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ELSEVIER
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JOURNAL
Progress in the Pipeline?
Efforts to Harmonize Gas Pipeline Operations with the Demands of the Electricity Sector
Ken Costello
Reactive Power from Distributed Energy
John Kueck, Brendan Kirby, Tom Rizy, Fangxing Li and Ndeye Fall
The Texas Energy-Only Resource Adequacy Mechanism
Eric S. Schubert, David Hurlbut, Parviz Adib and Shmuel Oren
Toward More Comprehensive Assessments of FERC Electricity Restructuring Policies: A Review of Recent Benefit-Cost Studies of RTOs
Joseph H. Eto, Douglas R. Hale and Bernard C. Lesieutre
Power Sector Reform in Developing Countries: A Return to Basics
James B. Douglas
Africa's Infrastructure Gathering: A Report Card
Reinier Lock

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Reactive Power from Distributed Energy

Distributed energy is an attractive option for solving reactive power and distribution system voltage problems because of its proximity to load. But the cost of retrofitting DE devices to absorb or produce reactive power needs to be reduced. There also needs to be a market mechanism in place for ISOs, RTOs, and transmission operators to procure reactive power from the customer side of the meter where DE usually resides.

John Kueck, Brendan Kirby, Tom Rizy, Fangxing Li and Ndeye Fall

I. Introduction

Reactive power, measured in volt-amperes reactive or VARs, is one of a class of power system reliability services collectively known as *ancillary services.* Ancillary services are essential for the reliable operation of the bulk power system. Reactive power flows when current leads or lags behind the voltage; typically, the current lags because of inductive loads like motors. Reactive power flow wastes energy and transmission capacity, and causes voltage droop. To correct this lagging power flow, leading reactive power (current leading voltage) is supplied to bring the current in phase with voltage.

Reactive power can be supplied from either static or dynamic VAR sources. Static sources are typically transmission and distribution equipment, such as static VAR compensators or capacitors at substations, and their cost has historically been included in the revenue requirement of the transmission owner (TO), and recovered through

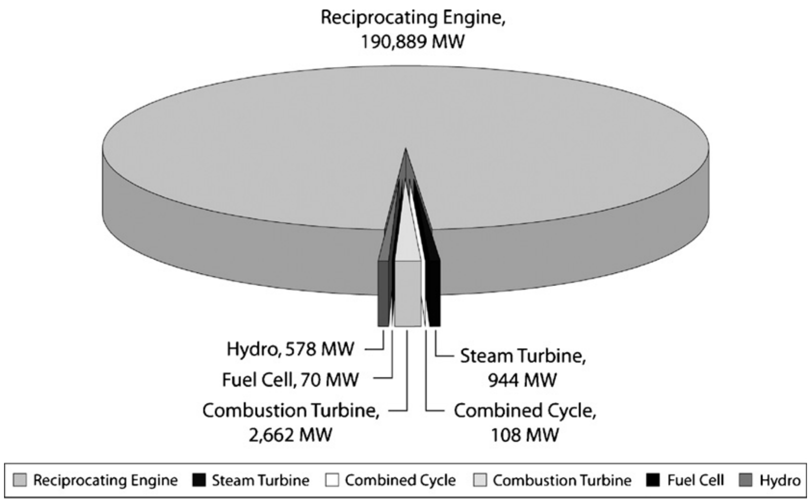

Figure 1: Total Installed Capacity by DE Technology[2] Smaller than 5 MW[3]

cost-of-service rates. By contrast, dynamic sources are typically energy producers, including generators capable of producing both real and reactive power, and synchronous condensers, which produce only reactive power. The equipment may be owned either by TOs or independent entities.[1]

Figure 1[2,3] shows that there is a surprisingly large amount of distributed energy installed in the United States. If we conservatively assume that 5 percent of the total is available for conversion to supply reactive power, we would have over 10,000 MVAR of reactive power capability. For comparison purposes, the entire New England Independent System Operator has approximately 12,000 MVAR of available reactive power capacity.

While the potential for DE-based reactive supply is great, presently the costs are higher than other readily available technologies, such as capacitors. However, DE-based reactive supplies can provide dynamic support capabilities that static devices like capacitors cannot match. In addition, DE supplies are usually located near loads, which is the most effective place to supply reactive power. Improving the power factor of the load significantly improves the reliability and efficiency of power system operation. Adequate local, dynamic reactive supply can greatly increase the margin to voltage collapse.

Evaluating the economics of reactive power compensation is complex, since there are no standard models or analysis tools and no fully functioning markets for reactive power in the U.S., meaning data on costs and benefits is difficult to find. It is an emerging area of analysis that is just beginning to attract the attention of researchers and analysts. This is not surprising, given that the revenue flow associated with reactive power is less than 1 percent of the total U.S. electricity market. However, the importance of reactive power as a component of a reliable power grid is not measured by its market share of power system sales. The role of reactive power in maintaining system reliability, especially during unforeseen system contingencies, is the reason for the growing interest by regulators and system operators alike in alternative reactive power supplies.

