An Economic Approach of Reactive Power Management in Restructured Power Market – A Review

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***Abstract*— In vertical integrated utility, generation, transmission and distribution were under the direct ownership and control of one utility and hence ancillary service payments were bundled in the energy price. Whereas in restructured power market these were different utility and so that, the ancillary services payment is critical issue in restructured electricity market. For reliable and secure operation of the system, reactive power management is one of the most important ancillary services in restructured electricity market. This paper present review of reactive power procurement in restructured power market based on cost of power generation, cost of transmission loss, and power transmission charge.**

***Index Terms*—Component, Reactive power management; Ancillary services; Reactive power market clearing**

I. INTRODUCTION

During nineties decades, many electric utility has been going through a process of transaction, from vertical integrated mechanism to open market system. As Zhong and Bhattacharya (2002) say by increasing competition in the generation sector and split-up generation and transmission this is achieved [1]. To accomplish this process certain class of services are created, generally this services is called as ancillary services.

Ancillary services are also defined as all those activities on the interconnected grid that are necessary to support the transmission of power while maintaining reliable operation and ensuring the required degree of quality and safety.

- Regulation of frequency and tie-line power flows
- Voltage and reactive power control
- Ensuring system stability
- Maintenance of generation and transmission reserves and many others

For maintaining an adequate security level, defining correct economic signals, providing a simple and transparent structure, ensuring market equity, and avoiding additional charges on the final energy price reactive power management is very important.

In North America, reactive power procurement is only considered for the synchronous generator. In NYISO, An embedded cost based pricing is used to compensate generators for their reactive power services, and it also imposes a penalty for failing to provide reactive power uses in the NYISO. If generator are reduce their real power for the generation of reactive power then they are compensated for their lost opportunity cost, this lost opportunity cost is also consider in PJM Interconnection and CAISO. CAISO and reliable must-run generators are made long-term contract for reactive power procurement in California. The generators are mandated to provide reactive power within a power factor range 0.9 lagging to 0.95 leading in the CAISO. The generators want to more reactive power then they are paid for their reactive power including a lost opportunity cost payment beyond these limits.

The rated terminal voltage within a +/- 5% range and power factor range of 0.9 lagging to 0.95 leading requires to operate generator in the IESO at Ontario, Canada. The IESO signs contracts with generators for reactive power support and voltage control. It was noted in (Bhattacharya, Canizares, and Samahy 2006) Due to the increased reactive power generation the energy loss in the winding is increase so that generators are paid for the incremental cost [2].

AEMO is work under the National Electricity Rules made under the National Electricity Law as ISO in Australia. Synchronous condensers also receive payments for providing reactive power apart from generators in Australia. Wherein reactive power is supplied by generators on a mandatory basis and without any financial compensation in Sweden. Individual network companies have to provide for their own reactive power, usually through bilateral contracts with local generators, who are only paid for the reactive capacity but not for reactive energy in Netherlands.

In the United Kingdom, the TSO - NGET invites half-yearly tenders for both “obligatory reactive power services” which correspond to the base reactive power each generator is required to provide, and “enhanced reactive power services” for generators with excess reactive power capabilities. There are two payment mechanisms: 1) a default payment agreement, where both the generator and NGET enter into an agreement for service provision and payments; and 2) a market-based agreement in which generators submit their reactive power bids to the NGET.

From the brief review of utility practices above, it is clear that there is no fully developed structure for competition or pricing of reactive power services in any system. In some cases the pricing is based on fixed contractual payments, and in other cases based on gross system usage (embedded cost), while in other markets there is no mechanism for payments. The ISOs do not have any well-defined reactive power management system in their operational portfolio that could create an optimal provision of reactive power service considering all the issues arising from competition.

In this paper we examine why the expected total market payment function is more superior. For the formulation of this function first we forecast the load then by using this load we minimize the three component total market payment function.

II. REACTIVE POWER MANAGEMENT AS ANCILLARY SERVICE

Wherever Chen (2008) examine that traditionally no separate cost for the reactive power service, the main reason is the system is fully controlled by one utility [3]. However, after the deregulation of electricity markets, reactive power has been consider as an ancillary service to be purchased separately by the ISO. Proper compensation for providing reactive power and reactive power capability ensures an adequate, reliable and efficient supply of reactive power, and encourages sufficient investment on producing reactive power.

A reactive bid structure is proposed in the context of a reactive power market. Bhattacharya and Zhong (2001) describe that Based on the reactive power price offers and technical constraints involved in reactive power planning, a two-tier approach is developed to determine the most beneficial reactive power contracts for the ISO [4]. The reactive capability of a generator and therefore the opportunity costs in providing reactive power is also included in the model.

