Reactive Power Management and Pricing Policies in Deregulated Power System: A Global Perspective

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Abstract
The present paper address the need for reactive power management and its pricing in deregulated power systems nowadays. Different reactive power support equipments differ in their costs and operating characteristics. A selection of an appropriate reactive power pricing scheme is an important issue for recovering reactive service costs and providing signals to users to control their reactive power consumption. Many nations have successfully framed and implemented reactive power pricing policies. Those pricing policies along with some proposals for Indian states are also discussed here.
Keywords: Reactive power management, reactive power pricing policies, reactive power market

1. Introduction

In steady state operation of electrical power systems, both active power and reactive power balances must be maintained. The reactive power generated by synchronous machines and shunt capacitances must be equal to the reactive power of the loads plus the reactive transmission losses. If the active power balance is not kept, the frequency in the system will be influenced, while an imbalance in reactive power will result in that the voltages in the system differ from the desired ones. As known from the Static Analysis, the voltage in a system is strongly affected by the reactive power flow. Consequently the voltage can be controlled to desired values, by control of the reactive power. Increased production of reactive power gives higher voltage in the vicinity of the production source, while an increased consumption of reactive power gives lower voltage. Therefore it is of great interest to study which components and devices can be optimally used to regulate the reactive power in a power system.

Initially, up to late 90’s, in vertically integrated power utility structure, the responsibility of generation, transmission and distribution of electric energy was centralized at one organization. Ancillary services such as reactive power support were also an integral part of the electricity supply and not separated. Reactive power support was only considered as a technical/engineering but not managerial/economic issue hence it was the obligation to all generators in the system to fulfill the local reactive power demand and further no extra incentive was given for this service. Therefore studies conducted before restructuring focused on whether reactive power and other alternating current characteristics were being represented correctly in engineering calculations, such as contingency models and distribution factors.

However, with the deregulation of the power industry, the main power system entities such as generation, transmission and distribution have become separate businesses. An idea of competitive electricity market is emerged for providing better economy, efficiency and services through competition in generation and distribution segments. The Independent System Operator (ISO) has to ensure the reliability and security of the entire power system with the help of ancillary services. ISO procure various services such as supply of emergency reserves and/or reactive power from other entities at reasonable price in efficient manner. Both, the technical as well as economic aspect of reactive power provision are considered by ISO. The technical aspect involves various issues like power system security, reliability, efficiency, optimal scheduling of generating units considering real and reactive power losses etc., whereas economic aspect involve the market structure, pricing scheme, cost minimization of losses and capital for procurement and dispatch, market settlements etc.

2. Need of Reactive Power Management

In AC power system, voltage is controlled by managing production and absorption of reactive power. At very light loading the system generates reactive power that must be absorbed, while at heavy loading the system consumes a large amount of reactive power that must be replaced. Injecting reactive power into the system raises voltages, and absorbing reactive power lowers voltages.

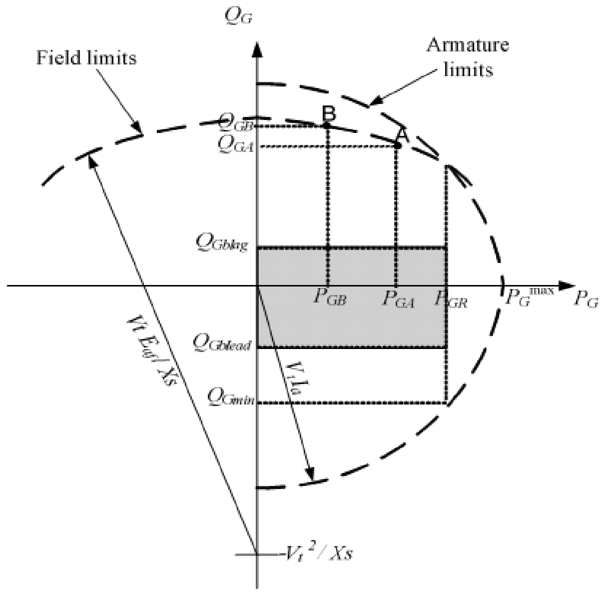

Figure 1. Synchronous Generator Capability Curve

It is necessary to manage reactive power and control voltage due to following reasons:

- Both customer and power-system equipment are designed to operate usually within a range ±5% of the nominal voltage. At low voltages, many types of equipment perform poorly; light bulbs provide less illumination, induction motors can overheat and be damaged, and some electronic equipment will not operate at all. High voltages can damage equipment and shorten their lifetimes.

