Swarm and Evolutionary Computation 28 (2016) 161–171

Contents lists available at ScienceDirect

Swarm and Evolutionary Computation

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

Regular Paper

Application of hybrid heuristic optimization algorithms for solving optimal regional dispatch of energy and reserve considering the social welfare of the participating markets

Marlon S. Chamba*, Osvaldo Añó, Rodolfo Reta

Instituto de Ingeniería Eléctrica, Universidad Nacional de San Juan, CONICET, Av. Lib. Gral. San Martín, 1109, Oeste J5400ARL, San Juan, Argentina

ARTICLE INFO

Article history:
Received 5 March 2015
Received in revised form
25 January 2016
Accepted 20 February 2016
Available online 2 March 2016

Keywords:
Regional markets
Reliability
Social welfare
Meta-heuristics
Means variance mapping optimization
Optimization algorithm

ABSTRACT

Market integration allows increasing the social welfare of a given society. In most markets, integration also raises the social welfare of the participating markets (partakers). However, electricity markets have complexities such as transmission network congestion and requirements of power reserve that could lead to a decrease in the social welfare of some partakers. The social welfare reduction of partakers, if it occurs, would surely be a hindrance to the development of regional markets, since participants are usually national systems. This paper shows a new model for the regional dispatch of energy and reserve, and proposes as constraints that the social welfare of partakers does not decrease with respect to that obtained from the isolated optimal operation. These social welfare constraints are characterized by their stochastic nature and their dependence on the energy price of different operating states. The problem is solved by the combination of two optimization models (hybrid optimization): A linear model embedded within a meta-heuristic algorithm, which is known as the swarm version of the Means Variance Mapping Optimization (MVMO^S). MVMO^S allows incorporating the stochastic nature of social welfare constraints through a dynamic penalty scheme, which considers the fulfillment degree along with the dynamics of the search process.

1. Introduction

Energy trading between different national electricity markets effectively improves the overall economic efficiency of the combined electricity markets and increases reliability of interconnected power systems. As a result, consumers can access lower-cost generation located in other areas and the combined social welfare is increased [1,2].

There are technical, economic, regulatory and political challenges in the operation of a regional market achieved by the interconnection of different participating markets (partakers). An economically significant barrier to integration is presented by the uncertainty in the individual benefits which would result from the interconnection [3]. These benefits can be objectively represented by the social welfare of each partaker (usually countries) resulting from the integration, hereinafter referred as “individual social welfare”.

The regional energy trading may impose different economic implications for consumers and producers of a participating market, depending on their status: as an importing or exporting market. This paper attempts to show that, although regional integration always produces a positive variation on the total social welfare, the individual social welfare of some partakers may be reduced.

Presumably, a power system or country agrees with its integration to a regional market, if its “individual social welfare” increases with respect to its “isolated social welfare” (social welfare computed when the partakers are not interconnected, i.e. when the market operates in an isolated way). In other words, the social welfare obtained in a regional economic dispatch (regional optimization), should be equal to or greater than the social welfare obtained in an isolated optimal operation [4,5].

Isolated energy prices of partakers will generally be altered by regional energy trading. As a result, interconnecting markets in a regional market can lead to significant changes in the surplus of consumers and producers of an individual market [5]. Therefore, the social welfare of a participating market can increase or decrease, as shown in this paper through a numerical example.

Energy prices of partakers can be altered as a consequence of particular features and complexities of electricity markets, such as

---

* Corresponding author.
E-mail addresses: santiagochamba@gmail.com (M.S. Chamba), agno@iee.unsj.edu.ar (O. Añó), reta@iee.unsj.edu.ar (R. Reta).

http://dx.doi.org/10.1016/j.swevo.2016.02.003

transmission network constraints and the necessity of reserve for a reliable operation.

These characteristics could lead to situations where the social welfare of a partaker diminishes after the integration, under the hypothesis that the integrated system and isolated systems are operated optimally. This possibility could hinder their effective integration [4,5].

Therefore, a compelling study of the economic impacts of regional energy trading on surpluses of consumers and producers of an individual market is necessary. In other words, the social welfare of each partaker ("individual social welfare") should be considered in the dispatch of energy and reserve to remove economic barriers of regional trading.

The objective of this paper is to develop a new model of dispatching energy and reserve, which contemplates the changes in "individual social welfare" of partakers as a constraint of the optimization problem. For this reason, changes in the "individual social welfare" of a market due to regional energy trade are analyzed, by considering the different economic implications of the exchange between partakers.

The paper is organized as follows: Section 2 presents the market model and analyzes the methodology considering changes of social welfare of partakers due to regional energy trade, transmission network congestion and reserve dispatch. Section 3 presents the proposed dispatch model of energy and reserve with social welfare constraints. This section also explains the dynamics of the search process and penalty scheme of the MVMO^S. The examples that indicate negative social welfare variation after integration are presented in Section 4. This section also presents the correction of social welfare of the example, using the proposed linear model embedded within a meta-heuristic algorithm. These examples indicating social welfare loss and its correction are the main contributions of this work. Finally, the main conclusions and analytical results are presented in Section 5.

