Electrical Power and Energy Systems 64 (2015) 250–259

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Centralized and decentralized optimal decision support for congestion management

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ARTICLE INFO

Article history:
Received 24 July 2013
Received in revised form 18 June 2014
Accepted 6 July 2014

Keywords:
AC optimal power flow
Decentralization
Open access
Optimal pricing
Power market
Security constrained optimal power flow

ABSTRACT

This paper presents a framework to carry out optimal power flow in a coordinated multi-transaction/utilities decentralized system. An AC power flow model has been used in this work for independent optimal dispatch of each utility. The global economic optimal solution of the whole electric energy system with congestion management has also been done in this work using the interior point (IP) optimization procedure. In this approach, each participant tries to maximize its own profit with the help of information announced by the operator which are information related to system security constraints and public issues. The developed algorithm can be run in parallel, either to carry out numerical simulations or to obtain an optimal generation schedule in an actual multi-utility electric system. The study has been conducted on a three utility modified IEEE-30 bus system with two market models and six utility modified IEEE-118 bus system. The results clearly show the effectiveness of the suggested IP optimization based optimal generation schedule in decentralized scenario. It has been demonstrated that the suggested decentralized approach produces improved optimal dispatch solution with enhanced market benefits and can effectively manage the congestion in the system as compared to the centralized approach.

Introduction

The congestion management is one of the most challenging operational problems with open access transmission. The power system is said to be congested if the transmission network is operated at or beyond one or more transfer limits [1]. Because of the present trends of bilateral and multilateral contracts in the electricity market, the role of independent system operator (ISO) is increasing. Under this new scenario, the role of ISO is to create a set of rules that ensure sufficient control over producers and consumers to maintain an acceptable level of power system security and reliability [2]. As such, in a tight pool market, ISO has constraints to operate the system without the violation of operational constraints. Due to this, all the market participants are bound by some rules of coordination. For a better competition in the market, it is essential that all the participants are free to optimize their own profits. Hence, a decentralized decision making based methodology can play a vital role in market competition [3]. As the electric power industry is undergoing restructuring, it results into higher degree of decentralized decision making in the power system. This change has been affecting long term expansion planning of independent investors with less centralized coordination. After the restructuring of the electric power industry, profit generating companies have been developed to deliver electric energy in a competitive market. In such a case, independent regulated transmission system operators (TSOs) manage the operation of the transmission system. The congestion management is one of the central issues of centralized optimal power flow (COPF) [4,5]. The recent trends in electricity market are towards large multinational electricity markets, such as, the internal electricity market (IEM) in Europe. However, there are technical and economic challenges in the operation of a single joint market by combining different regional electricity markets. If an individual market optimizes its own electricity market without coordinating with its neighbouring markets, seam issues arise among regional electricity markets. In multiple market environments, seam issues lead to market inefficiency in the operation of the combined markets. Hence, a decentralized approach is needed to facilitate economically efficient and viable energy trading among regional electricity markets [6].

A decentralized model partitioned by tie-line between individual markets has been proposed for coordinating trading between regional electricity markets [7]. The tie-line information is exchanged at the end of each iteration, until the final convergence is achieved. Different decomposition methods for dividing the interconnected electricity markets into individual markets have also been introduced [8]. After decomposition the single joint

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http://dx.doi.org/10.1016/j.ijepes.2014.07.026
0142-0615/

market, a decentralized approach to congestion management in interconnected markets has been proposed [9,10]. An efficient economic dispatch in competitive electricity market has been analyzed to solve seam problems and establishing the theory of duality and decomposition in mathematical programming [11]. As the demand for deregulation of electric utilities is on the rise, the selection of objective function for optimization of economic system operation is becoming more critical. The conventional benefit optimizations have been mainly based on economic dispatch that enables to achieve cost minimization in a single utility environment [12,13]. Currently, many of these issues are being played out in real time with the privatization of power system. This is particularly relevant in multi-utility or multi-country setting. In order to achieve economical optimal dispatch of the whole power system, a small interchange of information is sufficient among the involved utilities or countries to obtain a global solution instead of setting up a common control centre [14]. Decentralized optimal power flow (DOPF) algorithm is an iterative algorithm in which the TSO of each region iteratively solves a modified optimal power flow (OPF) sub-problem for its own region and exchanges tie-line information with the TSOs of neighbouring regions [14–16]. The congestion pricing and cost allocation based transmission congestion management in decentralized approach to maximize the profit independently has been reported in [17,18].

Recently, researchers have shown interest in including the demand to maximize the market profit. Also, the demand limits are incorporated with objective function of problems. In the early days of deregulation, customers did not have effective participation in power markets, and therefore, they were not able to respond to the prices effectively. However, to have a complete competitive market, there should be enough motivations for customers to participate in power market operations [19–26].

