Improving Power Line Utilization and Performance With D-FACTS Devices

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Abstract

This paper discusses the use of massively-dispersed mass-manufactured communications-enabled sensor, power-converter and actuator networks to realize a smart, fault tolerant, controllable and asset efficient power grid. A critical unfulfilled need, power flow control on existing lines, is solved using many modules of a Distributed Static Series Compensator (DSSC) device that can be clamped on to existing power lines, and can be operated so as to control the impedance of the conductor – realizing the first in a family of Distributed Flexible AC Transmission System or D-FACTS devices. This approach promises important system-wide benefits including – increased line and system capacity; increased reliability; improved asset utilization; improved operation under contingencies; reduced environmental impact; incremental deployment; and rapid implementation.

Introduction

As generation and consumption of electricity has grown, investment in the transmission infrastructure has declined. The grid is aging and few new lines are being built, given high cost and permitting delays. The inability to control power flow on the grid results in poor asset utilization and impedes the growth of the energy market. Uncertainties in transmission investment recovery and the high cost of existing power flow control solutions further exacerbate the problem. It is generally agreed that the transmission grid is under stress, and that steps need to be taken quickly to eliminate transmission constraints and bottlenecks and to improve the utilization of existing T&D assets, to ensure the flow of reliable and affordable electricity [1].

These problems are well recognized in the industry. However, the overall factors that govern our ability to act are extremely complex and multi-dimensional. Key issues include – public policy; a semi-regulated Balkanized utility industry; differing state regulations; gaming of existing regulations; impact of transmission investments that extends beyond the investor's territory; a centralized and aging technology architecture; substantial legacy infrastructure and potentially stranded assets; conversion of the T&D infrastructure to an 'energy super-highway'; right of way and environmental issues; foreign oil dependence and sustainability; etc. It is clear that technology is only a small piece of the overall puzzle. It is easy in such situations to declare that no progress is possible and to maintain status-quo. However, one only has to look at the IT industry and the Internet to see a situation where a regulated and established industry, much like the utility industry, was disrupted and transformed with significant societal benefit.

One of the key driving factors in the transformation of the IT industry was the advent of massively distributed solutions. Rapid advances in microelectronics, computing and communication technologies disrupted the established technology of centralized switches and copper pipes. The success and rapid adoption of cellular phones around the world clearly demonstrates the superiority of distributed solutions. Distributed solutions offer several unique advantages including –

- Use of commoditized mass-produced building blocks networked together realizes higher performance at lower cost,
- Massive redundancy, coupled with self-organizing and self-healing properties realizes high system reliability and availability,
- System can be implemented incrementally with full backward compatibility, and can be upgraded as technology or customer needs change

With the exception of a limited interest in distributed generation (driven by the need to appear 'green'), the utility industry has continued to concentrate on large 'lumped' systems as the preferred solution for its infrastructure. This paper suggests that a truly distributed approach to power networks may provide a cost-effective approach for modernization of the power grid.

Active Power Flow Control

One of the most pressing challenges facing the utility community is controlling power flow on the grid. The underlying assumption for a vibrant energy market is that the T&D infrastructure could optimally transport energy from where it was generated to where it was needed. New generating plants were located at the cross-section of gas lines and power lines, and much hope was riding on the ability of free markets to operate and realize their full potential. The laws of physics (Ohms Law, Kirchoff's Current Law – KCL, and Kirchoff's Voltage Law – KVL) have unfortunately prevailed, preventing the vision from becoming reality.

The distribution of current in a meshed network (important for high reliability) is governed by line impedances. In such a network, the first line that becomes 'congested', i.e. becomes overloaded, limits the capacity of the network. Trying to push more power through the network can cause lines to trip and can initiate a cascading failure, even though most of the lines may be operating below their rated capacity. The situation is rendered even more complex due to a requirement for continued operation under a (N-1) contingency condition. This requires that the system continue to operate with one failure, such as a tripped line. As a consequence, the system operator has to provide sufficient safety margin so that a line can continue to operate within its nominal rating even under the worst-case single failure condition that can be anticipated. This results in a further erosion of the available transfer capacity for the system. Another unintended consequence of KCL and KVL is 'loop flows', or circulating currents that flow in unintended paths. The presence of loop flows on a given line can limit the transfer capacity for the line owner, resulting in loss of potential revenue. As demand increases, these factors can result in transmission loading relief calls, gaming, curtailed service and poor system reliability – even as the critical assets (the power lines) remain under-utilized.

The conventional approach has been to balance power flows on the network to the extent possible through generator dispatch and the use of appropriately positioned reactive or VAR compensation. Unfortunately, shunt control approaches have a weak influence on how real power flows in a network. Achieving full control of the power flow on the power grid requires that the impedance of the power lines themselves, or the phase angle of the voltage across the power line, be made variable and controllable. Series capacitors are often used to decrease line inductance and increase the capacity of long lines, but can cause instability and sub-synchronous resonance and complicate the issue of system protection under fault conditions.

FACTS Technology

A new technology that holds the promise of realizing a smart grid and achieving power flow control is Flexible AC Transmission Systems or FACTS [2-4]. FACTS devices, such as STATCOM, SVC, SSSC and UPFC can be inserted in series with a line, connected in parallel, or a combination of the two, to achieve a myriad of control functions, including voltage regulation, system damping and power flow control. Typical FACTS devices can operate at up to 345 kV and can be rated as high as 200 MVA. Even though FACTS technology is technically proven, it has not seen widespread commercial acceptance due to a number of reasons –

- High total cost of ownership.
- Difficulty in computing ROI for investments that decrease congestion, or increase system capacity or reliability.
- High fault currents (60,000 Amps) and insulation requirements (1000 kV) stress the power electronics system, making implementation of FACTS systems, in particular series connected devices, very difficult and expensive.
- Single point of failure yields reliability of 94%, significantly lower than the 99.99% reliability that is typical for the utility system itself.
- Highly customized design of FACTS devices requires skilled work force in the field to maintain and operate the system.

As a result, even though FACTS technology has been commercially available for over 10 years, few installations have been purchased by utilities. Shunt connected devices, such as SVCs and STATCOMs that are used for voltage regulation and VAR support, have been more effective and are seeing broader deployment. Series connected devices, such as SSSCs that are required to achieve power flow control, are significantly more difficult and expensive to implement and have rarely been deployed. Active power flow control, important from a grid utilization and control