Voltage Regulation

Tapping Distributed Energy Resources

Reactive power is the key to an efficient and reliable grid.

Traditionally, the role of the distribution system is to provide the interconnection between the generation and transmission system and industrial, commercial, and residential load centers. The distribution systems generally can be considered to be passive networks— that is, they do little to dynamically regulate voltage. In contrast, the transmission system operator must deal with voltage problems that arise from a number of power-system events such as lost load, line or cable outages, dropped generation, capacitor bank outages, heavy power transfers, parallel flows, or unusually high or low load demands. The primary voltage control methods available to the operator include increasing or decreasing generation and adding or adjusting sinks or sources of reactive power in the system. In the future, real-time regulation of voltage at the customer's own buses may be best performed using local sources of active and reactive power, or distributed energy resources (DER). Local regulation is much more efficient with local sources, and the DER can supply precisely the level of regulation needed. In some areas it may be most economical for the distribution utility to supply only a nominal level of reliability, and the reliability would be elevated to the customer's requirements with DER.[1] Within the customer's distribution system, some buses may be designated for critical or sensitive loads, and some may be for loads that could be reduced or shed if needed to maintain correct voltage at the critical loads. This concept already is occurring in some parts of the country.

What about the reliability of power from local sources? Lambda is an index used to assess reliability by measuring the frequency of sustained outages. In a recent discussion of the attributes of distributed resources, the best frequency of interruption data, or lambda, for a primary distribution system is 0.515 based on Best In Class utility data.[2] Surprisingly, the subtransmission and transmission systems' contributions are quite low, 0.115, but the distribution primary contribution is 0.4, or 78 percent of the total frequency of interruption of 0.515. Breaking the distribution primary contribution down, 88 percent of the outages are due to the overhead-line component. The other two components, underground line and substations, have comparatively few failures. Typically, local power parks do not contain overhead lines. They are composed of cables in conduit and direct burial. Using the values for these components, and an availability of 0.95 for an internal combustion engine, outages at local power parks should be about four times better than the average T&D performance.

Dynamic reactive power reserves from generation increase in effectiveness as voltage decays, and they also are the most reliable means for voltage stability enhancement.[3]

Reserves provided from local generation reduce reactive losses resulting from increased active power transfer. Simulations found cases where a 15 percent increase in pure megawatts at a single bus can trigger a voltage collapse. This type of flow-triggered voltage collapse played a role in the

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Aug. 14 blackout. This is because the increased active power flow aggravates reactive losses in the occupied transmission paths. Dynamic reactive reserves available from generators, synchronous condensers, static var compensators, and other inverter-based devices are the most effective and reliable means to prevent voltage collapse due to unanticipated system contingencies (line loss, generator loss, etc.).

Today, most spinning reserve is provided from a few high-operating-cost machines. Spin is not evenly distributed across a control area. Reactive reserves are available from these same machines because they are operating in a "backed off" mode and have high reactive power levels available. Thus the reactive reserves are not distributed evenly. With an unequal pick up of reserves around an area, there is an impact on power flow. When planning reactive reserves for contingency cases, these "lumpy" reactive reserves can cause problems. Flow paths have to be held open to provide enough flow capacity, and some paths actually have to be de-rated. This, in turn, has caused the curtailment of operating units. One solution is to build more transmission. This will take 5 to 10 years in many cases. A better solution is to provide reactive power from DER units that are evenly spread across the control area.

DER Defined

Distributed energy resources (DER) are small power sources such as microturbines, fuel cells or engine generators installed throughout the distribution system. An important role for these small power sources may be the supply of reactive power. Reactive power could be supplied dynamically, that is, it could be increased or decreased quickly. Reactive power could be used to regulate voltage at the distribution level. Reactive power supply currently is unevenly distributed and is typically available only in limited quantities in distribution systems. Having a dynamic supply of reactive power available from the distribution system would make the entire grid more efficient and reliable.

Who Could Provide Voltage Regulation?

Utility-owned DER would be possible in areas where there is no market for local generation. Ancillary service or regulated resource contracts could reimburse small generators for reactive power produced during heavy load periods or absorbed during light load conditions. In fact, some utility contracts already provide financial inducements for power factor correction. This concept would simply tighten the band because the capability to provide real-time sensing and control is available, and the incentive signal would increase the availability of power factor correction.

