Electric Power Systems Research 158 (2018) 297–305

Contents lists available at ScienceDirect

Electric Power Systems Research

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

A risk-constrained Energy Reallocation Mechanism for renewable sources with a Marginal Benefit approach

Paula Valenzuela, Delberis A. Lima *, Sergio Granville

Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, Brazil

ARTICLE INFO

Article history:
Received 7 July 2017
Received in revised form
17 November 2017
Accepted 16 January 2018

Keywords:
Renewable energy
Energy Reallocation Mechanism
Risk measurement
Marginal Benefit
Cooperative game theory

ABSTRACT

Because electricity generation from renewable energy is seasonal and intermittent, the risk associated with its cash flow volatility may discourage investments in this area. In this paper, a method called Energy Reallocation Mechanism is proposed to mitigate this problem. The idea, inspired by the current mechanism used in Brazil for Hydropower plants, consists of the creation of a renewable energy portfolio and the allocation of the quotas of this portfolio to each source. Because the portfolio cash flow is more stable than the individual cash flows, the financial risk of being in the portfolio is reduced.

The proposed mechanism is based on a stochastic approach and it combines future scenarios of generation in order to produce future scenarios of cash flow. Beyond the Expected Value applied in the Brazilian mechanism, it also considers the Conditional Value at Risk to account for average and risk, respectively, associated with the generation profile of each source. Finally, based on the aforementioned, the Marginal Benefit method is applied to allocate the portfolio's quotas for the renewable sources guaranteeing that the solution provided is suitable under the cooperative game theory viewpoint.

For didactic reasons a small renewable energy portfolio, formed by Wind Power, Small Hydro and Biomass, is used for comparing the proposed mechanism with the Shapley Value method and the current method applied in Brazil. The applicability for larger systems is demonstrated with real data from the Brazilian Power System.

1. Introduction

There is no doubt that renewable generation is a very attractive resource to reduce the greenhouse effect. However, despite technology developments, its production still has a high-level of intermittence and seasonality due to its climatic dependence. Consequently, the financial risk of these projects may discourage new investors from considering it as an asset.

One way to mitigate this problem is to combine the energy production from different sources into a portfolio in order to harness their complementarities and obtain a more stable cash flow. After that, the next challenge is to allocate the quotas of the portfolio among the agents. This framework is called Energy Reallocation Mechanism (ERM) in Brazil and it is used to mitigate the cash flow volatility of Hydropower plants.

Due to the growth of the renewable energy utilization worldwide, the portfolio theory applications have emerged in electricity markets in order to increase revenue, reduce financial losses or mitigate risks. In Ref. [1], the authors analyzed the application of the ERM for Wind Power in Brazil taking into account the seasonality of this source and its complementarity with Hydropower plants. Moreover, such mechanism was also proposed to be applied in Great Britain [2] in order to reduce the financial risk for new Wind Power investors.

Recently, in Ref. [3], the authors investigated how much capacity is needed to invest in renewable energy, dynamically over time, in order to create a portfolio to maximise its revenue in bilateral contracts.

A critical analysis of portfolio theory applied to mitigate the energy price risk for suppliers, distributors and traders is presented in Ref. [4], highlighting the best applications for electricity markets. In Ref. [5], the authors define risk as the probability of the Hydropower plants failing to fulfil their contract volumes and, because of this, they propose a model to compute the best generator contract under the risk criteria previously defined.

In Ref. [6], a stochastic optimization model combining the electricity production from Hydropower and Biomass into a portfolio is presented for the electricity market under the hydrological and fuel unavailability risks constraints. In Ref. [7], Wind generation and Pumped-storage units are combined to achieve the best outcome

* Corresponding author.
E-mail address: delberis@ele.puc-rio.br (D.A. Lima).

https://doi.org/10.1016/j.epsr.2018.01.016
0378-7796/

Notation

Constants

λ	Risk aversion parameter that combines the Expected Value and the Conditional Value at Risk
α	Risk aversion parameter that defines the confidence level of the Conditional Value at Risk measure of the portfolio
P_u	Price of the forward contract for the renewable source u
Q_u	Quantity of the energy contracted for the renewable source u in the forward contract
$moc_{i,k}$	Marginal operation cost for the period i and the scenario k
$\pi_{i,k}$	Spot price for the period i and the scenario k
$G_{u,i,k}$	Generation of the renewable source u simulated for the period i and the scenario k

