Reactive Power Pricing Framework Problems & a proposal for a competitive market

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***Abstract* - It is necessary to restructure the reactive power pricing framework. The exchange of real energy is the dominant intention of the electric power exchange and the reactive power has its inherent limitation. But the importance and stimulation effect of a effective reactive power cost structure is important also, especially to the performance of the power market, the quality of electric power exchange and the security of the power system. This paper explores the technical and economic issues of determining reactive power pricing structures in an open-access environment. It also discusses the necessity of the Reactive Power. This paper also reveals different aspects of Reactive Power Pricing. Since Reactive Power Pricing carries significant importance, different mechanisms of Reactive Power Pricing are proposed. Little attention is paid in the literature to reactive power reserve and its price. If this approach is achieved and a clear reactive reserve market established, the security margin of the system increases and the transaction of even more active power will be possible without considering a voltage collapse problem.**

***Keywords:* Deregulated Power System, Reactive Power, Reactive Power Sources, Reactive Power Pricing.**

1. INTRODUCTION

Deregulation in power industry is a restructuring of the rules and providing economic incentives by the government to control and drive the electric power industry. One of the first steps in the restructuring process of the power industry is that separation of the transmission activities from the generation activities. The subsequent step was to introduce competition in generation activates either through the creation of power pool, provision for the direct bilateral transaction or bidding in the spot market. An important point is to note that the restructuring process was however not uniform in all countries. In brief, Electric utilities are expected to split apart into unbundled companies, with each utility re-aligning itself into several other companies that respectively focus on each part of the new industry, i.e power delivery and retailing. This is known as Desegregation.[6]

In a deregulated power system, the main responsibility of an independent system operator (ISO) is to maintain system reliability and security by using ancillary services. To maintain the power flow limits on transmission lines as well as voltage limits at bus bars, sufficient reactive power is vital for the power system. In the vertically integrated utility

(VIU) structure, generation, transmission, and distribution were owned by a single entity, and consequently reactive power provision and voltage support were bundled with other services in supplying electricity to the customers. However, in the deregulated environment of the United States, like many other deregulated electricity industries, reactive support and voltage control from generation source, according to FERC order 888, is known as one of the six ancillary services. In the new open access environment, in pursuit of profit, the power producer has the incentive to sell active power as much as possible. A generator can sell its active power if only there is enough reactive power to support it. Otherwise, the generator is no longer able to sell active power due to system security constraints (e.g., the voltage stability limits). So, it is essential to establish *a* mechanism for financial compensation of the reactive power ancillary service.[4]

Analyzing the costs of providing reactive power services and establishing an appropriate price structure are important both financially and operationally for the deregulated electric industry. First, correct price signals will facilitate transmission access and improve economic efficiency. With the proper costing and pricing of reactive power, transmission users will have the ability to make intelligent decisions about economic activities such as energy transactions, investments, and asset utilization. Second, the efficiency and reliability of system operation will be improved when well-balanced reactive power resources are available to support the transmission network since active power losses in the transmission system will be reduced by properly distributing reactive power generation. Last, voltage profiles will be improved which, in turn, will reduce the incidents caused by high and low voltage problems.[1]

Reactive power management [3] and payment mechanisms differ from one electricity market to another, and no uniform structure or design has yet evolved. In most cases, the ISO enters into contracts with the reactive power providers for procurement of their services. These contracts are usually bilateral agreements based on ISO experience and traditional practices used for reactive power support, rather than through well formulated competition mechanisms.
When transmission operation[1] an d control are independent of the generation system, the reactive power charge, in principle, should recover all costs of producing reactive power from all facilities which are not included in the transmission ratebase. In order to establish a price for the reactive power, however, multiple and conflicting objectives have to be balanced. These include technical and economic considerations, such as maintaining system reliability, providing correct signals for system expansion, simplifying the administrative requirements, and ensuring equity among the transmission customers.