In order to study the economic benefits of using DE for reactive power support service, it is necessary to know their capabilities, their cost, and the possible revenue stream from consumers of reactive power services. The cost of providing reactive power includes capital costs as well as operating costs, such as for operations and maintenance (O&M). Although the capital costs of capacitors and other static devices are much lower than for generators and network VAR devices, they are far less functional, cannot adapt to rapid changes during system contingencies, nor provide variable reactive power.

Some small generators have been tested and have the capability to be dispatched as a source of reactive power supply if appropriately modified. There are also some instances, typically in urban centers, where there is a need for dynamic reactive power supplies and DE-based reactive power service shows competitive payback periods.

For DE to become widely used as a reactive power resource, the cost of modifying these devices to provide reactive power needs to be reduced and system operators must develop a compensation plan for a local voltage regulation service.

A. Hidden economic benefits. Other ''hidden'' economic benefits are briefly discussed here. To help the reader understand these benefits, a simple two-bus system shown in Figure 2 is used to illustrate the benefits. In the figure there is a generation bus, a load bus, and a line connecting the two buses. The generation bus represents a generation center, the load bus represents a load center, and the line represents an inter-tie or an interface between the two areas. The tie line is congested due to the maximum transfer capability between two areas. We assume the generation center has a cheap unit with a cost of \$20/MWh. The load center has a large amount of load, served by a utility as a load-serving entity (LSE), and an expensive unit, owned by an independent power producer (IPP), with a cost of \$25/MWh.

The original import into the load center is $P_{im} + jQ_{im}$. If there is a local VAR injection (Q_c in the figure), the flow at the receiving end will be reduced to $P_{im} + j(Q_{im} - Q_C)$. If the same MVA transfer limit is maintained, then we can send more real power over the tie-line since the reactive power flow has been reduced. Therefore, more MW can be dispatched from the cheap generation center. Hence, the output from the expensive IPP generator may be reduced. Thus, the total system cost will be reduced and the LSE utility will pay less to serve the same load.

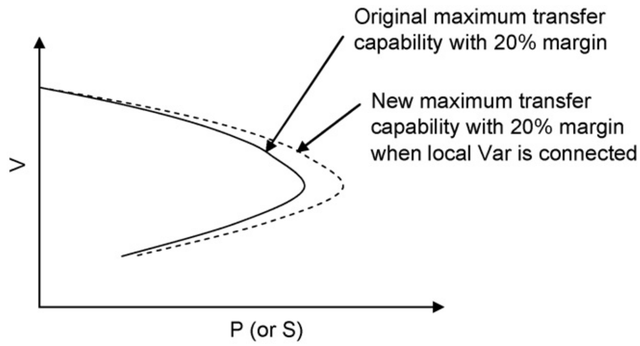

Figure 3: The Original and New Transfer Capability Considering a Certain Security Margin

Further, the local VAR injection may benefit the LSE utility because the transfer capability of the tie line will be increased due to the local VAR compensation. As indicated in Figure 3, the local VAR compensation in the stressed area may increase the maximum transfer capability constrained by voltage stability. This increase of transfer capability indicates that additional cheap MW can be delivered from the generation center without compromising the tie line stability. Hence, the expensive unit may be dispatched at lower output achieving lower overall cost. The total production cost will be reduced further and, eventually, the LSE utility will pay less money to purchase electricity.

Interest in voltage support and reactive power compensation issues increased considerably as a result of the August 2003 blackout affecting the Northeast and Midwest, which identified failure of the LSEs to monitor and manage reactive reserves for various contingency conditions as a causative element.[4] Based on this analysis the Federal Energy Regulatory Commission (FERC) staff undertook a more detailed analysis of reactive power compensation issues, an effort that recently culminated in release of a report entitled *Principles for Efficient and Reliable Reactive Power Supply and Compensation*[1]

Dynamic reactive power may be provided by devices in the following three categories:

- **Pure reactive power compensators** such as synchronous condensers and solid-state devices such as static VAR compensators (SVC), static compensators (STATCOM), D-VAR, and SuperVAR. These are typically considered as transmission service devices.
- **DE with oversized generators or inverters** to provide a broader range of reactive power. These DE Technologies include diesel

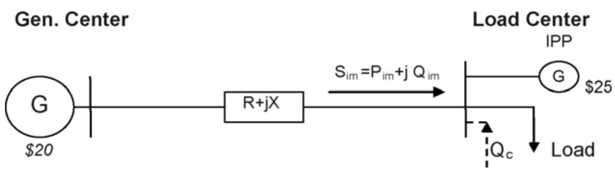

Figure 2: A Two-Bus System

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engine generators, fuel cells, microturbines, etc. Conventionally, they are purchased to provide backup real power (MW) supply under emergency with a limited range of reactive power output. To increase the capability of supplying reactive power, some upgrades are necessary such as oversizing the generator for diesel engine generators and oversizing the inverters for fuel cells and microturbines.

- **Adjustable-Speed Motor Drives** (ASDs) to supply reactive power. Adjustable-speed drives are inverter-based devices that change the voltage magnitude and frequency at the motor terminals. Adjustable-speed drives save energy because motors that drive pumps or fans can be easily controlled to supply a precise amount of water or air that is needed, without wasted energy. New ASD designs can control their power factor. ASDs can draw a leading power factor and still provide full power output to the motor without a reduction in service if they are designed to carry extra current.

As far as costs go, the capital costs of static power sources such as capacitors are much lower than the capital costs of dynamic sources such as the SVC or D-VAR; however, a capacitor is limited since it will only supply or absorb reactive power in set quantity steps or increments. In addition, its reactive power production drops with the square of any voltage reduction; reactive power from capacitors ''drops off'' when it is most needed. The cost of providing reactive power from non-generating reactive power devices is basically their capital cost and O&M expense, as they have no fuel requirements. In the case of adjustable-speed drives, or generators used in CHP or back up power applications, the capital cost may have already been amortized in the purchase of the equipment for its primary purpose, that is, controlling pump motor speed, combined heat and power, or back-up generation.

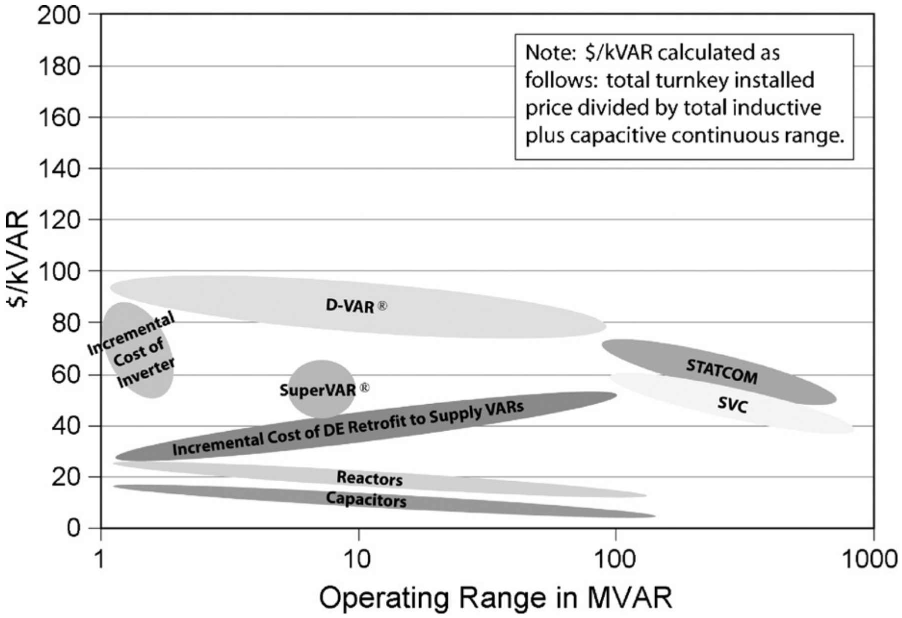

Figure 4: Average Costs of Reactive Power Technologies

Figure 4 is an estimate of the cost regimes for various nongeneration reactive power sources.

II. Dynamic Reactive Power Technologies

This section identifies and describes several of the technologies capable of producing dynamic reactive power. An estimate of cost of these technologies is also given.

A. Synchronous condensers

A synchronous condenser is a synchronous motor that can be controlled to generate or absorb reactive power by changing its field excitation. The synchronous condenser can also dynamically supply reactive power and adjust its output depending on system conditions. The synchronous machines are costly to purchase initially, and they have internal losses, which present a continuous operating cost. Generally, an average cost for synchronous condensers varies from \$10 to \$40 per kVAR and maintenance runs about from \$0.4 to \$0.8/kVAR per year. Existing synchronous motors in industrial applications could be used for this service if they are no longer needed for a process or have excess kVA capacity. Also, the generator on existing distributed generators (DGs) could be used as a synchronous condenser as described below.

B. Retrofit of engine generators to a synchronous condenser

Engine generators installed by utilities or end-users for emergency, standby, or peaking purposes have the potential to operate as synchronous condensers and provide dynamic reactive power to the grid. A large portion of these generators are underutilized, as they are called upon to produce real power output only a portion of the time, e.g., during emergencies or blackouts. Thus, there may be a real opportunity to increase their utilization and benefit the power grid by enabling dual operation of the generator as a real and reactive power producing technology. Also, engine generators could be equipped with oversized generators so that they can supply the needed real power and still have the capacity to supply reactive power. Technology is available to allow many types of generators to be converted into synchronous condensers, i.e., sources of reactive power, by using a clutch.

