REACTIVE POWER MANAGEMENT AND PRICING IN THE CALIFORNIA MARKET

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Abstract: This paper presents the characteristics of reactive power and voltage support and proposes two generic methods for pricing reactive power. The first is a capacity based method and the second is based on actual reactive power production. A combination of both is also presented in the paper as a possible alternative. The framework for reactive power management and pricing along with the specific market rules for the California market is further presented in detail.

Keywords: Reactive Power, Voltage Support, Reactive Power Pricing, Ancillary Services, Electric Industry Restructuring.

I. INTRODUCTION

One of the responsibilities of Independent System Operators (ISOs) is to ensure that reactive power and voltage throughout the system are maintained under both normal and emergency conditions to prevent loss of load and keep system reliability at acceptable levels. The amount of reactive power that needs to be supplied for each transaction must meet specific reliability requirements for maintaining transmission voltage within limits that are generally accepted in the region and consistently adhered to by transmission providers. The reactive power service is one of the control area ancillary services that must be in place to make the provision of electric services possible.

Reactive power is supplied by several different sources, including transmission equipment (such as capacitors, reactors, Static Var Compensators (SVCs) and static compensators), generators, and synchronous condensers. Reactive power does not travel over long distances at high line loadings due to significant losses on the wires. Thus, reactive power usually must be procured from suppliers near where it is needed. This factor limits the geographic scope of the reactive power market and, thus, the number of suppliers that can provide reactive power and the amount of competition at any place and time, at least in the short term before other suppliers can enter the market.

The goal should be to develop rules that ensure that adequate supplies of reactive power (including reactive reserves) are available in all locations to ensure that operation of the grid is reliable and efficient and that reactive power is procured at least cost over the short and long run. As we discuss below, transparent and nondiscriminatory markets and prices for reactive power have the potential to promote this goal.

Reactive power pricing and procurement should be designed to encourage two efficient outcomes. First, it should encourage efficient and reliable investment in the infrastructure needed to maintain the reliability of the transmission system. Second, it should provide incentives for the reliable and efficient production and consumption of reactive power from the existing available infrastructure, taking into account the opportunity costs of the provision of competing uses of the available resources (such as real power and operating reserves). Additionally, it is important that any pricing system allows the system operator real-time control over reactive power resources.

FERC in its Open Access Rule Order No. 888 concluded that "reactive supply and voltage control from generation sources" is one of six ancillary services that transmission providers must include in an open access transmission tariff [1]. The Commission noted that there are two ways of supplying reactive power and controlling voltage: (1) installing facilities as part of the transmission system and (2) using generation facilities. The Commission concluded that the costs of the first would be recovered as part of the cost of basic transmission service and, thus, would not be a separate ancillary service. The second (using generation facilities) would be considered a separate ancillary service and must be unbundled from basic transmission service. In the absence of proof that the generation seller lacks market power in providing reactive power, rates for this ancillary service should be cost-based and established as price caps.

In its recent Generation Interconnection Rule, Order No. 2003, the Commission concluded that a producer should not be compensated for reactive power when operating within its established power factor range. (Under Order No. 2003, the required power factor range is 0.95 leading [producing] and 0.95 lagging [consuming], but the transmission provider may establish a different power factor range.) However, the transmission provider must compensate the producer for reactive power during an emergency.

In some cases reactive power and voltage support is procured through long-term contracts with Reliability Must-Run (RMR) units. In most markets, ISOs compensate generators that provide reactive power and voltage support. These countries include England and Wales, Australia, India, Belgium, the Netherlands, and certain provinces of Canada. Sweden follows a different policy. Reactive power in Sweden is supplied by generators on a mandatory basis without compensation. In the province of Alberta, Canada, generators are penalized for failing to produce or absorb reactive power, and in Argentina, such penalties are imposed not only on generators, but also on transmission operators, distribution operators, and large loads. Finally, in Japan, Tokyo Electric Power Co. gives its retail customers a financial incentive to improve their power factors through discounts of the base rate.

