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Full Length Article

# A Market Center Based Clearing and Settlement of Pure Reactive Power Market in Deregulated Power System

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ABSTRACT

DC Power Flow Model is a constant matrix, a non-iterative model which is built into DC Optimal Power Flow Model for market clearing and settlement of real power market. DC Optimal Power Flow Method is fast when compared to nonlinear Optimal Power Flow and the accuracy level is acceptable for security analysis. It is widely used for active power flow analysis in the deregulated power system. As of now, there are few papers available in DC Optimal Power Flow Model for reactive power flow analysis. This paper proposes a new Optimal Q Flow (OQF) method for market clearing and settlement of pure reactive power market. A lumped linear model is proposed for power balance equality constraint for fast convergence. In this method, a unique reference for delivery/withdrawal point for reactive power called Market Center is proposed to share the total transmission loss equitably between the GENCO and DISCO participants in a transparent manner for pure Q Market using incremental loss factor method. This model uses a slack bus independent loss factors measured with respect to "Market Center". The objective function is to minimize the cost of the reactive power payable to GENCOs with respect to the market center. The compensation received by GENCO participants and Locational Marginal Price to be paid by DISCOs participants are derived for N bus. The OQF method is tested on a Radial Five Bus System, Ward and Hale 6 Bus System and IEEE 30 Bus System.The bus voltage magnitude computed using the Iterative Q Flow method is accurate and obtained for a mismatch tolerance of 0.1 MVAr. In the proposed method it is found that the total bus loss is reduced considerably thereby minimizing the cost of the objective function.



## 1. Introduction

Reactive power plays an important role in the power system. Sufficient reactive power support is to be provided in the system in order to maintain 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 conditions, the mix of the load and availability of reactive support devices [1]. In the deregulated power system, the Independent System Operator (ISO) is responsible to provide ancillary services which are used to support the transmission of electrical energy while maintaining secure and reliable operation of the power system. The total price paid by the system operator to the generators for providing the required reactive power support is minimized in [2].

The procurement, remuneration and charging of reactive power control is proposed in [3]. A marginal pricing is also proposed to remunerate the suppliers and to charge the consumers of the services.

Reference [4] proposes a cost-based reactive power pricing, which can integrate the reactive power cost minimization and the voltage security problem into the Optimal Power Flow (OPF) problem and the Sequential Quadratic Programming (SQP) is employed to solve the optimization problem. It integrates the production cost of reactive power and the voltage stability margin requirement of pre and post contingencies into the OPF problem. The production cost of reactive power is interpreted as the opportunity cost from various generation sources such as generators and the explicit cost from reactive power sources such as reactive compensators.

A methodology to allocate reactive power cost in the deregulated market is given in [5]. Here the reactive power supply service is decomposed into voltage regulation and reactive power spinning reserve. The proposed methodology is based on sensitivities and the postage-stamp method in order to allocate the total costs service among all participants.

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**Nomenclature**

| | |
|---|---|
| i,j,k,m | indices for bus |
| N | number of buses |
| OQF | Optimal Q flow |
| $LFg_i$ | Loss factor for bus generation at bus i |
| $LFd_i$ | Loss factor for bus demand at bus i |
| $CG_i$ | Cost for the GENCOs at bus i |
| $[B'']$ | Negative bus susceptance matrix of dimension $(N-1) \times (N-1)$ |
| $[X'']$ | Inverse of negative bus susceptance matrix $[B'']$ |
| Ig | Total generator current |
| Id | Total load current |
| $V_k$ | Voltage magnitude at bus k |
| $Qg_i$ | Reactive power bus generation at bus i |
| $Qd_i$ | Reactive power bus demand at bus i |
| [ ] | Signifies vector or matrix. |
| $[B_s]$ | Last column of bus susceptance matrix |
| $LMCQg_i$ | Locational Marginal Compensation for GENCO at bus i |
| $LMPQd_i$ | Locational Marginal Price for reactive power demand at bus i |
| AG | Bus-Genco Incidence Matrix |
| $QG_i$ | Reactive Power GENCO at bus i |
| $QD_i$ | Reactive Power DISCO at bus i |
| NG | Number of GENCOs |
| ND | Number of DISCOs |
| GENCO | Generation Company |
| DISCO | Distribution Company |

The reactive power ancillary services pricing is taken into account for the technical and economic issues for allocating reactive power support cost. To improve the computation efficiency the reactive power charges for consumers are calculated using cost allocation and bisection method [6]. A new methodology of reactive loss allocation among generators and loads for each transmission line is proposed in [7]. The method is based on orthogonal current projection concept and (generators) load buses which (produce) consume more reactive power are penalized to improve system stability.