Instead of switching capacitors in and out of the grid, there is a way to generate controllable reactive power directly by switching power converters. These converters are operated as voltage or current sources and produce reactive power without energy storage components by switching alternating current among the phases of the AC system. Their operation is similar to that of an ideal synchronous machine whose reactive power output is varied by excitation control.[4] If they are supplied with an energy source, they can also supply active power to the AC system. These converters are often called static synchronous generators (SSGs) when supplied with an energy source and static synchronous compensators (SSCs) when operated without an energy source.

These compensators are capable of providing both direct voltage support and transient and dynamic stability improvements to increase stability margin and provide power oscillation damping. Regulation of the voltage at intermediate points and selected loads can limit voltage variation significantly, increase the capability to transport active power, prevent voltage collapse, increase transient stability limits, and even provide power system oscillation damping as well as reducing energy losses.

As the cost of the power electronics switches in converters decreases with technology improvements and the devices become mass-produced, it is likely that their use in distribution systems and to interface small power generators will become ubiquitous.

Fast-Acting Voltage Regulation: An Answer

There is a possibility that the voltage regulators on generators could be controlled much more quickly to deliver the services provided by the rapid control of static var compensators (SVC).[5] The SVC behaves like a shunt-connected variable reactance and generally is used for transmission voltage regulation. It can either produce or absorb reactive power to regulate voltage. It is basically a capacitor bank in parallel with a thyristor controlled reactor. The strength of the SVC is that it is very fast acting and can dampen power system oscillations. Thus, the transmission voltage is directly regulated at high speed. The droop (slope) setting of a SVC is usually small compared to generators regulating terminal voltage. This means the SVC will respond much more quickly, including responding to transients while the generator responds more slowly, usually based on a voltage schedule.

We suggest that the DER's voltage regulator (or switching converter) be controlled to provide services such as control of the customer's voltage, assistance in regulation of distribution voltage, and providing unity power factor both in the distribution system and transmission system. The most important service may be the increase in margin of reactive power.

To meet the rising demand for reactive power, American

Voltage Instability and Reactive Power

Voltage instability is a growing concern in modern power systems. Restructuring of the power system has reduced voltage security margins for a number of reasons.

- To reduce capital investment cost, generation companies are buying generators with lower reactive support capability since they have a lower cost per megawatt;.
- To minimize reactive power payments, system planners are relying more and more on capacitor banks instead of the more expensive dynamic reactive sources such as generators, synchronous condensors, static var compensators, etc.;
- Due to the higher reactive impedance and the resulting difficulty in moving reactive power, the strength of the system to withstand voltage instability is location dependent; and
- Reactive power losses in the transmission grids are rising due to increased intra- and inter-zone energy transfer levels.

As a result, several utilities have suffered from voltage stability incidents, and some of which evolved into voltage collapses in the 1990s. The blackout of Aug. 14, 2003, was made much worse by uncontrolled voltage oscillations. Dynamic voltage control provided by local generators or converters could have a system-wide functionality in preventing future voltage collapses. The transmission network can consume so much reactive power that VAR supply from remote generators can fail to enter a load area. Thus there is a significant value for reactive power delivery and dynamic reactive reserves .[1]

1. G. Huang, H. Zhang, "Dynamic Voltage Stability Reserve Studies for Deregulated Environment," IEEE Power Engineering Summer Meeting, 15-19 July 2001, pp. 301-306

Superconductor has developed a superconducting synchronous condensor with an 8 MVAR continuous rating and a 64 MVAR short-term rating. It is designed to provide steady state VAR support while maintaining this large reserve for transient problems. One is being installed near a steel mill in Gallatin, Tenn., and if it works well, Tennessee Valley Authority (TVA) has plans to install five more soon. American Superconductor also has plans to develop much larger devices.

DER generally will increase voltage along a feeder, but the impact depends on its active and reactive power and the feeder loading. The DER easily can be controlled to help regulate voltage. If voltage increases when DER active power increases, decreasing reactive power will typically cause voltages to drop. In some cases, reactive power control alone may not be adequate to control voltage. In these cases, the voltage would need to be controlled by a voltage regulator. Present-day voltage regulators sometimes make decisions as to the optimum tap setting based on the sensed voltage, the secondary current, the secondary voltage and the line resistance and inductance.