The aim of this paper is to present the basic technical and economic issues related to reactive power management and to develop the framework for managing, procuring, and pricing the reactive power service in the California market. Specifically, the economic and technical issues of providing reactive power and voltage support services are discussed in Section II. Section III presents two basic pricing methodologies for reactive power services. The specific market rules for managing, procuring, and pricing reactive power in the California market are presented in Section IV. The conclusions are summarized in Section V.

II. TECHNICAL AND ECONOMIC ISSUES OF THE REACTIVE POWER SERVICE

This Section reviews the important considerations that affect how the reactive power is managed and priced. They include: reactive power reserves, management of inductive and capacitive reactive power, management of dynamic and static reactive power, and reactive power capacity and production costs.

Adequate supplies of reactive power reserves must be available at all times and distributed throughout the system in order to effectively control voltages. The reactive power reserve requirements, in general, are determined by performing many power flow simulations for various contingencies and operating scenarios. In an interconnected system it is expected that each control area is responsible for providing its share of the reactive power requirements. Reactive power reserves are stored by generating units, synchronous condensers and SVCs and can be applied automatically when contingencies occur.

Reactive power requirements for transmission services are heavily dependent on system conditions. During peak hours, transmission lines are heavily loaded and this in turn leads to large inductive reactive power losses. Under these conditions, generators are usually producing reactive power and capacitor banks are turned on to maintain the reactive power balance and keep voltages within specified limits. During off-peak hours, transmission lines are much less loaded and this leads to much less inductive reactive power losses. Under these conditions, generators are usually consuming reactive power and reactor banks are turned on to absorb the excess reactive power in the system. Therefore, both reactive power production and consumption should be taken into account in determining the reactive power charge.

Furthermore, reactive power support is divided into two categories: static and dynamic. Static reactive power is produced from equipment that, when connected to the system, cannot quickly change the reactive power level. Capacitors and inductors supply and consume static reactive power. These devices act as "baseload" units and usually have little value in satisfying the instantaneous fluctuation of the reactive power requirement. Dynamic reactive power is produced from equipment that can quickly change the MVAR level independent of the voltage level. Thus, the equipment can increase its reactive power production level when voltage drops and prevent a voltage collapse. SVCs, synchronous condensers, and generators provide dynamic reactive power. The equivalent "AGC" function for reactive power is achieved by using these devises [2].

Both the variable and fixed costs of producing static reactive power are much lower than those of producing dynamic reactive power. If cost were the only issue, a transmission provider at any instant in time would use static reactive power equipment first in procuring reactive power, and use the dynamic equipment only after the static equipment had been fully used. However, two factors force transmission providers at times to use more expensive dynamic reactive power sources in place of cheaper sources. First, the lowest cost sources cannot always produce reactive power as reliably as necessary. Second, because reactive power does not travel far (due to significant transmission losses), it usually must be produced near the location where it is needed. Thus, expensive reactive power sources must sometimes be purchased even if cheaper sources are idle because the expensive source is more reliable and/or is near the location needing the reactive power, while the cheaper sources cannot get the reactive power to where it is needed.

In terms of costs, a generator's cost of producing reactive power can sometimes include opportunity costs associated with forgone real power production. When a generator is operating at certain limits, a generator can increase its production or consumption of reactive power only by reducing its production of real power. As a result, producing additional reactive power results in reduced revenues associated with reduced real-power production. In general, however, the variable costs of producing reactive power are often negligible compared to the costs of providing reactive power capacity. Furthermore, if pricing of reactive power is based on capacity, gaming opportunities among generators, by creating circulating reactive power flows, are reduced. This means that it may be preferable to have all costs recovered from a capacity related payment only. In some markets, such as the British system, the majority of cots are recovered from a reactive power capacity payment and the rest from the actual reactive power production [3].

III. REACTIVE POWER PRICING OPTIONS

In both ISO and non-ISO markets, reactive power capability is paid on a cost-of-service basis to transmission suppliers. Static sources of reactive power such as capacitors, generally have their costs rolled into transmission charges or into the regulated retail rate structure [4-5]. As far as generators are concerned, there are two general ways to compensate them for providing reactive power.