2. Market model and social welfare

2.1. Market model

This section shows a new model of regional dispatch that optimizes energy and reserve. The reserves are recognized as a fundamental service of power systems, but how reserves are established and settled depends on the structure of each market, and there are currently different cost recovery and management methodologies [6].

There is an extensive practice to determine and allocate reserves in electricity markets, such as sequential and joint markets of energy and reserve. The sequential procedures are used to optimize first the energy market and then meet reserve requirements [7–9].

Currently, there is broad consensus that the energy and reserve services are strongly linked. These services must be dispatched simultaneously by minimizing the total cost of energy and reserve [10]. These models assign the energy and distribute the reserve requirements between the generating units that provide the service. For example, in references [11,12], the reserve allocation is calculated during the energy dispatch taking into account lost opportunity cost and expected energy not supplied, respectively.

The multilateral energy-reserve dispatch among electricity markets considering the integration of renewable resources is approached in reference [13]. This problem is solved by two-stage stochastic programming, representing uncertainty in the market-clearing procedure. On the other hand, a comprehensive mixed integer linear programming to resolve the energy and reserve dispatch under variable renewable generation is used in [14].

Meta-heuristic tools for optimal requirement calculation and allocation of the reserve are used in the references [15–17]. Specifically, Iteration Evolutionary Particle Swarm Optimization (EIPSO) and Particle Swarm Optimization (PSO) are used in [15,16], respectively. These algorithms ignored the transmission network of the power system. Furthermore, reference [17] used a hybrid model that integrates meta-heuristic algorithms with linear programming to integrate the transmission network of the power system.

The reserve requirement must be computed considering the interaction between economics and security of the systems, minimizing the costs of energy, reserve and energy not supplied. This approach allows the determining of the optimal reserves from the perspective of customers. The cost of energy not supplied reflects the willingness of the consumer to pay for reliability of supply [13].

In addition, the model must consider that energy and reserve will compete for the same generation capacity. Also, the reserve units must be optimally distributed in the nodes of the power system. This means that the model should consider the network congestion in order to ensure reliability in all areas of the power system.

In order to consider all the features, the optimization model proposed in [17] is used. This model is useful for analyzing the reliability of the real time market (single demand period), from an economic perspective. The loads are assumed to be inelastic and do not participate in the reserve market.

This model considers the reserve requirements endogenously to the optimization model, comprising a stochastic formulation, where the objective function is the minimization of the expected costs of energy, reserves and energy not supplied, as shown below:

$$min\left\{\sum_{A\in\Gamma_{SR}}\sum_{k}\pi^k\cdot\left[\sum_{i\in A}\left[Cg\left(u^k_{i,A}\cdot P^k_{i,A}\right)+Cr\left(u^k_{i,A}\cdot R_{i,A}\right)\right]+\sum_{n\in A}C(ENS^k_n)\right]\right\} \tag{1}$$

where SR represents the regional system, A is a participating system belonging to SR, Γ_{SR} are the set of participating systems belonging to SR, i is the i-th generating unit, k is the k-th operating state, n denotes the node index, π^k is the occurrence probability of the operating state k, $u^k_{i,A}$ is the operating status of generating unit i of system A in the operating state k (0 out of service, 1 in operation), $P^k_{i,A}$ is the active power output of the generating unit i of system A in the operating state k, $R_{i,A}$ is the reserve output of generating unit i of system A, $Cg\left(u^k_{i,A}\cdot P^k_{i,A}\right)$ is the generation cost of generating unit i of system A in the operating state k, $Cr\left(u^k_{i,A}\cdot R_{i,A}\right)$ is the reserve offer of generating unit i of system A in the operating state k, and $C(ENS^k_n)$ is the Cost of Energy Not Supplied (ENS) of the node n in the operating state k.

The cost of energy not supplied reflects the reliability of the power service and assesses the inconvenience suffered by customers owed to load curtailment actions. This cost is calculated with the energy not supplied (ENS) and the Value of Lost Load ($VOLL$):

$$C(ENS^k_n)=ENS^k_n\cdot VOLL_A=\sum_{j\in\chi_{n,A}}Pd^k_{j,A}\cdot VOLL_A,\ \forall A\in\Gamma_{SR} \tag{2}$$

where j is the j-th power demand or load, $\chi_{n,A}$ is the set of loads at node n of system A, and $Pd^k_{j,A}$ denotes the lost load of demand j in system A in the operating state k.

The constraints are explicitly represented through a linear DC, considering a network loss approximation. This approximation supposes that the voltage nodes are equal to 1 pu. Note that by using the piecewise linear model in [18,19], losses can be solved in the proposed model. The model comprises the following constraints: