A novel cost reducing reactive power market structure for modifying mandatory generation regions of producers

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ABSTRACT

In this paper, a new reactive power market structure is studied and presented. Active power flow by itself causes active and reactive losses. Considering such losses in the reactive power market is the main purpose of this paper. Therefore, this study attempts to improve the reactive power market and create fair competition between producers. To that end, first, a new allocation method for reactive power losses is presented and the contribution of each producer in reactive losses is calculated. In the next step, this share of losses is used to modify the mandatory generation region of units. Then, a new structure is proposed for the reactive power market. This novel structure leads to reduction of system costs in the deregulated power system, which is one of the main policy implications of this paper. Finally, simulations show that the total payment by Independent System Operator will be reduced via application of the proposed methods leading to reduction in system costs. This cost reduction will be significant enough to encourage Independent System Operators to utilize such a structure. In addition, by implementing the new proposed methods, assignment of costs related to reactive power loss will be more justifiable for each generator.

1. Introduction

In recent decades, electrical grids have been restructured around the world and changed from the previous exclusively vertical state to the competitive one. This change has been achieved by the complete separation of generation and transmission activities and development of competition in the generation sector. Such restructuring has led to the separation of different services, which were previously supplied by electricity companies. Although energy exchange is the main purpose of electricity markets, in order to have a secure and reliable power system, ancillary services are vital and should be appropriately supplied. In most electricity markets, system operators supply these services via commercial contracts with the market participants.

Among the six ancillary services defined in Order No. 888 of the Federal Energy Regulatory Commission (FERC), supplying reactive power is one of the most important services in system security. This service plays a very effective role in the secure operation of power systems. Nowadays, reactive power markets are implemented in different countries including Canada, India, Australia, Japan, Argentina, Netherlands, Belgium, Sweden, Britain, Iran, etc. In the restructured power system, economic signals besides network constraints are the basic factors of ISO in making operational decisions (Acharya and Mithulananthan, 2007; Balamurugan et al., 2015; Bradbury et al., 2014; Ghazvini et al., 2015; Govardhan and Roy, 2014; Ikeda et al., 2012; Jiang et al., 2015; Zheng et al., 2015). In a competitive electricity market, the appropriate components of the market are formed by proper selection of the following factors:

1) Market structure  
2) Payment mechanism  
3) Pricing model

The reactive power market structure is chosen according to environmental and political circumstances. This ancillary service is usually separated from real power for which an independent market is implemented. Nevertheless, in some references, integrated optimization has been performed on the costs by simultaneously executing active and reactive power markets (Ahmadi and Foroud, 2016). In order to prevent interference of the reactive power market and the energy market, independent markets are used for both powers (El-Samahy et al., 2008; Kargarian et al., 2012; Rabiee et al., 2009b). In this model, the output of the active power market is used as the input for this market. Because of different constraints in a reactive power market, the amount of active power cannot be constant in all generators and has to change in order to maintain the stability of the grid. As a result, one of the important issues in the separated active and reactive power markets is the fair allocation of costs related to system losses.
reactive power markets is the method of approaching this issue, which is
directly related to the lost opportunity cost. In (Ahmadi and Foroud,
2014; Hasanpour et al., 2009; Ketabi et al., 2010), by considering a
combined objective function, a framework has been presented for
optimization in all active and reactive power costs. In (Biswas et al.,
2016) the economic effect of double auction bilateral power transaction
on the reactive power market is considered. Reactive power may be
implemented as real time, day-ahead (Ketabi et al., 2010; Malakar
et al., 2016; Rabiei et al., 2009b; Saraswat et al., 2013; Zhong and
Bhattacharya, 2002), seasonal (El-Samahy et al., 2006; Kargarian et al.
2011; Miguelez et al., 2007; Tamimi et al., 2010; Vyjayanthi and
Thukaram, 2011), or a combination of the mentioned time frames
(Aragon et al., 2015). Because of market sensitivity to load and grid
circumstances, the day-ahead reactive power market can create market
power and raise the total cost of reactive power. Being close to
consumption time and, consequently, making more precise predictions
about generation and consumption volumes and better allocation of
reactive power are the advantages of the day-ahead market. (Aragon
et al., 2015) proposes a three-stage time frame for the reactive power
market. In the first stage, the ISO determines the technical require-
ments of the service considering different scenarios for the next annual
period. In the next stage, in a day-ahead period, the ISO estimates the
variable costs associated with the service. Once these have been incurred, and added to the fixed costs to conform to the total costs of

\[ Q_{loss,ij}^{Tm,n} \]

Allocated reactive power loss in branch i, j caused by active power flow
when contract Tn,m is deactivated,  
\[ Q_{loss,ij}^{Tm,n} \]

Allocated reactive power loss in branch i, j caused by reactive power flow when contract Tn,m is deactivated,  
\[ Q_{bus,ij}^{Tm,n} \]

Allocated reactive loss for transaction Tn,m caused by reactive power
flow,  
\[ Q_{bus,ij}^{Tm,n} \]

Reactive power loss in branch i, j caused by active power flow,
\[ Q_{bus,ij}^{Tm,n} \]

Reactive power loss in branch i, j caused by reactive power flow,
\[ Q_{bus,ij}^{Tm,n} \]

Positive partition of allocated reactive power,
\[ Q_{bus,ij}^{Tm,n} \]

Negative partition of allocated reactive power,
\[ Q_{bus,ij}^{Tm,n} \]

Reactive power loss in branch i, j caused by reactive power flow,
\[ Q_{bus,ij}^{Tm,n} \]

Reactive power loss in branch i, j caused by active power flow,
\[ Q_{bus,ij}^{Tm,n} \]

Reactive power loss in branch i, j caused by reactive power flow,
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