When there is a mix of voltage control devices such as capacitor banks, voltage regulators and DER control, the local control decision making will become more complicated, but not excessive. A local intelligent agent would be ideal for sensing local conditions and making decisions regarding tap settings, DER reactive power output, and capacitor bank connections. Central dispatch would still control the voltage and power factor of the central generators, and would provide the local intelligent agent with instructions such as the voltage schedule to be maintained.

Devices using power electronic interfaces will simplify coordination greatly among the conventional distribution equipment and DER. Response to some types of transients, such as voltage sags, will have to be quite fast. Power electronics devices are fast enough to distinguish between a large non-linear load or motor start and an actual sag caused by short circuit current flowing into a fault.

What Feeder Design and Control Is Needed?

From the point of view of voltage stability, existing feeders could be retrofitted to provide local voltage regulation with DER by using a microprocessor that is provided with the needed information. The local microprocessor needs only a small, selected set of data. A relatively simple local microprocessor could be used if a hierarchical control system were used with a group of distributed system managers geographically spread over a wide area. A study by Hydro Quebec of a decentralized approach found that a completely peer-to-peer distributed architecture could be applied without changing the system dynamic operation.[6] In fact, improved damping to contingencies was achieved with distributed control. For one »

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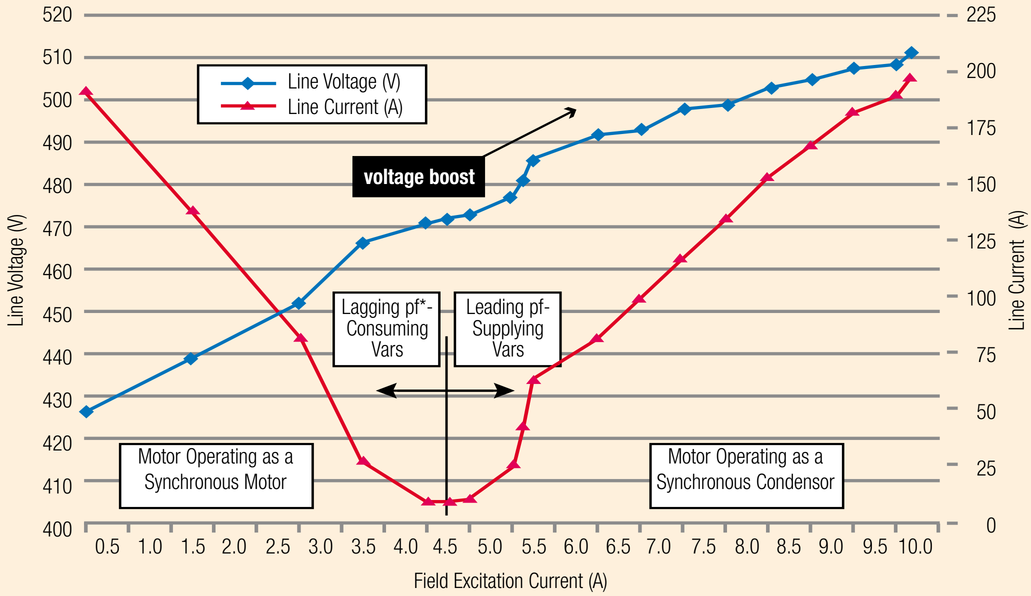
FIGURE 1 **LOAD SUPPLY OF REACTIVE POWER**

An Old Idea with a New Economic Incentive - Supply of Reactive Power from Distributed Resources: Local 480-volt bus voltage as field current is increased on a 250 Hp synchronous motor.



* pf = Power Factor

contingency, global control using a hierarchical/decentralized architecture was the only scheme capable of keeping the system stable. One of the significant benefits was the enhanced voltage profile at remote weak buses. All this can be accomplished using conventional processor and SCADA technology. The difference is in the placement of the control authority.

New feeders can be designed to provide DER voltage control with and without a hierarchical/decentralized architecture as described above. Obviously, with a hierarchical/decentralized architecture, there are significant advantages in system operation. However, local voltage regulation still could be provided to some degree without distributed control. The challenges, again, will be protection, coordination and voltage stability.

Local control will not require a major replacement of infrastructure. A few sensor locations with communications (such as radio) distributed along the feeder would be needed to advise the central control authority of voltage conditions, but no more locations than are presently used.