The present investigation deals with the congestion management using decentralized and centralized approaches. The model reported in present work, though similar to [11,22], include transmission losses cost in the objective function; however the solution is obtained by interior point (IP) method. The IP has been applied to solve large-scale OPF problems in recent past [27–34]. In IP based OPF, the computation of gradient, Jacobian and Hessian matrices of objective functions are constraint functions. The basic property of IP to cut the solution space across the interior points has been exploited in this work to achieve faster solution. In this work, the accuracy of the decentralized approach is authenticated by comparing its results with that of centralized approach. Modified IEEE-30 and IEEE-118 bus systems have been used to show the performance of the proposed method. The test results reveal that the proposed method yields superior results as compared to the results reported in [11,22].

Mathematical formulation

Two market models have been proposed for the congestion management in literature, namely COPF and DOPF. In COPF, the lack of transparency of market participants is bounded by centralized authority and thus becomes a superpower. This is not considered as an appropriate approach for a healthy competitive market. On the other hand in DOPF model the participants are free to optimize their own profits. In the following sections of this work, the mathematical models of these two markets have been formulated and discussed.

Centralized optimal power flow market model

In COPF, forward contract market for real power is mainly based on dc load flow based solution. In a perfect competitive market, the ISO adjusts the contracts to maximize the benefit and social welfare to achieve efficient operation with all constraints satisfied. With this assumption, the mathematical model of COPF is given by

$$max\, f(P_{D_j}, P_{G_i}) = \sum_{j=1}^{N_d} B_j(P_{D_j}) - \sum_{i=1}^{N_g} C_i(P_{G_i}) \quad (1)$$

subject to

$$\sum_{i=1}^{N_g} P_{G_i} - \sum_{j=1}^{N_d} P_{D_j} - P_{loss} = 0 \quad (2)$$

$$P_{G_i}^{min} \le P_{G_i} \le P_{G_i}^{max} \quad (3)$$

$$Q_{G_i}^{min} \le Q_{G_i} \le Q_{G_i}^{max} \quad (4)$$

$$P_{D_j}^{min} \le P_{D_j} \le P_{D_j}^{max} \quad (5)$$

$$P_{ij} \le P_{ij}^{max} \quad (6)$$

where N_g is the number of generator buses; N_d is number of demand buses; P_{G_i} is active power output of ith generator; Q_{G_i} is reactive power output of ith generator; P_{D_j} is active power demand of jth consumer; P_{loss} is active power loss; B_j is benefit function of jth consumer; C_i is cost function of generator i; P_{ij} is active power flow of transmission line between buses i and j; and P_{ij}^{max} is the maximum active power flow limit of transmission line between buses i and j in MW.

The objective of (1) is to maximize the total benefit and social welfare of the system. The first term of (1) represents the demand cost and second term represents the generation cost of all generator buses. The equality constraint in (2) denotes the active power balance for each utility considering the losses. The inequality constraints in (3) and (4) denote the output active and reactive power limits of the generators. The demand limits of consumers are represented in (5), which also includes the problem of congestion management. Inequalities constraints represented in (6) denote the line capacity limits. The power flow in lines due to various transactions has been obtained using the power transfer distribution factor used in [35].

Decentralized optimal power flow market model

The COPF model (1)–(6) are converted into DOPF model by rewriting them into simpler form by redefining the decision variables of contract $u^k = f(P_{G_i}^k, P_{D_j}^k)$ for kth utility, where $k \varepsilon T$. Taking (7) into consideration, the welfare related to utility k can be defined as

$$w^k(u^k) = \sum_{\substack{j=1 \\ j \in D(k)}}^{N_d} B_j^k\left(P_{D_j}^k\right) - \sum_{\substack{i=1 \\ N_g \neq N_{g\,slack} \\ i \in G(k)}}^{N_g} C_i^k\left(P_{G_i}^k\right) - C_{N_{gslack}}(P_{G_{slack}}) \quad (7)$$

where $D(k)$ is the set of consumers in utility k; $G(k)$ is set of generators in utility k; $N_{g\ slack}$ is slack bus number index; $P_{G_i}^k$ is active power output of ith generator in utility k; $P_{D_j}^k$ is active power demand of jth consumer in utility k; $P_{G_{slack}}$ is active power output of slack bus generator; P_{loss}^k is active power loss due to kth utility; B_j^k is benefit function of jth consumer in utility k; C_i^k is cost function of ith generator in utility k; and $C_{N_{g\,slack}}$ is the cost function of slack bus generator.

In decentralized model, the cost of slack bus generator has been taken separately in order to incorporate the cost of power supplied by the slack bus due to losses in multi-utility market operation. In fact, the losses incurred would be supplied by the