- Reactive power consumes transmission and generation resources. To maximize the amount of real power that can be transferred across a congested transmission interface, reactive-power flows must be minimized.
- Reactive power production can limit a generator's real-power capability. The shaded area in Fig. 1 represents the obligatory base reactive power provision range set by the system operator. Any reactive power provision required by the operator beyond this area is eligible for payment, due to the increased cost of losses in its windings. Such *mandatory* and *ancillary* classification of reactive power capability is in line with what most system operators have in place for reactive power management. For example, the Independent Electricity System Operator (IESO) of Ontario requires a mandatory provision from all generators within the power factor range of 0.9 lead and 0.95 lag. Because of the requirement that reactive power generated should be within or on the limiting curve, i.e., in the dotted area in Fig. 1 ($Q_{GA} \leq Q_G \leq Q_{GB}$), any reactive output increase requested by the ISO beyond Q_{GA} will require a decrease in active power generation, and hence an *opportunity cost payment* is expected for the reactive power service to account for the lost opportunity of the generator to sell its real power in the energy market and the associated revenue loss. Generator's maximum production or consumption of reactive power increases as its real power production is reduced below the maximum level.
- Moving reactive power on the transmission system incurs real-power losses. Both capacity and energy must be supplied to replace these losses. Reactive power does not travel far on the transmission system, and many electrical and physical requirements determine where the reactive resources need to be placed and how they are used.
- System Voltage collapse: A major reactive power insufficiency has already caused a problem of voltage collapse and blackout in different countries. Due to voltage collapse, the blackouts of July 2, 1996 resulted in United States, and August 10, 1996, on the West Coast. Voltage collapse also factored in the blackouts of December 19, 1978, in France; July 23, 1987, in Tokyo; March 13, 1989, in Québec; August 28, 2003, in London; September 23, 2003, in Sweden and Denmark; and September 28, 2003, in Italy. While the August 14, 2003, blackout in the United States and Canada was not due to a voltage collapse as that term has been traditionally used by power system engineers, the U.S.-Canada Power System Outage Task Force Final Report April 2004 said that "insufficient reactive power was an issue in the blackout."

3. Reactive Power Support Devices and Their Locations

A sufficient reactive power support need to be provided in the system in order to maintain the power flow limits on transmission lines and voltage limits at bus bars. Also, since it is not desirable to transport reactive power over the network, it should be procured at different locations in the system depending upon perceived demand condition, mix of load and availability of reactive support devices. Reactive power support devices can be broadly categorized as Dynamic & Static sources. The cost of various equipment, applications and characteristics such as ability to support voltage for these power support devices are listed below in Table 1.

4. Reactive Power Markets and Pricing

Reactive power pricing in real time addresses the important issue of providing information to both the utility and customers about the true burden on the system in terms of the cost and other system parameters viz. voltage drop and increases transmission losses from time to time. Real time pricing of reactive power has been shown to perform better than power factor penalty scheme in terms of providing incentive to all customers to reduce their consumption of reactive power irrespective of their power factor. In other words Reactive Power Pricing is a fair chance of earning normal profits (or, equivalently, of recovering costs on these services). Reactive power pricing also provide signals that encourage customer to make efficient choice about how they use or consume reactive power.

Table 1. Different types of reactive power support equipments used for voltage control

<table>
<tr><th>Equipment*</th><th>Ability to support Voltage*</th><th>Capital cost (per KVAr)*</th><th>Operating cost*</th><th>Opportunity Cost*</th><th>Category of Reactive power Support devices</th><th>Applications</th></tr>
<tr><td>STATCOM</td><td>Fair, drops with V</td><td>$50-55</td><td>Moderate</td><td>NO</td><td rowspan="4">Dynamic Reactive Sources
Merits and Demerits:
• These are fast, continuous & controllable reactive support devices.
• Dynamic reactive devices can, on demand, increase their output above the normal rating for short periods of time.
• Synchronous machines can produce several multiples of their normal reactive power rating for short periods.</td><td rowspan="4">Dynamic reactive resources are typically used to adapt to rapidly changing conditions on the transmission system, such as sudden loss of generators or transmission facilities.</td></tr>
<tr><td>Static VAr compensator</td><td>Poor, above its rated value it drops with V^2</td><td>$45-50</td><td>Moderate</td><td>NO</td></tr>
<tr><td>Synchronous condenser</td><td>Excellent, additional short- term capacity</td><td>$30-35</td><td>High</td><td>NO</td></tr>
<tr><td>Generator</td><td>Excellent, additional short- term capacity</td><td>Difficult to separate</td><td>High</td><td>Yes</td></tr>
<tr><td>Capacitor</td><td>Poor, drops with V^2</td><td>$8-10</td><td>Very low</td><td>NO</td><td colspan="2">Static devices are typically used to adapt to slowly changing system conditions such as daily and seasonal load cycles and changes to scheduled transactions.</td></tr>
</table>

*Source: Reactive power as an identifiable ancillary service (March 18, 2003) By Fernando Alvarado *et al.*
*An appropriate combination of both static and dynamic resources is needed to ensure reliable operation of the transmission system.