II SOURCES OF REACTIVE POWER

Reactive power [5] is a concept used by engineers to describe the background energy movement in an Alternating Current (AC) system arising from the production of electric and magnetic fields. These fields store energy which changes through each AC cycle. Devices which store energy by virtue of a magnetic field produced by a flow of current are said to absorb reactive power; those which store energy by virtue of electric fields are said to generate reactive power. Power flows, both actual and potential, must be carefully controlled for a power system to operate within acceptable voltage limits. Reactive power flows can give rise to substantial voltage changes across the system, which means that it is necessary to maintain reactive power balances between sources of generation and points of demand on a 'zonal basis'. Unlike system frequency, which is consistent throughout an interconnected system, voltages experienced at points across the system form a "voltage profile" which is uniquely related to local generation and demand at that instant, and is also affected by the prevailing system network arrangements. National Grid is obliged to secure the transmission network to closely defined voltage and stability criteria. This is predominantly achieved through circuit arrangements, transformers and shunt or static compensation.

Sources of Reactive Power

Most equipment connected to the electricity system will generate or absorb reactive power, but not all can be used economically to control voltage. Principally synchronous generators and specialized compensation equipment are used to set the voltage at particular points in the system, which elsewhere is determined by the reactive power flows.

Synchronous Generators -Synchronous machines can be made to generate or absorb reactive power depending upon the excitation (a form of generator control) applied. The output of synchronous machines is continuously variable over the operating range and
automatic voltage regulators can be used to control the output so as to maintain a constant system voltage.

Synchronous Compensators - Certain smaller generators, once run up to speed and synchronized to the system, can be declutched from their turbine and provide reactive power without producing real power. This mode of operation is called Synchronous Compensation.

Capacitive and Inductive Compensators - These are devices that can be connected to the system to adjust voltage levels. A capacitive compensator produces an electric field thereby generating reactive power whilst an inductive compensator produces a magnetic field to absorb reactive power. Compensation devices are available as either capacitive or inductive alone or as a hybrid to provide both generation and absorption of reactive power.

Overhead Lines and Underground Cables - Overhead lines and underground cables, when operating at the normal system voltage, both produce strong electric fields and so generate reactive power. When current flows through a line or cable it produces a magnetic field which absorbs reactive power. A lightly loaded overhead line is a net generator of reactive power whilst a heavily loaded line is a net absorber of reactive power. In the case of cables designed for use at 275 or 400kV the reactive power generated by the electric field is always greater than the reactive power absorbed by the magnetic field and so cables are always net generators of reactive power.

Transformers - Transformers produce magnetic fields and therefore absorb reactive power. The heavier the current loading the higher the absorption.

Consumer Loads - Some loads such as motors produce a magnetic field and therefore absorb reactive power but other customer loads, such as fluorescent lighting, generate reactive power. In addition reactive power may be generated or absorbed by the lines and cables of distribution systems

III. DIFFERENT ASPECTS OF REACTIVE POWER PRICING

A proper pricing mechanism [2] needs absolute identification of the power system and also sources of active and reactive power. An accurate model of active and reactive costs results in fair pricing and, consequently, ensures that the producers will participate with enough incentive as well as the consumers to utilize as much electrical energy as required. Accordingly, this situation facilitates power system improvement and development in addition to optimizing social welfare. If the reactive power price is considered lower than its actual value, there would be no incentive to produce reactive power and almost the whole capacity of the generator would be specified to active power production. On the other hand, the consumers, because of low price, increase their reactive demand. The inadequate reactive power of the system and its demand increase would lead to un-feasibility of active power transmission, reliability decline, and finally power system instability (voltage collapse) risk. Conversely, if the reactive power price becomes greater than its actual value, producers like to produce more reactive power while the consumers, because of high cost, decrease their demands. This time, the surplus reactive power in the network causes voltage stability problem. Therefore, the pricing mechanism should be as precise and fair as possible.

The price of reactive power is strongly dependent on the location of its producers. But despite that, in active power the producer location is not as important, i.e., a far-away producer of reactive power is not favorable as it would be a low-cost generator. Thus adapting a uniform auction reactive power pricing, regardless of the producers' locations, is not a priority. However, zonal reactive power pricing is a better solution for the problem.

The cost of producing reactive power is much lower than that of active power because it does not involve fuel costs. On the other hand, the capital cost of the reactive compensator, especially generator and synchronous condensers, is remarkably high. Accordingly, the pricing mechanism should include the capital cost of the components.