Generators have limits in their reactive power capability set by the different thermal limits of their armature, field and core. These limits are outlined in the generator's capability curve. The curve is also called a ''D'' curve, due to its shape. **Figure 5** shows an example of a generator D curve. The blue lines projecting out from the D curve are used to calculate the generator's reactive power output capability at different power factors (0.4 lagging to 0.4 leading is shown) given a real power output.

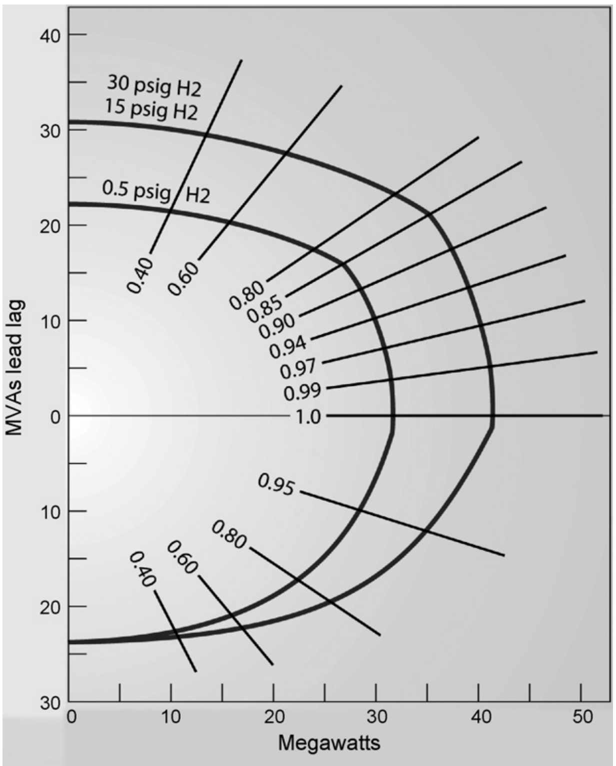

Figure 5: 44.5 kVA Generator D Curve. Source: SSS Clutch Company

When a generator operates at a lagging or leading power factor (not unity or 1.0), higher currents are produced in the generator and generator step-up transformer. These higher currents cause significant losses to occur from resistive heating or I^2R losses associated with the armature winding and field winding of the generator, as well as increased eddy currents or stray losses. These losses can be calculated as the real power that is consumed to produce reactive power and, therefore, a cost that is directly attributable to reactive power production.

Several companies make clutches that can be installed between generators and drivers such as reciprocating engines, steam and combustion turbines. The clutch operates by completely disengaging the prime mover and the generator when only reactive power is needed. When active or real power is needed, the clutch engages for electric power generation. When the turbine is shut down, the clutch disengages automatically leaving the generator rotating to supply reactive power only for power factor correction, voltage control, or spinning reserve. Throughout these changing modes, the generator can remain electrically connected to the grid, thus providing a quick response to system demands.

C. Static VAR compensators

Static VAR Compensators (SVCs) are shunt capacitors and reactors connected via thyristors that operate as power electronic switches. They can consume or produce reactive power at speeds in the order of milliseconds. One main disadvantage of the SVCs is that their reactive power output varies according to the square of the voltage they are connected to, similar to capacitors. So, their reactive power capability ''drops off'' with the lower voltage. As a result, an SVC has limited ability to mitigate voltage instability, leading to voltage collapse situations. An average cost for SVCs that allow rapid switching between capacitors and reactors varies from $40 to $60 per kVAR. An SVC with only capacitors cost less at $30 to $50 per kVAR.

D. Static compensator (STATCOM)

STATCOMs are power electronics-based SVCs. They use gate turnoff thyristors or insulated gate bipolar transistors (IGBT) to convert a DC voltage input to an AC signal chopped into pulses that are recombined to correct the phase angle between voltage and current. While capacitors and reactors cost $10 to $20 and $20 to $30 per kVAR, respectively, STATCOMs cost $55 to $70 per kVAR in large systems sized at 100 MVAR or more. STATCOMs have a slightly smaller footprint than SVCs because they use power electronics instead of capacitors and reactors. STATCOMs have a response time in the order of microseconds.

E. Dynamic VAR (D-VAR) system

The Dynamic VAR (D-VAR®) system is an advanced STATCOM

technology, developed by American Superconductor.[5] The D-VAR is a dynamic FACTS (flexible AC transmission system) device with specialized software to control reactive power output in several sophisticated ways. Its price depends on size. The D-VAR responds to voltage dips by dynamically injecting exact amounts of reactive power. The system can prevent voltage collapse and uncontrolled loss of load when critical transmission elements fail. It can control capacitors and regulate steady-state voltages and provides reactive power support to wind farms.[6] The D-VAR also protects critical manufacturing operations from voltage sags. One of the most important features of the D-VAR system is its overload ability, which enables it to inject anywhere up to three times its continuous rating for several seconds. This feature is particularly useful in addressing transmission voltage stability problems or to improve power quality and correct voltage sags of incoming power sources. D-VAR systems can range anywhere from 2 MVA to over 100 MVA in size and the smallest units cost approximately $200,000. The price per kVAR varies from $80/kVAr to $100/kVAr for the total installed cost depending on the site specifics, and the price becomes more competitive as the unit gets larger in size.