5. Reactive support schemes and pricing mechanisms

5.1. England and Wales(UK)

The National Grid Company(NGC), like the ISO, arranges the tenders of reactive support services. The generator bid reactive power support includes capacity (price per MVAr and quantity on offer) and utilization (MVAr-h price curve) components. The bidder that is selected is paid for both the capacity and utilization components through annual bilateral contracts with NGC.

The Grid Code places a minimum obligation on all generating units, with a power generating capacity more than 50 MW, to provide a basic (mandatory) reactive power service. In order to receive payment for this service, the generators must enter into *a Default Payment mechanism (DPM)* or a tendering system. The tendering system consist of either an *Obligatory Reactive power Service (ORPS)* or an *Enhanced Reactive Power Service (ERPS).*As an incentive for generators to enter the tendering system, the *DPM* ratio of capability to utilization was introduce as 80:20 in 1997/98 when the scheme was started and was them modified incrementally to 0:100 up to the April 2000.Alternatively, the generators can tender specific prices for capability and utilization with regards to *ORPS* or *ERPS.* The rounds for tenders have been held every six months since 1997 and the ninth tender round was for contracts effective from 1 April, 2002.The tenders are for supplying a reactive service for a period of twelve months or more.

The cost of providing reactive power services is currently recovered by National Grid via use of system charge in the balancing mechanism. The cost of Reactive power contracts are recovered by National Grid via the daily IBC (Incentive Balancing Cost). These are the cost that National Grid is incentivized to manage and are the basis upon which incentive payment to (or from) National Grid is calculated. The Reactive power contracts costs are included in the daily BSCCA (Balancing Service Contract Costs Allocation) that is a component of IBC.

5.2. United States

NYISO (New York Independent System Operator) is responsible for operating the transmission system in the New York State. In Operating the transmission system NYISO is required to procure reactive power services from generators. Reactive power services are specified ancillary services and therefore qualify for payments for the provision of such services. In order to qualify for payment, suppliers of voltage support services must provide as resource that has an Automatic Voltage Regulator (AVR) and has passed reactive power capability testing in accordance with the NYISO procedures and standards. The NYISO directs the suppliers to operate within their tested reactive capability limits. The schedule of voltage support services is the responsibility of NYISO and the transmission owners. The transmission owners are responsible for the local control of reactive power support. The NYISO provides reactive power support service at embedded cost based price. The reactive power support cost includes:

- The total annual embedded cost for payment.
- Any applicable lost opportunity cost to provide reactive power service.
- Total of prior year payments to suppliers of reactive power service less the total of payments received by the NYISO from transmission customers in the prior year for reactive power service.

5.3. Nordic Electricity Market (Norway, Sweden, Finland and Denmark)

In Norway, the generators are paid for reactive power service if only the generators operate in a power factor beyond the mandatory operating range of 0.92 lagging to 0.98 leading.

In Sweden, there is not any organized reactive power market but reactive power service is provided on a mandatory basis and there is no scheme for financial compensation to the providers of this service. The reactive power exchange on the national grid is controlled by instructions from the *Svenska Kraftnät*, the Swedish ISO. It is recommended that reactive power flow between different parts of the grid be kept near zero. The ISO has the right to supply reactive power from spinning generators connected directly to the national grid.

In Finland, *Fingrid* is responsible for the maintenance of adequate reactive power reserves. This is done through the use of its own resources and also by acquiring reactive reserves from Independent parties. Now this provision becomes mandatory. As per the guidelines, generators of more than 10 MVA rating are required to maintain reactive power reserves during the normal status of the power system.

5.4. Australia

The NEMMCO (National Electricity Market Management Company Limited) an ISO is responsible for reactive power provision same as NYISO. With regard to the reactive power provision scheduled generators are required to provide obligatory reactive power provision and the generator receives no payment.

The provision of a network transmission service requires reactive power support; therefore the Transmission Network Service Providers (TNSP) must provide a significant amount of reactive power support in order to ensure such a provision. The reactive power support provided by TNSP is available to NEMMCO to utilize free of charge. NEMMCO will utilize all obligatory generator reactive power support and all TNSP reactive power support in order to maintain the security of Power System. Where NEMMCO requires additional reactive power support it is procured via a contract tender process. Suppliers of such power services are paid by NEMMCO as follows:

- *Generators:* Availability + Compensation fee.
- *Synchronous Compensators:* Availability + Enabling fee.