One way is the capacity payment option, in which the generator is paid in advance for the capability of producing or consuming reactive power. The payment could be made through a bilateral contract or through a generally applicable tariff provision. Once the generator is paid, it could be obligated to produce or consume reactive power up to the limits of its commitment without further compensation when instructed by the ISO. To ensure that the generator follows instructions in real time, the generator could face penalties for failing to produce or consume when instructed. Currently, this is the most common method for compensating reactive power providers. The other way is the real-time price option, in which the generator is paid in real-time for the reactive power that it actually produces or consumes. This pricing option falls under the general method of nodal reactive power pricing [6-8]. Under this option, the generator is paid only for what it produces or consumes, but it pays no penalty for failing to produce when instructed. It is also possible to combine some of the features of each of these options. For example, a generator might receive a capacity payment in advance in exchange for the obligation to produce or consume reactive power within a specified power factor range upon instruction by the ISO, but might also receive a spot price for producing or consuming additional reactive power beyond the specified range.

The capacity payment under the capacity payment option, can be based on cost based methods or the ISO could hold an auction for reactive power capability and the winners of the auction would receive the applicable market clearing price.

Under the real time option, the payment could be based on one of the following:

1) Pay nothing for reactive power produced within a specified power factor range. This option may be most appealing when the generator has received a capacity payment in advance for the capability to produce within the specified range.

2) Pay unit-specific opportunity costs due to reduced real power production.

3) Pay Market Clearing Prices determined through auction. MCPs are based on a spot market auction for reactive power. In the auction, all accepted bidders at a location could receive the same market-clearing price based on the highest accepted bid. One issue for the auction is whether reactive power prices (i) are calculated directly or (ii) are derived from the implicit opportunity costs associated with real power prices and the supplier's real-power energy bids. Under the direct pricing approach, reactive power sellers would submit price bids for supplying (or consuming) specific amounts of reactive power, and the reactive power price at any location and time would be the highest accepted price bid. Under the derived approach, reactive power suppliers would submit price bids for supplying real power as well as information indicating the trade-off between supplying various amounts of real and reactive power. However, the supplier would not submit a specific price bid for producing reactive power. From the submitted information, the ISO would calculate the implicit opportunity cost (i.e., the forgone real-power revenue associated with supplying or consuming reactive power) incurred by each supplier. The price for reactive power in the auction would be calculated based on these derived opportunity costs.

4) Pay a price based on a pricing formula announced in advance. This method is currently used in the United Kingdom and India.

Choosing among the options depends on the goals and objectives. Clearly, adoption of a bid-based reactive power spot market has substantial benefits, but more experience is needed to better understand the impact of various design alternatives. Furthermore, the issue of market power in reactive power markets needs to be addressed. It is expected that with the advent of technology and new equipment, the barrier to entry and consequently market power will be substantially mitigated. At the present time the majority of markets have implemented the opportunity cost based option [9].

IV. THE CALIFORNIA REACTIVE POWER MARKET

Reactive Power Management

ISO Responsibilities

The main responsibility for reactive power management in the California ISO Grid lies with the California ISO. The ISO monitors loads and generators for operation at the appropriate voltage level, verifies that each Participating Entity complies with voltage support requirements, and coordinates adjustments to prevent offsetting or competing voltage support measures. The ISO also monitors the interconnections with other Control Areas to confirm that the interconnected power system is operated at the appropriate voltage level with acceptable MVAR exchange, and coordinates adjustments with interconnected Control Areas as needed.

More specifically, the ISO coordinates the use of voltage support equipment among Participating Transmission Owners (PTOs), Utility Distribution Companies (UDCs), Generators, and other Control Areas in order to:

- Ensure that Participating Entities maintain appropriate voltage schedules;
- Ensure that Participating UDCs maintain reactive power flow at grid interface points within an appropriate power factor range, namely, 0.97 lag and 0.99 lead;
- Coordinate switching of voltage support equipment such as shunt capacitors and reactors;
- Ensure that Participating Generating units operate within an appropriate power factor range, namely, 0.90 lag and 0.95 lead, unless otherwise specified in the relevant Participating Generator Agreement (PGA);
- Coordinate events and changes that impact the voltage support equipment availability, reliability, or ability to operate within its applicable power factor range;
- Ensure that the grid provides the appropriate reactive power supply and reserves to the interconnected power system; and
- Coordinate and optimize voltage schedules and VAR flows between Control Areas for system stability.