F. SuperVAR

The SuperVAR[7] is a high-temperature superconductor (HTS) dynamic synchronous condenser meant to run continuously, costing between $1 million and $1.2 million. The SuperVAR machine, developed by American Superconductor, dynamically absorbs or generates reactive power, depending on the needs of the grid. The SuperVAR will be rated at 10 MVA, but its first prototype being demonstrated at the Tennessee Valley Authority (TVA) in Gallatin, Tennessee, is 8 MVA.[8] The device responds instantly to disturbances such as lightning, short circuits, and equipment failures. It allows pure voltage regulation on a continuous basis, mitigates voltage flicker, and provides power factor correction.

TVA installed the first prototype of the machine to mitigate a flicker problem from a steel mill.

G. Oversizing the inverter of a distributed energy device

An inverter that is connected with a distributed energy device such as a fuel cell or a microturbine can provide dynamic control of real and reactive power. The solid-state inverters have quicker response and a larger reactive power adjustment range at rated real power than the excitation circuit of the synchronous machines. Although conventionally the range of the reactive power supply from such devices is limited, it is possible to upgrade the inverters to supply reactive power in a much larger range. Oversizing of the inverter can significantly increase the range of reactive power supply. Basically, the approximate marginal cost per kVAR is about $56 to $93/kVAR and this marginal cost increases as the reactive power capability is increased.

H. Adjustable-speed drives

Adjustable-speed drives are devices that use inverters to change the voltage magnitude and frequency at the motor terminals. Adjustable-speed drives are excellent energy savers because motors that drive pumps or fans can be controlled to supply just the flow of water or air that is needed, with tremendous energy savings.[9] Reactive power could be supplied at the drive terminals. The cost of installing adjustable-speed drives is usually amortized by the energy savings realized by the reduction of losses in the air or water flow. Adjustable-speed drives are often paid back in six months or less because of their energy savings. Some utilities offer rebates for the installation of adjustable-speed drives. To supply meaningful levels of reactive

power, the inverter would need to be oversized as described above.

III. Compensation for Reactive Power

The nature of the market for participants providing reactive power supply – e.g., generator, transmission owner, load-serving entity (LSE), or end-use customer – will determine whether a solid business case can be made for entering the reactive power supply market. This discussion focuses on regions of the country that have implemented wholesale competition and created system/transmission operation organizations (**Table 1**).

The range of payment methods include: (1) pay nothing to generators, but require that each generator be obligated to provide reactive power as a condition of grid connection; (2) include within a generator's installed capacity obligation an additional requirement to provide reactive power, with the generator's compensation included in its capacity payment; (3) pay nothing to generators (or include their reactive power obligations as part of their general capacity obligation), but compensate transmission owners and load-serving entities for the revenue requirements of transmission-based solutions; (4) determine prices and quantities for both generator-provided and transmission-based solutions through a market-based approach such as a periodic auction (for reactive power capability) or an ongoing spot market (for short-term reactive power delivery); and (5) centrally procure (such as on a zonal basis) reactive power capability and/or supplies according to a cost-based[10] payment schedule set in advance.[11]

Provision of static reactive power supply through capacitors and load tap changers is generally arranged for by LSEs/electricity distribution companies (EDCs) as a normal part of distribution network planning and operations. The institutional arrangements for providing reactive power supply from static devices are straightforward, as they are an asset owned by LSEs or EDCs. These

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Table 1: Regional Comparison of ISO/RTO Arrangements for Reactive Power Compensation

Region	Method of Compensating Generators for Reactive Power Supply	Provisions for Testing/Confirming Reactive Power Capability of Generators and Other Facilities	Required Power Factor Capability Range for Generators (leading/lagging)	Annual Payment to Generator	Compensation for Lost Profits on Real Energy Sales	Annual Reactive Power Service Requirement
PJM	Payment equal to revenue requirement approved by FERC	Capability test every 5 years	0.95/0.90	$2,430/MVAR[a]	Yes	$185,957,688[b]
NYISO	Capacity	Capability test once a year	0.95/0.90	$3,919/MVAR	Yes	$61,000,000[c]
CAISO	No compensation for operating within power factor range	Tests are not normally run unless ISO detects a problem	0.95/0.90	None[d]	Yes	None
ISO-NE	Capacity	Capability test every 5 years	0.95/0.90	$1050/MVAR	Yes	$12,514,950[e]
SPP	Pass-through of revenues collected by control area operators	Control area operators negotiate with generators	Not available	Not available	Not available	Not available
MISO	Payment equal to revenue requirement approved by FERC	Control area operators negotiate with generators	0.95/0.95	Generator revenues are aggregated by pricing zone	No	Not available
ERCOT	No capacity payment	Capability test every 2 years	0.95/0.95	Paid the avoided cost of DVAR or equivalent equipment	Yes	None