Availability fee is related to the supplier's readiness in providing the service. Compensation fee is related to opportunity cost to a supplier. Enabling fee is related to the start-up of the service by a supplier. The NEMMCO mandates that generators provide reactive power in the power factor range of 0.9 lagging to 0.93 leading. If a generator operates in a power factor beyond this range then it will be compensated financially based on the lost opportunity cost.

5.5. India

According to the CERC (Central Electricity Regulatory Commission) Notification No.L/68(84)/2006-CERC (14th March, 2006), the beneficiaries are expected to provide local VAr compensation/generation such that they do not draw VArs from the EHV grid, particularly under low-voltage condition. However, considering the present limitations, this is not being insisted upon. Instead, to discourage VAr drawl by Beneficiaries, VAr exchanges with Inter State Transmission System (ISTS) shall be priced as follows:

- The Beneficiary pays for VAr drawl when voltage at the metering point is below 97%
- The Beneficiary gets paid for VAr return when voltage is below 97%
- The Beneficiary gets paid for VAr drawl when voltage is above 103% Indian Electricity Grid Code (IEGC) 51.
- The Beneficiary pays for VAr return when voltage is above 103%

The charges of reactive power support are user-specific. According to CERC Approach Paper on Formulating Pricing Methodology for Inter-State Transmission in India,(May 15, 2009), CERC imposes a 5 paisa/kVArh (~$1/MVArh) price on reactive power in over-voltage and under-voltage conditions (1.03 < voltage < 0.97). Table 2 presents a snapshot of reactive pricing schemes and proposals for Indian states.

Table 2: Reactive pricing schemes and proposals for different states of India

State	Reactive Power Pricing Scheme
Gujrat[1]	Tariff for reactive energy drawl by *Bagasse* based cogeneration shall be the same as that for solar or wind generators, which is as under: • 10 paisa/ kVArh: For the drawl of reactive energy at 10% or less of the net energy exported. • 25 paisa/kVArh: For the drawl of reactive energy at more than 10% of the net active energy exported.
Haryana[2]	Reactive Energy charge @5paise/unit on utilities for drawl at voltage lower than 97% of the normal voltage and for reactive energy injection at voltage higher than 103% of the normal levels.
Maharashtra[3]	The Bombay Electric Supply and Transport Undertaking (BEST) has implemented a system, in which there is an additional charge on kVArh recorded instead of penalty charge on low p.f. During 1996-97, BEST introduced a double-metered tariff based on kWh and kVArh meter reading for voltage class LT consumers. The charges on kVArh reading were roughly 40-50% of the charges on the kWh bill.
Orissa[4]	Reactive Energy Charges @6.00paisa/kVArh for FY 2010-11 in line with the Commission's order dated 06.04.2009 in Case No. 22/2009 on Reactive Energy Charges for FY 2009-10 and as per Clause 1.7 of Orissa Grid Code 2006 which states that the rate for charge/payment of Reactive Energy Charges shall be 5 paisa/kVArh with effect from 14.06.2006 and shall be escalated at 0.25 paisa/kVArh per year thereafter, unless otherwise revised by Orissa Electricity Regulatory Commission (OERC).
Tamil Nadu[5]	Reactive energy charges of 5 paisa/kVArh with effect from 1-4-2006 with an escalation of 0.25 paisa/kVArh every year thereafter. The present order stipulates reactive power charges @6 paisa/kVArh. The Commission wishes to adopt the IEGC and therefore prescribes 5.75 paisa/kVArh as on 1-4-2009 and escalated by 0.25 paisa/kVArh every year thereafter.
Uttar Pradesh[6]	If the power factor of a consumer is leading and is within the range of 0.95-1.00 then for tariff application purposes the same shall be treated as unity. However, if the leading power factor was below 0.95 (lead) then the consumer was to be billed as per the kVAh reading indicated by the meter. The cutoff of 0.95 (lead) was consciously adopted by the Commission because below 0.95(lead) the reactive compensation of the consumer may relax the grid slightly but at the same time it may cause localized over-voltages that may endange the surrounding system.

6. Conclusion

In this paper, after highlighting the characteristics and need of reactive power, the discussion is focused on various power support devices used for reactive power management and overview of various reactive power pricing mechanism. We have tried to investigate how reactive power support over the system is managed along with some proposals in the various deregulated power systems. This varies from one country (or state) to another in the way power contracts are framed, or payment mechanism is devised or the power system is operated. In India, most of the reactive powers pricing schemes proposed are based on penalty factor based charges.

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