Due to the high dependency of the voltage profile on reactive power, the system operator may be forced to price reactive power higher than its actual price to maintain the integrity of the system. In other words, reactive power pricing is a multi objective approach that all effective factors should be taken into account during price setting. It is worth mentioning that pricing reactive power based on the rule of active power pricing, because of the special characteristics of reactive power, is not logical although some earlier reactive power pricing works are similar to active power pricing.

IV. MECHANISMS OF REACTIVE POWER PRICING

Profit maximization is the main principle used in microeconomics[2]. In a perfectly competitive market, the profit is maximized if the marginal revenue CMR)_is equal to marginal cost (MC). Spot pricing, the actual MC, provides the correct economic signals and clarities both generator and consumer states in the power market while balancing demand and supply in the power system. The spot pricing theory can be used for real-time reactive power pricing by using modified optima] power flow (OFF). In 1991, Baughinan and Siddiqi, for the first time, determined the marginal price of active and reactive power on an arbitrary bus of system by means of the Lagrange multiplier. However, the application of marginal reactive pricing may not be practical, owing j£ the volatility and erratic behayior of such prices. Moreover, MC pricing is subject to the problem of reconciling MC prices with the requirement to recover costs.

In some literature, reactive power pricing is addressed as a cost allocation problem. Reactive power tracing, graph theory, and the modified Y-bus method are in this category. The approach of such works is to determine the reactive power that each generator produces to each individual load and the system participants charge accordingly. But due to

the coupling of real find reactive power flows in transmission networks, the calculation of a contributing factor by these methods to some extent, subjective.
The costs of reactive power consist of explicit and implicit costs. Explicit costs refer to those that directly must be paid such as capital costs of reactive power participants and the reactive power production costs. The production cost of reactive power, unlike the active power, is small, and therefore the explicit cost is almost related to the capital cost. The implicit cost is substantially related to opportunity cost. If a generator is required by the ISO to produce the amount of reactive power that is forced to decrease its active power, due to capacity constraint the generator will loose revenue from selling active power. Thus the generator should be compensated financially (LOC).

Nodal reactive power pricing is another way to design a price structure. It is the sensitivity of the generation production cost to the reactive power demand and usually computed by OPF. that are strongly related to fuel cost. The main difference between active and reactive power costs is that the variable cost This production cost includes the variable costs of generation of reactive power production is so small that it is often negligible. In other words, this method represents only a power production. It is approximately less than 1% of the active power price in a well-designed system. Further more, it is so volatile, and the capital cost of reactive power services is not included in this pricing mechanism. As a result, nodal reactive power pricing is not effective enough.

Due to the negligible variable cost of reactive power production, the availability of reactive power capacity should be a part of the reactive power charge. In this way, the possibility of gaming among generators, by creating circulating reactive power flows, will be remarkably reduced. In the British system, for example, initially, about 80 and 20% of the total reactive power charge was considered for capacity payment and actual reactive power production cost, respectively. Then gradually the payment for capacity was eliminated, and the generator was compensated only for the utilization of reactive energy. This approach made the generator participate in the market arrangement with enough incentive instead of admitting the default payment for capacity.

V. CURRENT GLOBAL SCINARIO IN REACTIVE POWER MARKET

The reactive power market mechanisms are not the same in all deregulated systems. In the United Kingdom, the National Grid Company (NGC), like the ISO, arranges the tenders of reactive support services. The generator bid reactive power support includes capacity and utilization components. These components are (price per MVAr and quantity on offer) and (MVAr-h price curve), respectively. The bidder that is selected is paid for both the capacity and utilization components through annual bilateral contracts with NGC. Eliminating the power pool, the United Kingdom instituted the NET A (New Electricity Trading Arrangements) on 27 March 2001 to deal in the wholesale market. NET A is based on long-time bilateral trade, and it also includes a short-lime balancing market that settles in bidding: strategy. In the newly structured market, META, the reactive power market is changing, and it is expected that the reactive power market will become an exclusively tender market and the obligatory provision of capability of generators will be eliminated.