The fundamental concept of Locational Marginal Price (LMP) in the electricity market is discussed in [8]. Under market environment, LMP based settlement strategy is used to determine the amount of money earned from ISO by the energy sellers and paid to ISO by the energy buyers. Thus, depending on different market designs, four different calculation models and corresponding properties on LMP are discussed in this paper.

Reference [9] proposes a method to obtain a truly reference-independent LMP decomposition. This is achieved with loss factors based on a new AC based distribution factor model, which depends on the network topology and the present operating condition. This model gives reference independent loss prices, which can serve for a better loss hedging Financial Transmission Rights since the choice of reference bus will not change the loss prices. This paper uses the Fictitious Nodal Demand (FND) mode to obtain loss distribution factors (LDFs).

A matrix loss distribution methodology is developed in [10] for the DCOPF based marginal loss pricing with increased power flow accuracy. While the currently employed DCOPF model allows only a fixed-ratio distribution of the aggregated system loss, the proposed methodology provides the flexibility to assign a different distribution vector to each line.

An optimization based methodology is proposed in [11] to resolve the energy reference dispute for the ACOPF based Locational marginal pricing. The respective dispute arises because of the reference dependent nature of the congestion components of locational marginal prices. A simple quadratic programming problem is employed for solving this problem.

Different AC and DC optimal power flow models are presented and analyzed in [12] to understand the determination of LMPs. The objective of the paper [13] is to obtain LMP with constrained reactive power by using optimal power flow. In this paper, LMP is obtained using Loss distribution matrix method.

Reference [14] reviews the current reactive pricing around the world, which are classified into three categories viz the compulsory requirement for power factor, the adjustment for electricity quantity or electricity fees based on power factor and the excessive reactive power fees based on the excessive reactive power.

An optimal reactive power flow program is used to evaluate the marginal costs of the reactive power demand and marginal benefits of the reactive power production are taken into account for Italian EHV transmission system [15].

A new method for reactive power pricing in a pool based power market is proposed in [16]. This method utilizes the accurate relation between active and reactive power to assign an accurate function for the cost of reactive power production. Furthermore, a new approach based on tracing algorithm is also proposed for pricing of reactive power which considers the cost of both active and reactive losses allocated to each generator.

In the deregulated environment, Ancillary Services (AS) play a vital role, as they are required for reliable and secure operation of the power system. Operating Reserve (OR), as one of the main AS, is a capability of a power system to prevent any unexpected imbalances caused by generation or transmission outage has been considered in Reference [17]. This paper considers a flexible disaggregated energy and AS dispatch approach, which can support the development of an effective reserve allocation and pricing methodology. This approach is based on the sequential clearing of Energy Market (EM) and Ancillary Service Market (ASM) with the objective of procurement cost minimization.

Reference [18] proposes the optimal reactive power scheduling problem considering minimization of active power loss and system cost while maintaining the allowable bus voltage limits. The system cost consists of purchasing cost of compensating devices including installation cost.

Reference [19] proposes a new and reasonable algorithm to allocate transmission losses to consumer loads and generators of the network in a fair manner. This method can be applied to any topologies of the system. This algorithm is based on exchanged active and reactive power in the network. Therefore, the loss of each line is composed of two terms. The first term is due to the injected active power and the second term is due to injected reactive power to each line. Hence, the power loss of each line is allocated to each load and each generator due to active and reactive power flows separately.

Reference [20] presents a methodology to allocate the cost of real power loss including the reactive power requirements of the loads. The real power loss is calculated from the conventional AC load flow solution. The real power loss is apportioned into two parts, one due to the transaction and the other due to the reactive power requirement of the load. The cost of loss due to the transaction is allotted to both generators and loads equally based on transaction loss factor. Transaction loss factor is purely proportional to its generation and load. The real power loss increases due to the reactive power demand of the load. This increase in loss and its associated cost is allotted to the respective loads based on

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