The California ISO does not operate a formal reactive power market. Reactive power and voltage support is procured through long-term contracts with Reliability Must-Run (RMR) units. There are two types of these contracts: Condition 1 and Condition 2. Condition 1 RMR units may bid and participate in the market, but if they are needed for reliability, their bids are mitigated to contractual cost-based rates, and they receive a portion of their fixed costs. Even if Condition 1 RMR units do not bid in the Day-Ahead Market, the ISO may issue a RMR dispatch notice for these units to run if they are needed for reliability. Condition 2 RMR units may not bid in the market, but are dispatched by the ISO as needed for reliability and they are paid all their fixed and operating costs.

Aside from dispatching RMR Units, nominal voltage support is automatically obtained from all Participating Generating units operating within their applicable power factor range. Under exceptional conditions, the ISO may request additional Voltage Support requiring operation outside of that power factor range.

The ISO conducts power flow studies periodically to determine future reliability and voltage/reactive power requirements of the grid, reevaluating RMR contracts.

Participating Entity Responsibilities

Besides the ISO, Participating Entities are also responsible for reactive power management.

Participating Generators operate generating units within established protocols and procedures, specifically normal MW/MVAR capacity profiles, at the applicable voltage schedule. Participating Generators produce or consume reactive power when requested by the ISO, and notify the ISO of coordinated voltage support equipment switching and of events and changes that impact the MW/MVAR capacity, reliability, or ability to operate within the applicable power factor range.

Participating Loads/UDCs operate in accordance with Good Utility Practice within established protocols and Operating Procedures, and adhere to specified voltage schedules. Participating Loads/UDCs maintain reactive power flow at grid interface points within the applicable power factor range, and notify the ISO of coordinated voltage support equipment switching and of events and changes that impact the voltage support equipment availability, reliability, or ability to operate within the applicable power factor range.

Participating Transmission Owners operate the system in accordance with Good Utility Practice and in a manner that ensures safe and reliable operation. PTOs maintain appropriate voltage schedules, and notify the ISO of coordinated voltage support equipment switching and of events and changes that impact the voltage support equipment availability, or reliability.

Voltage Support Remuneration

Due to its locational effect and use, reactive power and voltage support is a reliability service that cannot be procured through a market via a competitive auction as other ancillary services because of market power concerns. Voltage support is mainly procured through long-term contracts with RMR units. Remuneration for voltage support is thus subject to the specific contractual arrangements.

There is no remuneration for nominal voltage support from Participating Generating units while they operate within their applicable power factor range. This is because supply or consumption of reactive power within that range does not have an appreciable impact on the active power generation capability, thus it does not impede full participation in the energy market or the fulfillment of any contractual energy agreements or financial commitments such as the Day-Ahead schedule.

However, if the ISO instructs the unit to provide additional voltage support by operating outside of the applicable power factor range, the additional reactive power supply or consumption usually comes at some expense of active power generation and thus may result in some lost opportunity cost. In this case, the additional voltage support is remunerated the lost opportunity cost (LOC), which is calculated as follows:

$$LOC = \int_a^b \max\left(0, LMP - c(p)\right) dp$$

Where:

LMP	is the Locational Marginal Price at the unit location;
p	is the unit operating level;
$c(p)$	is the unit energy bid as a function of its operating level;
b	is the highest operating level of the unit's energy bid; and

a	is the dispatch operating level required for additional Voltage Support.

Figure 1 illustrates the calculation of the LOC for additional voltage support that requires operation outside of the normal power factor range, based on typical P-Q generating unit capability curves.