Developing Markets for Reactive Power

The New York ISO provides reactive power services at embedded cost-based prices. Generators and synchronous condensers are paid for reactive support based on a calculation involving an annual fixed rate, current capital investment, and operation and maintenance expenses. In addition, if the ISO dispatches a generator to increase reactive power generation and as a result the generator must reduce active power output, the generator receives a Lost Opportunity Cost (LOC) payment for the amount of revenue it loses from the lost generation.[7]

In California, the ISO purchases reactive power from reliability must-run (RMR) units on long-term contracts. The short-term requirement is determined on a day-ahead basis. Daily voltage schedules are issued to contracted generators. For reactive power absorption or generation beyond the limits of 0.9 lagging and 0.95 leading, the generators are compensated, with an additional payment if they are required to reduce their active power output.

In the PJM RTO, voltage control services are paid for with a two-part tariff. In the first part, for reactive power within rated capacity, the customer pays a charge proportional to the generation owner's total revenue requirement and the amount of monthly use of the network. For the second part, generators are paid when they are required to reduce active power production in order to produce reactive power.

Dynamic Reactive Power As A Regulated T&D Resource

There may be several advantages to providing voltage regulation from DER technologies as a regulated T&D resource. These benefits relate to reducing the risks (reliability and financial) associated with new technologies. Regulating the asset allows system operators and state regulators to control the testing and deployment of new technology. Consequently, they can proactively seek technology-driven improvements. The technology would be deployed only as rapidly as it proved itself and the system operator gained confidence in it.

Ratepayers benefit as well because new cost-reducing and reliability-improving technologies get introduced much more quickly. Technology also is tested in a way that does not jeopardize system reliability. Regulators perform their historic task of acting for ratepayers and assessing when benefits likely will exceed costs and approving worthwhile demonstrations. Ratepayers assume the reasonable risk of funding promising test programs.

Technology investors benefit, too. They can move incrementally toward full-scale deployment. They need not overcome all technical and market-rule obstacles. Instead, they can focus on technical viability. Similarly, T&D companies benefit. They too can focus on technical implementation and getting the technology right. Both are guaranteed cost recovery (assuming the technology performs competently).

The technology may migrate to the competitive market once the system operator is satisfied that it is technically proven and that there is sufficient potential resources to warrant going to the effort to change any market or reliability rules. Alternatively, it may be more appropriate for the technology to remain a regulated T&D asset.

Urgent Need

The supply of dynamic reactive power has been dwindling over the last few years for a number of reasons: (1) generators are being purchased with lower reactive support capability; (2) system planners are relying more on capacitor banks instead of the more expensive dynamic reactive sources; and (3) increased energy transfer levels absorb higher levels of reactive power.

The reactive power supplied by capacitors decreases with the square of voltage, however, and the dynamic response of capacitors is problematic under a disturbance. Excessive use of capacitors can aggravate the imbalance of reactive power and can actually become one of the causes of voltage collapse. Dynamic reactive power reserves from generation increases as voltage decays, and are the most reliable means for voltage stability enhancement.[8]

Reactive power does not flow long distances from a source, especially during times of system stress. Reactive power absorption on transmission lines increases with the square of the flow. Additionally, existing reactive power reserves tend to be lumped together. If reactive power is supplied from resources that are evenly spread across the control area, congestion from contingency planning could be greatly relieved.

Reactive reserves provided from local generation reduce reactive losses resulting from increased active power transfer. In addition, distribution losses are the largest percentage of total system losses, comprising about 27 percent of total losses. When reactive power is supplied from DER, losses on the distribution feeder can be reduced, and local power quality can also be significantly improved.

Reactive power markets are developing both in the United States and in Europe. In general, generators are paid for providing reactive power based on the amount of revenue they lose from lost generation sales and for having the capacity available. In Australia, providers receive an availability payment and an enabling payment when they are dispatched, and generators receive a compensation payment when they are restrained from operating according to market conditions. In France, EdF has found that distributed generators provide a powerful tool for regulating voltage and a concept of local controllers to manage the system in real time is being developed. Bonneville Power Administration is developing a new concept called "Energy Web," which includes local smart voltage regulation. As the causal factors of the Northeast blackout are more fully explored, the authors suspect that much greater emphasis will be placed on providing dynamic reactive power reserves, and that DER will play a large role in providing these reserves. Classifying the DER technologies as a regulated T&D resource could greatly hasten their development. F

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Endnotes

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