specifically, the charge is stored by ions as in a battery. But, as in a conventional capacitor, no chemical reaction takes place in energy delivery. An electrochemical capacitor consists of two oppositely charged electrodes, a separator, electrolyte and current collectors.

2.5 Battery Energy Storage Systems:
In recent years much of the focus on the development of electric storage technology has been on battery storage. There is a wide variety of battery types serving various purposes which would be examined in this paper. In a chemical battery, charging causes reactions in electrochemical compounds to store energy from a generator in a chemical form. Upon demand, reverse chemical reactions cause electricity to flow out of the battery and back to the grid. The first commercially available battery was the flooded lead-acid battery which was used for fixed, centralized applications. The valve-regulated lead-acid (VRLA) battery is the latest commercially available option. The VRLA battery is low-maintenance, spill- and leak-proof, and relatively compact. Zinc/bromine is a newer battery storage technology that has not yet reached the commercial market. Other lithium-based batteries are under development. Batteries are manufactured in a wide variety of capacities ranging from less than 100 watts to modular configurations of several megawatts. As a result, batteries can be used for various utility applications in the areas of generation, T&D, and customer service. Batteries currently have the widest range of applications as compared to other energy storage technologies. The type and the number of battery storage applications are constantly expanding mainly in the areas of electric and electric hybrid vehicles, electric utility energy storage, portable electronics, and storage of electric energy produced by renewable resources such as wind and solar generators. They are also used for a variety of applications such as: power quality assurance, transmission and distribution (T&D) facility deferral, voltage regulation, spinning reserve, load leveling, peak shaving, and integration with renewable energy generation plants. Battery systems appear to offer the most benefits for utilities when providing power management support and when responding to instant voltage spikes or sags and outages.
Operation
Electric batteries are devices that store electric energy in electrochemical form and deliver direct (dc) electricity.
Electrode plates, typically consisting of chemically reactive materials, are placed in an electrolyte which facilitates transfer of ions within the battery. The negative electrode, or anode, "gives up" electrons during discharge via the oxidation part of the oxidation-reduction electrochemical process. Those electrons flow through the electric load connected to the battery, giving up energy. Electrons are then transported to the positive electrode, or cathode, for electrochemical reduction. The process is reversed during charging. Battery systems consist of cells, which have a characteristic operating voltage and maximum current capability, configured in various series/parallel arrays to create the desired voltage and current. Typically a BESS consists of a power conditioning system (PCS) that processes electricity from the battery and makes it suitable for alternating current (ac) loads. This includes (a) adjusting current and voltage to maximize power output, (b) converting DC power to AC power, (c) matching the converted AC electricity to a utility's AC electrical network, and (d) halting current flow from the system into the grid during utility outages to safeguard utility personnel. The conversion from DC to AC power in the PCS is achieved by an inverter, which is a set of electronic switches that change DC voltage from battery to AC voltage in order to serve an AC load.

3. DESCRIPTION:

Establish standards and measurement methods for smart grid and microgrid PCSs and associated component technology needed to transition from today's low penetration of non-dispatchable intermittent renewable energy sources to the future high penetrations of dispatchable smart grid-interactive distributed generators, storage, and microgrids.

Power electronics technologies and PCS applications have continuously progressed since the invention of the power transistor (the key enabling technology) and are transforming the way electricity is generated, stored, delivered, and used, as well as the way mechanical systems are actuated [2].

Many *"loads"* on the power grid today are already interfaced through PCSs that provide the type of electricity needed by the load and also provide valuable grid interface characteristics such as unity power factor (phase of AC current draw is aligned with AC voltage) and reduced waveform harmonics (reduced sinusoidal distortion of load current). The transition to PCS-based loads occurred over the last three decades, starting with low power loads and evolving toward high power loads such as today's large variable speed electric motor drives (up to 100 MW). In some grids it has begun to use PCSs such as Flexible AC Transmission System (FACTS) devices that inject corrective power waveforms into the grid, and High Voltage DC Transmission (HVDC) stations that convert between AC and DC for long distance transmission (at 1000 kV, 1000 MW levels). About only a fraction of power generators today are PCS-based (<<1% overall), but it is on the verge of a transformation to much higher penetration levels of PCS-based generators (>10%) that will occur over only a few years. The transformation is partially due to the addition of renewable/clean energy sources that produce DC (photovoltaic and fuel cell) or variable AC (wind turbines) and thus require a PCS to convert to regulated AC meeting grid interconnection requirements. The distributed nature of solar energy also poses unique challenges in simultaneously meeting the requirements to provide grid stability by remaining connected during abnormal grid conditions, while also ensuring safety by de-energizing or separating into a microgrid island when the distribution grid goes down. Microgrids also provide resiliency and power quality advantages to consumers and can contribute to overall stability of the grid. Advanced smart grid-interactive PCS-based generator and microgrid functions developed as a result of this paper enable solutions to these and many other issues and will enable distributed generators to provide grid interactive functions that increase their value proposition.

Future grid architectures involving fleets of stationary microgrids plus tactical mobile microgrids can play a critical role during disaster response involving wide-area electricity outages by enabling individual microgrids to continue to operate or to be brought back up before transmission lines and substations are restored. In the future, tactical mobile microgrids consisting of compact, lightweight PCS units on trucks might be used to rapidly integrate diverse types of generators, storage, loads and feeders during wide area disaster recovery efforts. Disaster-recovery capability might also be integrated intrinsically within power conditioning units of critical infrastructure equipment such as nuclear power plant cooling systems or municipal flood pump stations so that they can rapidly interface to alternate electricity sources during disaster recovery. The interagency coordination of PCS, Distributed Energy Resources (DER) and microgrid technology and standards development will be performed, that will aid in more rapid adoption of advanced disaster recovery strategies.

Microgrids will be treated as resources to the grid, as initiated by either the grid operator or a third party; which can run as either single entities or in aggregate (including clusters).

Three tasks must be addressed: 1) metrology and standards for advanced interface functionalities of PCS-based generators and microgrids, 2) advanced PCS technologies and metrology needed to support these applications, and 3) application integration through conformity and interoperability testing and demonstration:

Task 1 – Grid PCS Performance Specifications and Test Methods:

- Continue to establish a sustainable process for advancement of PCS functionalities, international standards, regulatory and business models, conformity testing, and microgrid architectures to facilitate high penetrations of DER and enable a more resilient grid.
- Establish a laboratory to address critical metrology challenges in conformity and interoperability testing of smart grid-interactive PCS functions for grid interconnection of DER and microgrids.
- Develop and evaluate measurement methods and procedures to support industry conformity and interoperability testing of smart grid-interactive PCS functions.
- Document and publish improvement in system performance due to use of advanced smart grid-interactive PCS interfaces with automated control.

Task 2 – PCS technologies and metrology for cost effective smart grid PCS applications:

- Continue to coordinate multi-agency programs to develop advanced PCS component technologies and system demonstrations and provide data and analysis enabling advancement.

- Develop measurement systems and methods to characterize performance of advanced PCS component technologies.
- Establish theoretical foundation, compact simulation models, virtual prototypes, and model parameter extraction and validation procedures for advanced High Megawatt PCS technologies.

Task 3 – Microgrid PCS Testing and Application Integration:

- Phase 1: Functionality Development and Testing.
- Phase 2: Testing in a real Smart Grid Interoperability Facility.
- Phase 3: Transition microgrid PCS devices to applications – possibly Net Zero House.

Major Accomplishments:

- Several standards in the IEEE 1547 family and UL1741 are available, forming a technical foundation to support increased utilization of smart grid-interactive distributed energy resources (DER), and increased use of these standards is anticipated. Public rulemaking proceedings are also being conducted by FERC, the California Public Utility Commission and others referencing the need for the new functionalities of these standards.[3]
    - IEEE 1547.4 for grid islanding applications and IEEE 1547.6 for secondary networking.
    - UL 1741 Certification Requirements Document (CRD) "Special Purpose Utility Interactive Product Requirements".
    - IEEE P1547.8 for advanced grid-interactive DER functionalities.
    - IEEE 1547a (Amendment 1 to IEEE 1547).
    - IEC 61850-7-420 new edition.

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[2] Ridge Energy Corporation, http://www.Ridgeenergystorage. com/

[3] Electricity Storage Association, http://www.NIST.org/.