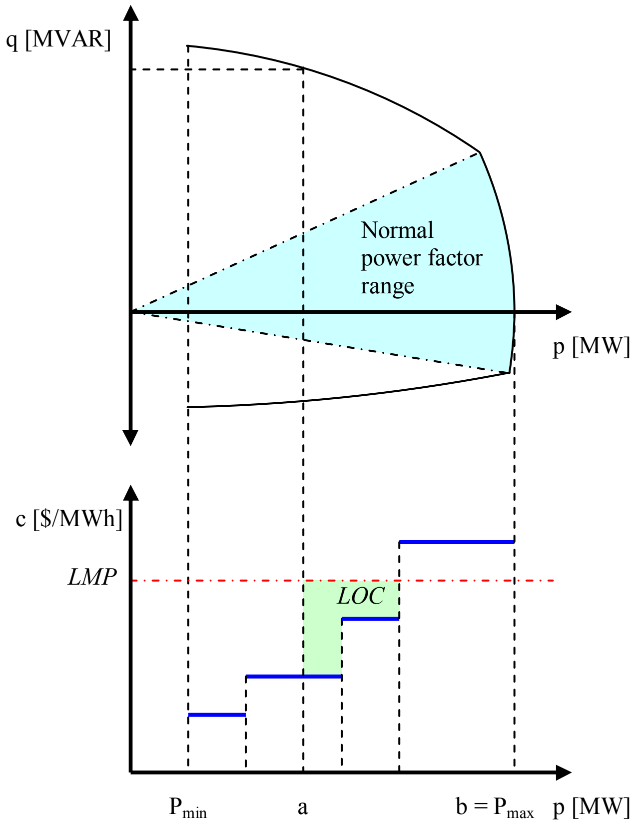

Figure 1. *Lost Opportunity Cost calculation for Voltage Support*

There is no remuneration for voltage support from Participating Loads/UDCs while operating within their applicable power factor range. There is also no remuneration for voltage support from PTOs switching or adjusting Voltage Support equipment such as shunt or series capacitors or reactors, tap-changing transformers, static VAR compensators, etc.

V. CONCLUSION

This paper presents the characteristics of reactive power and voltage support and proposes two generic methods for pricing reactive power. The first is a capacity based method and the second is based on actual reactive power production. A combination of both is also presented in the paper as a possible alternative. The framework for reactive power management and pricing along with the specific market rules for the California market is further presented in detail.

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VII. BIOGRAPHIES

Dr. Alex Papalexopoulos is president and founder of ECCO International, a specialized Energy Consulting Company that provides consulting services and expert advice on electricity market design, power systems, energy management systems and software issues within and outside the U.S. to a wide range of clients such as Regulators, Governments, Utilities, Independent System Operators, Power Exchanges, Marketers, and Brokers. Prior to forming ECCO International in 1998, Alex was a director of the PG&E’s Electric Industry Restructuring Group in San Francisco, California. He has made substantial contributions in the areas of network grid optimization and pricing, ancillary services, congestion management, competitive bidding, forward and real-time energy markets and implementation of EMS applications and real time control functions and forecasting. Dr. Alex Papalexopoulos received the Electrical and Mechanical Engineering Diploma from the National Technical University of Athens, Greece in 1980, and the M.S. and Ph.D. degrees in Electrical Engineering from the Georgia Institute of Technology, Atlanta, Georgia in 1982 and 1985, respectively. He has published numerous scientific papers in IEEE and other Journals. He is the 1992 recipient of PG&E's Wall of Fame Award, and the 1996 recipient of IEEE’s PES Prize Paper Award. He is a Fellow of IEEE.

Dr. George A. Angelidis was born in Athens, Greece, in 1962. He received his B.Sc. degree from the Aristotle University of Thessaloniki in 1984, and his M.A.Sc. and Ph.D. degrees from the University of Toronto in 1988 and 1992, respectively, all in Electrical Engineering. He worked for four years for the Pacific Gas and Electric Company in San Francisco as a Principal Market Analyst on issues related to the California Electricity Industry Restructuring. He is currently an Independent Consultant, associated with ECCO International, working for the Market Operations Department of the California Independent System Operator where he is involved heavily in the design and implementation of many aspects of the California Electricity market. His research interests and expertise are in electricity market design and advanced computer applications in large-scale electric power systems, with emphasis on steady-state and dynamic analysis and optimization. Dr. Angelidis is a member of IEEE and the Technical Chamber of Greece.