The market-based solution for managing reactive services by transmission operators is present by Hao (2003) [5]. Three distinct features for the proposed solution are: 1) obligating generation facilities to provide reactive services in proportion to their active power output; 2) optimizing and integrating the reactive procurement with market operation for least-cost solution; and 3) taking into account the interactions of active and reactive powers for accurate calculation of the lost opportunity costs of generators. Whereas Bhattacharya, Samahy, and Canizares (2006) present the three-step approach in which they are consider the calculation of marginal benefits and based on appropriate Lagrange multipliers pertaining to the generator's capability curve they maximize social welfare function [6]. This scheme is easy to implement in real sized power systems and reduces the computational procedure.

Reactive power provisions can also be framed as two classes of a problem in the context of deregulated electricity markets, namely,

- Reactive power procurement
- Reactive power dispatch

III. REACTIVE POWER PROCUREMENT

There are various scenarios for the reactive power procurement in different country. As per NERC only synchronous generator is used for reactive power procurement whereas, In AEMO synchronous generator and synchronous condenser are used.

In the reactive power procurement, first reactive power offers from the reactive power providers are called and based on the received bids. The method which is suggested by Zhao, Irving and Song (2005) is especially suitable for a power market using pool model. A novel pricing approach for reactive production is introduced [7].

$$Cost(Q) = a'' Q^2 + b'' Q + c'' \qquad (1)$$

where, a", b", c" are constants depending on power factor (cos θ) and are calculated as follows:

$$a'' = a_p \sin^2\theta \qquad (2)$$

$$b'' = b_p \sin\theta \qquad (3)$$

$$c'' = c_p \qquad (4)$$

The calculation formulae of reactive power production costs are derived and economic pricing strategy has been employed as shown in figure 1.

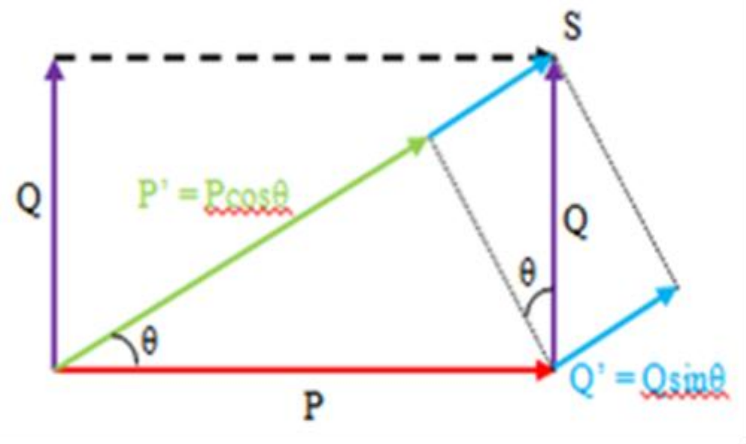

Figure 1 An illustration of the reactive power cost allocation

In another approach, Xiea, Songa, Zhangb, Nakanishib, Nakazawa, (2004) have used a second-order polynomial for the cost of reactive power in which cost coefficient a, b, and c are approximated to be one-tenth of those for the cost of active power [8]. But these methods drawbacks are they are not consider all the cost which are related to the reactive power production like, investment cost, operation cost, opportunity costs and availability cost. So, here Hasanpour, Ghazi, Javidi (2009) developed new approach for the reactive power procurement [9]. This new method is based on calculation of the accurate cost which will be imposed on generators due to supporting reactive power. The proposed method is fair, accurate and realistic and it can be formulated very easily.