[a] Dividing the total zonal revenue requirement by the total gross lagging MVAR capability at maximum power output for all generators in the zone yields rates ranging from $1005/MVAR-year to $5907/MVAR-year with an average zonal rate or $2,430/MVAR-year. **Source**: http://www.pjm.com/committees/working-groups/rswg/downloads/20050520-item-1-reactive-compensation.pdf.
[b] Available at http://elibrary.ferc.gov/idmws/common/OpenNat.asp?fileID=10443890.
[c] F. Alvaredo *et al.*, *Reactive Power as an Identifiable Ancillary Service*, Mar. 2003, available at http://web.ta-alberta.ca/tar/ReactivePowerasIdentifiableAncillaryService.pdf.
[d] The only true VAR support payment from the ISO to a VAR provider is a special contract covering some privately owned synchronous condensers near Contra Costa, California. **Source**: Email communication with Dave Timpson, CAISO.
[e] ISO-NE VAR Status Report Aug. 1, 2005, states there are 11,919 MVAR of qualified generator VARs. The capacity payment is $1050/MVAR-year for a total of $12,514,950; see http://www.iso-ne.com/stlmnts/iso_rto_tariff/schd2/var_status/2005/VAR%20Status_08_2005.rtf.

devices are simply put into the utility's rate base and fixed and variable costs are recovered via retail rates of the customers served. A similar arrangement can be used for the capital costs of dynamic transmission-based devices (STATCOMs and SVCs) placed in operation by transmission owners.

Generally speaking, ISOs, RTOs, and TOs do compensate generators (both affiliates of vertically integrated utilities and independent power producers, or IPPs) for providing reactive power. The institutional arrangement provides compensation using a cost-based schedule set in advance, usually a payment equal to the generation owner's monthly revenue requirement. In exchange, the generators must be under the control of the control area operator and be operated as dispatchable to produce or absorb reactive power. In some cases, when there is a reduction in real power output due to a request for reactive power production, the RTO will provide an additional payment to compensate the generator for the lost opportunity of delivering real power into the network. Cost-based compensation to generators for providing reactive power supply is regulated by FERC, and all ISOs/RTOs must provide a Schedule 2 tariff for reactive supply and voltage control as part of their Open Access Transmission Tariff (OATT).

There is a significant disconnect between the arrangements for procuring reactive power supply from generators and the arrangements for acquiring reactive power supply from transmission-based sources owned by transmission owners/providers. A transmission owner who mitigates a reactive power compensation problem by investing in a transmission-based reactive power provision will be able to rate base the investment, but at the present

may not receive any Schedule 2 compensation from the RTO. This is despite the possibility that transmission-based solutions may be a least-cost alternative for reactive power supply and be more valuable during system contingencies. The situation for reactive power producing DE is even more ambiguous.

Institutional arrangements directly affect the economic framework for evaluation of investments in providing reactive power supply. Although a generator can rely on a stream of Schedule 2 capacity payments based on the revenue required for their reactive power supply operations, a transmission provider installing a STATCOM or SVC must rely on retail regulator approval of a rate base for recovery of the investment and variable costs. A DG or other DE device would have to either be approved as a source of reactive power supply under Schedule 2, including testing requirements and automatic voltage regulation (AVR), or rely on negotiations with their LSE for a compensation arrangement. Each situation will call for a different economic evaluation framework.

Several of the RTOs – notably ISO-NE, PJM, NYISO – are addressing this disparity in payment provisions for generators and all other sources of reactive power supply. These RTOs are attempting to create a more level playing field by applying the principle of consistent compensation for similar supply types. The objective is a single and consistent compensation approach for all types of reactive power sources that would replace the generator-specific Schedule 2 now in effect.

IV. Locational Pricing for Reactive Power?

Locational reactive power pricing should encourage efficient locational siting of new distributed energy. New generation siting decisions are often based on real power prices and incentives. However, new real power generation that displaces existing real power resources may place an increased burden on the system's need for reactive power due to its location on the network. Alternatively, new generation might choose locations that reduce system reactive power needs if the reactive power pricing incentives are apparent. Because reactive power losses in transmission lines are very high, generators near loads can supply reactive power with much lower losses than generators located long distances from loads. The system's reactive power needs and costs might be addressed through improved pricing mechanisms that encourage siting decisions that are consistent with the system's reliability needs.