Variables

$R_{u,i,k}$	Income of the renewable source u calculated for the period i and the scenario k
$R_{S,k}$	Income of the set S of renewable source for the scenario k
mb_u	Marginal Benefit value associated with the renewable source u
ϕ_u	Energy reallocation factor associated with the renewable source u
$\phi_u^{(\lambda=0)}$	Energy reallocation factor associated with the renewable source u for $\lambda = 0$
$\phi_u^{(\lambda>0)}$	Energy reallocation factor associated with the renewable source u for $\lambda > 0$
M_S	Income associated with the set (S) of players
M_S^*	Optimal income associated with the set (S) of players into the grand coalition

Sets

K	Set of the scenarios simulated for the energy contract
K^*	Set of the scenarios used to calculate the value of the CVaR
I	Set of periods (months) for the energy contract
S	Set of players in a coalition
N	Set of all players in the grand coalition

Decision variables

x_u	Auxiliary variable that takes the value 1 if the renewable source u belongs to the coalition S. Otherwise, the variable is 0
a	Auxiliary variable that represents the left deviation of the revenue of all scenarios and the period of analysis ($)
z_k	Auxiliary variable that achieves the α-value-at-risk of the partial value of the revenue in each scenario k at the optimal solution ($)

in the day-ahead electricity market. The operation of the Pumped-storage units is used as a decision variable and the arrangement is compared with the uncoordinated operation in order to highlight the advantages of the proposed model. A Hydro-Wind portfolio was proposed in Ref. [8] to minimize the financial risk of the seasonal generation for each source. In this case, the amount of energy contracted for each one was defined by a genetic algorithm using the CVaR as risk measure.

In another category of applications, the ideas of portfolio and cooperative game theory are combined to prove that, under the cooperative game constraints, the energy quota allocation can be optimized to make the portfolio more attractive for investors. The set of constraints is defined by the Core of the game [9], which represents the set of solutions where all players in the portfolio (grand coalition) have more benefits than acting individually or forming smaller coalitions.

In Ref. [10], four different methods were analyzed to share quotas of a portfolio formed by three renewable sources in order to make them viable in the electricity market. Among the analyzed methods, the Nucleolus, which is formulated by the Core constraints, was recommended as the solution of the problem. The downside of the Nucleolus method is the number of combinations needed to solve the optimization model. Because of this, in Ref. [11] the combinatorial problem was solved by Benders decomposition [12].

Cooperative game theory was also proposed to allocate Firm-Energy Rights (FER) among Hydropower plants in Brazil [13]. For this case, the Aumann–Shapley (AS) approach [14] was proposed to share the energy quotas of a portfolio formed by Hydropower plants in the same hydrographic basin.

Following the idea of the combination between portfolio and cooperative game theory, this paper proposes an improvement in the ERM currently applied in Brazil. This improvement consists of incorporating a risk term to compute the value of each source into the portfolio and, after that, sharing the quotas of the portfolio by a cooperative game theory method. The Conditional Value at Risk (CVaR) and the Marginal Benefit (MB) method were proposed to compute the risk term and to allocate the energy quotas of the portfolio, respectively. As will be shown in this paper, the MB method is equivalent to the AS approach under the conditions presented.

In summary, the main contributions of this paper are:

- To propose a new ERM for renewable energy incorporating the CVaR to account for the risk of each source into the portfolio;
- To apply the MB method to allocate the quotas of the portfolio;
- To show that the solution provided by the new arrangement is suitable under the constraints of the cooperative game theory.

To achieve the objectives, this paper is organized into five sections. In Section 2 the mechanism currently applied in Brazil is presented in detail. In Section 3 the new ERM is presented as well as its desirable properties under the cooperative game theory viewpoint. In Section 4 a comparison among the ERM used in Brazil, the traditional Shapley Value and the proposed method is presented to highlight its advantages in terms of allocation and computational efficiency for applications in large systems. Finally, Section 5 presents the conclusions of the work.

2. Brazilian Power System

2.1. Regulatory framework

As the Brazilian system is strongly based on hydrothermal generation, the short-term operation is centrally coordinated by an Independent System Operator (ISO). The coordination is based on the minimal cost dispatch model and a by-product of this model is the marginal operation cost, which defines the spot price.[1] In more detail, the optimization model aims to minimize the system cost to meet the supply security criteria defined by the system regulator considering the simulation of future generation scenarios for

[1] The spot price is the marginal operation cost limited by a cap and floor value.