In Australia, the National Electricity Market Management Company (NEM-CO) 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 the mandatory range, it is known as ancillary service component, and the generator will be compensated financially based on the lost opportunity cost (LOC).

In the Nordic Electricity Market, including Norway. Sweden, Finland, competitors. When several firms control a significant share of market sales, the resulting market structure is called an oligopoly or oligopoly. An oligopoly may engage in collusion, either tacit or overt, and thereby exercise market power.

VI. CURRENT INDIAN SCINARIO IN REACTIVE POWER MARKET

In present Indian electricity scenario, the provision of ancillary services are either embedded with real power supply or made with certain regulatory basis. Availability based tariff (ABT) mechanism provides frequency linked incentives/penalties to beneficiaries/suppliers. In the ABT, a two part tariff is supplemented with a charge for unscheduled interchange (UI) for the supply and consumption of energy in variation from the pre-committed daily schedule and depending on grid frequency at that point of time. Hence, the compensation for frequency control has been made embedded with the real power tariff structures. Frequency control ancillary service by UI mechanism has been provided through a spot market which determines the price by using an incentive/penalty based approach designed by Central electricity regulatory commission (CERC).

Similarly, for provision and control of reactive power, certain fixed price has been charged. According to Indian Electricity Grid Code (IEGC) prepared by CERC, (i)beneficiaries pays for VAr drawl when voltage is below 97% at point of drawal, (ii)beneficiaries pays for VAr return when voltage is above 103% at point of return, (iii)beneficiaries gets paid for VAr return when voltage is below 97% at point of return, and (iv)beneficiaries gets paid for VAr drawl when voltage is above 103% at point of drawal. The charges/payment for VArs have been made at a nomina paise/kVArh rate as may be specified by CERC from time to time, and was between beneficiaries and regional pool account for VAr interchanges.

VII. CONCLUSION

Under normal operating conditions, the generators as dynamic reactive power sources are not allowed to operate at their maximum capacity because a margin of reactive reserve should be held on all generators and other dynamic compensation plants. How much reactive power should be considered as reserve? What is the price of reactive power reserve? And how the participants of the market operate in a corresponding manner? Who are the participants of reactive power reserve? Can only generators FACTS devices such as STATCOM and UPFC be considered as participants of reserve market? Little attention is paid in the literature to reactive power reserve and its price. If this approach is achieved and a clear reactive reserve market established, the security margin of the system increases and the transaction of even more active power will be possible without considering a voltage collapse problem.

Only synchronous generators and condensers are recognized by the ISO as ancillary services and compensated for reactive support service; other reactive power compensators are not considered ancillary services. Although power system generators are the most important components of a dynamic reactive power support service, due to the high capital cost of generators as well as opportunity cost, the reactive power of the generator will be expensive. Therefore the reactive power compensation of the generator is not economic. On the other hand, other compensators of reactive power such as capacitor banks, reactors and SVCs have no incentive to participate in reactive power market. It seems that the ISO should change its policy in the reactive power ancillary service and identify capacitor banks, reactors. SVCs, and FACTS devices as the other competitors of the reactive market and compensate them financially for their reactive power services.

REFFERENCES

[1]. Shangyou Hao Alex Papalexopoulos, ”Reactive Power Pricing and Management”, IEEE Transactions on Power Systems, Vol. 12, No. 1, February 1997

[2]. Gerald B. Sheble, “Reactive Power Pricing, *problems & a proposal for a competitive market*”, IEEE power & energy magazine, january/February 2009

[3]. El-Samahy, K.Bhattachrya and C.A.Canizares, ”A Unified Framework for Reactive Power Management in Deregulated Electricity Markets”

[4]. Sanjoy K. Parida, **“**Road Map to Develop Ancillary Services Model for Indian Electricity Scenario”, POWER MANAGEMENT INSTITUTE NTPC LTD

[5]. “An Introduction to Reactive”, The National Grid Company plc

[6]. Raghuram L.Naik, Dr.Udaykumar R.Y. and Shantaram Rai, ”Deregulation in Power Industry” proceedings of National conference on “Power Industries” at NITEE 2004

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