The system operator could hold an auction for reactive power capacity in which suppliers would be compensated for a commitment to make reactive power capacity available to the system. This approach allows competition among generation and transmission elements to supply reactive power needs. Requirements would likely be set locally, based on the needs determined by the system operator. This would allow prices to reflect the locational value of reactive power capacity and avoid paying for excess capacity in areas that do not need it.[12] The locational zones for reactive power would most likely be smaller than the zones for real power because reactive power does not travel well and the need is locational in nature. Smaller zones would mean that a larger number of zones would be required, and this adds to market complexity. An option being considered by some ISOs is a single, blanket price to be paid for reactive power regardless of location, and then dispatching the reactive power as needed by the system operator to control voltage and ensure adequate reactive reserves. This approach certainly simplifies the market operation, but it loses the incentive mentioned above to place new generation with the ability to supply reactive power in locations where it is most needed.

V. Examples of Reactive Power Compensation

This section identifies and documents examples of reactive power compensation service market development, administrative solutions, or regulatory frameworks in wholesale markets (transmission level). In particular, it identifies well-developed examples/designs for obligatory reactive power service or market-based reactive power services. Please note that these examples were correct at the time of the preparation of the report upon which this article is based; compensation methods for reactive power are changing quickly, and the reader should not be surprised to find that specific payments for his location differ from the methods provided here.

A. PJM

PJM Interconnection, LLC (PJM) compensates all generators (affiliates of investor-owned utilities and independent power producers) with a payment equal to the generation owner's monthly revenue requirements as accepted or approved by FERC.[13] Dividing the total zonal revenue requirement by the total gross lagging MVAR capability at maximum power output for all generators in the zone yields rates ranging from $1,005/MVAR-year to $5,907/MVAR-year with an average zonal rate of $2,430/MVAR-year. PJM also provides lost-opportunity cost payments when there is a reduction in real power output. These costs are filed with and approved by FERC and are allocated to network transmission service customers in the zone where the generator is located.

B. ISO-NE

ISO New England Inc. (ISO-NE) compensates generators based on four components: (1) capacity costs: the fixed capital costs incurred by a generator associated with the installation and maintenance of the capability of providing reactive power; (2)

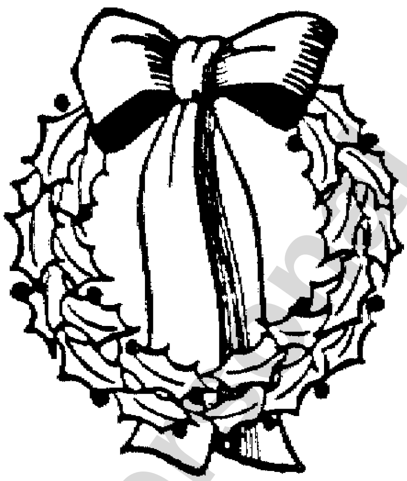
lost opportunity costs: the value of the generator's lost opportunity cost in the energy market where a generator would otherwise be dispatched by ISO-NE to reduce real power output to produce reactive power; (3) cost of energy consumed: the cost solely to provide reactive power support, such as the energy for ''motoring'' a hydroelectric generating unit; and (4) cost of energy produced: the portion of the amount paid to market participants for the hour for energy produced by a generating unit that is considered under the Schedule 2 to be paid for VAR support. ISO-NE provides $1,050 per MVAR-year for reactive compensation and currently has 11,919 MVARs available to receive capacity payments. This translates to an annual compensation of $12.5 million.[14]

C. MISO

The Midwest Independent Transmission System Operator Inc. (MISO) compensates generators owned by transmission owners for providing reactive power. Rates are based on control area operator rates filed at FERC and are paid where the load is located (zonal basis) and loads outside MISO are charged an average system-wide rate. MISO does not provide for lost-opportunity costs for producing reactive power instead of real power. Compensation for reactive power is treated as a pass-through of revenues from individual control area operators.[15] MISO compensates generators owned by transmission owners for providing reactive power, but has no mechanism to compensate IPPs.[16]

D. NYISO

The New York Independent System Operator Inc. (NYISO) compensates all large, conventional generators for reactive power, but those owned by utilities are compensated differently from non-utility generators (or IPPs) under purchased power agreements. Payments are made from a pool consisting of total costs incurred by generators that provide voltage support service, and 2004 rates were calculated by dividing 2002 program costs of $61 million by the 2002 generation capacity expected of 15,570 MVAR, resulting in a compensation rate of $3,919 per MVAR-year.[17]



E. ERCOT

In the Electric Reliability Council of Texas (ERCOT) region, generators must be capable of providing reactive power over at least the range of power factors of 0.95 leading or lagging, measured at the unit's main transformer high-voltage terminals. There is no compensation for reactive power service within this range. Generators receive a variable payment of $2.65 per MVAR-hr for MVARs beyond 0.95 leading/lagging.[18]

F. SPP

The Southwest Power Pool Inc.'s (SPP) compensation for reactive power is a pass-through of the revenues collected by individual control operators.[19] Each control area operator shall specify a voltage or reactive schedule to be maintained by each synchronous generator at a specified bus. Generators shall be able to run at maximum rated reactive and real output according to each unit's capability curve during emergency conditions for as long as acceptable frequency and voltages allow the generator to continue to operate. Generators shall be exempt from this if they meet the following criteria:[20]

- Generator output is less than 20 MW.
- Generation is of intermittent variety (wind generation).