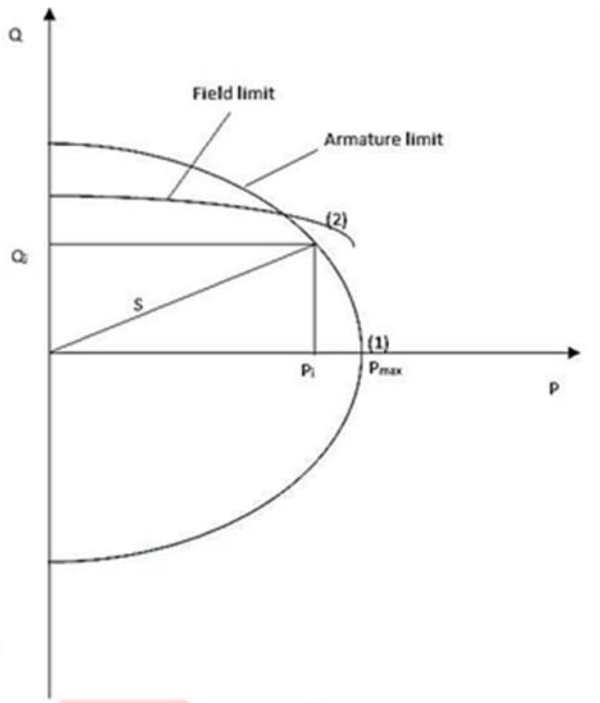

Figure 2 Capability curve of generator

After considering the reactive power procurement determine the loss quota of any transaction and any participant entity in a multilateral open access power system. This new concept, which is based on the ITLA technique, is proposed by Moghaddam, Raoofat, Fam (2006) for application on multilateral open access power systems [10].

Shirmohammadi, Filho and Gorenstin, Pereira (1996) describe the various methods for the transmission prices [11]. They also briefly discuss the role of these methodologies in promoting "economic efficiency".

Shirmoharnnadi, Gribik, Law, Malinowski, O'Donnell (1989) describe the transmission pricing method [12]. There are various method for transmission pricing but among them author is describe MW-Mile method. In this methodology they are using two category of transaction. In first one they are assume that the entity have fixed location and same generation and load means in power balance condition and in second they the transaction is dependent on location of the generation and load and range of variation in generation and load.

IV. REACTIVE POWER DISPATCH

Singh, Chauhan, Upadhyay (2011) explain that reactive power dispatch is the short-term management function, which takes place one to half hour ahead of real-time [13]. Current operation condition is accounted for the real- time dispatch of reactive power using OPF. Based on actual usage and actually dispatch requested, cumulative payment to a supplier is calculated post real time operation.

Bhattacharya, Pan, Canizares, Samahy explain that the real power generation is decoupled and assumed fixed during the reactive power dispatch procedures; however, due to the effect of reactive power on real power, real power generation is allowed be rescheduled within given limits [14].

Classical ORPD is usually formulated as a deterministic optimization problem, such that the network structure and load power injections are known and fixed. Hence, the influences of load uncertainties and branch outages are not typically considered. A chance-constrained programming formulation for ORPD that considers uncertain nodal power injections and random branch outages present by Hu, Wang, and Taylor (2010) [15]. A solution method combining both probabilistic load flow and a genetic algorithm is proposed and demonstrated in order to solve the problem. Simulations on several test systems show that the proposed method can prevent under-compensation or over-compensation of reactive power and increase voltage security margins. These advantages are achieved with the acceptable expense of a small increase in active power loss when compared with the results of classical deterministic ORPD.

V. MULTI OBJECTIVE MARKET CLEARING

Based on the current practices for reactive power provision by various ISOs in competitive electricity markets, a hierarchical reactive power market structure. Bhattacharya, Samahy, Canizares, Anjos, and Pan (2008) proposed two stage market model [16]. In first stage they consider reactive power procurement based on seasonal basis, and second stage reactive power dispatch based on a real-time. Now for the reactive power procurement they are using two stage optimization model. In first stage for the improving system security they are calculate marginal benefit of reactive power and by using it they maximize a reactive power societal advantage function.

In another approach Ahmadi, Akbari and Foroud (2013) tries to solve the problems of traditional nodal pricing methods to be able to consider opportunity and availability costs for the generators [17]. A modified model of generators reactive power production cost has been used in OPF objective function considering normal and contingency conditions. Availability cost would be estimated considering the volume of network demand from the generators in contingency states through probability calculations. This cost would be paid to all the units that possibly will needed to produce reactive power in contingency states. This method encourages providers to invest in areas where the network demands are higher and increases tendency to reactive power. generation in critical areas due to higher prices in that areas. Therefore fair distribution of reactive power production costs over several producers are some advantages of the proposed method.

Whereas this report proposes a method to minimize the excepted total market payment and it is applied to the IEEE 24 bus RTS present in IEEE Reliability Test System (1979). Which describes an enhanced test system (RTS-96) for use in bulk power system reliability evaluation studies [18][19]. The value of the test system is that it will permit comparative and benchmark studies to be performed on new and existing reliability evaluation techniques. The test system was developed by modifying and updating the original IEEE RTS (referred to as RTS-79 hereafter) to reflect changes In evaluation methodologies and to overcome perceived deficiencies.

VI. Conclusion

Ancillary service procurement is important and complex issue in deregulated market. As reactive power procurement is an important ancillary service, which involves various factors consideration. Reactive power is important for system security and reliability, hence technical issue should be thought out as well as economic issues in market clearing should also consider. Present work describes various methods of reactive power procurement and reactive power cost optimization considering various constraints.

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