G. CAISO

In the California Independent Service Operator Corporation's (CAISO) service territory generators are required to provide reactive power by operating within a power factor range of 0.90 lagging and 0.95 leading. The CAISO tariff states that generators receive no compensation for operating within this range. Generators that are producing real power are required, upon the ISO's request, to provide reactive energy output outside their standard obligation range, for which they receive lost opportunity costs.

VI. Conclusion

Distributed energy or DE is an attractive option for solving reactive power and distribution system voltage problems because of its proximity to load. Providing dynamic reactive power near the load provides significant economic benefits such as reduced losses, increasing availability of local generation, and improved local voltage control. Several technology options are available to supply reactive power from DE; these include small generators, synchronous condensers, fuel cells, and microturbines. They can provide continuous/variable dynamic reactive power which can respond quickly to reactive power demand.

Several criteria need to be met for DE to become widely integrated as a reactive power resource.

- The overall costs of retrofitting DE devices to absorb or produce reactive power need to be reduced.
- There needs to be a market mechanism in place for ISOs/RTOs/TOs to procure reactive power from the customer side of the meter where DE resides.
- Novel compensation methods need to be introduced to encourage the dispatch of dynamic resources close to areas with critical voltage issues.■

Endnotes:

1. *Principles for Efficient and Reliable Reactive Power Supply and Compensation*, FERC Staff Report, Docket No. AD-05-01-1000, Feb. 4, 2005, available at http://www.ferc.gov/EventCalendar/Files/20050310144430-02-04-05-reactive-power.pdf.

2. Graph includes DE Installations smaller than 5 MW only. Source: The Installed Base of U.S. Distributed Generation, Resource Dynamics Corporation, 2005 Edition.

3. *Id.*

4. *U.S.-Canada Power System Outage Task Force Final Report on the August 14, 2003, Blackout in the United States and Canada: Causes and Recommendations*, Joint US-Canada Power System Outage Task Force, April 2004, at 17, available at ftp://www.nerc.com/pub/sys/all_updl/docs/blackout/ch1-3.pdf.

5. Available at http://www.amsuper.com/products/library/PES_DVR_01_0804a.pdf.

6. Available at http://www.amsuper.com/products/applications/windEnergy/documents/AMSC_EDF_SuperVARResults2006FINAL.pdf.

7. Available at http://www.amsuper.com/products/motorsGenerators/quickVAR.cfm.

8. Available at http://www.amsuper.com/products/motorsGenerators/documents/IEEESuperVAR-030910-Paper.pdf.

9. *Screening Pumping Systems for Energy Savings Opportunities*, available at http://eetd.lbl.gov/ea/indpart/publications/lbnl_53054.pdf#search=%22adjustable%20speed%20drive%20energy%20savings%20doe%22.

10. The cost basis could be actual costs for reactive power provision or could be based on the opportunity costs of providing reactive power in lieu of real power.

11. *Principles for Efficient and Reliable Reactive Power, supra* note 1.

12. *Id.*

13. Available at http://www.pjm.com/documents/ferc/documents/2005/march/20050311-er05623.pdf.

14. Comments from ISO-NE and NEPOOL Committee to FERC, Apr. 2005, Docket No. AD05-1-000, available at http://www.iso-ne.com/regulatory/ferc/filings/2005/apr/ad05_1_000_04_04_05isonepool.pdf.

15. *FERC Report on Supply and Consumption*, Docket AD05-1-000, Feb. 4, 2005, available at http://www.ferc.gov/EventCalendar/Files/20050310144430-02-04-05-reactive-power.pdf.

16. MISO filed with FERC to add a new Schedule 21 to compensate IPPs separately from Schedule 2 compensation of utility-owned generation. On June 25, 2004, FERC rejected the specific proposal for Schedule 2 while agreeing that generators providing reactive power to support the transmission system should be compensated. This issue is still under adjudication. Midwest Independent System Transmission Operator, Inc., Docket No. ER04-961-000 109 FERC 61,005.

17. Available at http://www.nyiso.com/services/documents/b-and-a/rate_2/2005_oatt_mst_sched2_vss_rates.pdf.

18. Available at http://pjm.com/committees/working-groups/rswg/downloads/20050713-item-2-reactive-compen-comp.pdf.

19. FERC Report on Supply and Consumption, Docket AD05-1-000, Feb. 4, 2005, available at http://www.ferc.gov/EventCalendar/Files/20050310144430-02-04-05-reactive-power.pdf.

20. Available at http://www.spp.org/Publications/SPP_Criteria.pdf.

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